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Semiconductor Industry Service
Gallium Arsenide Technology Analysis

Dataquest

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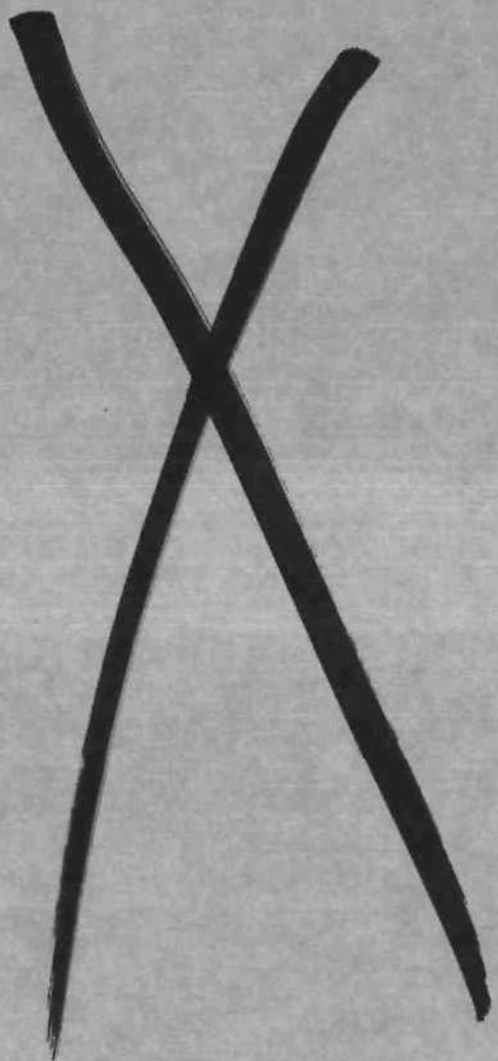


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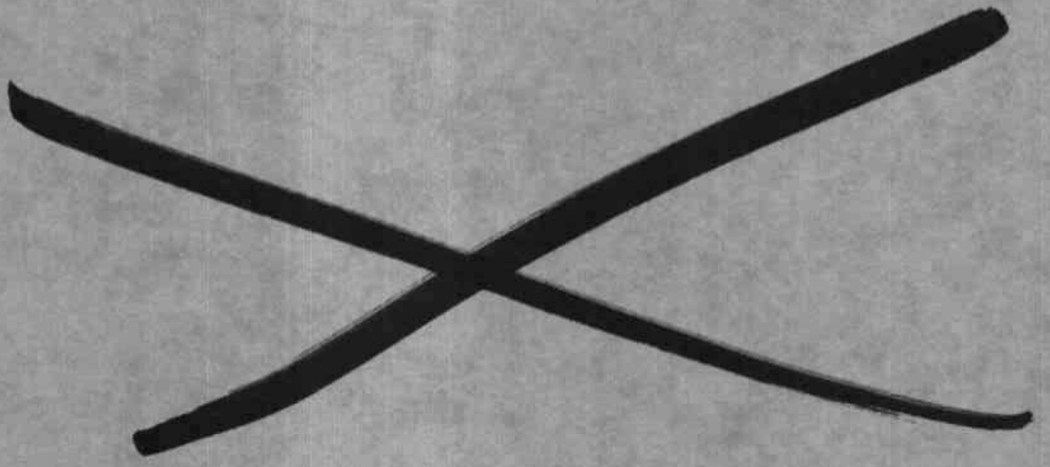
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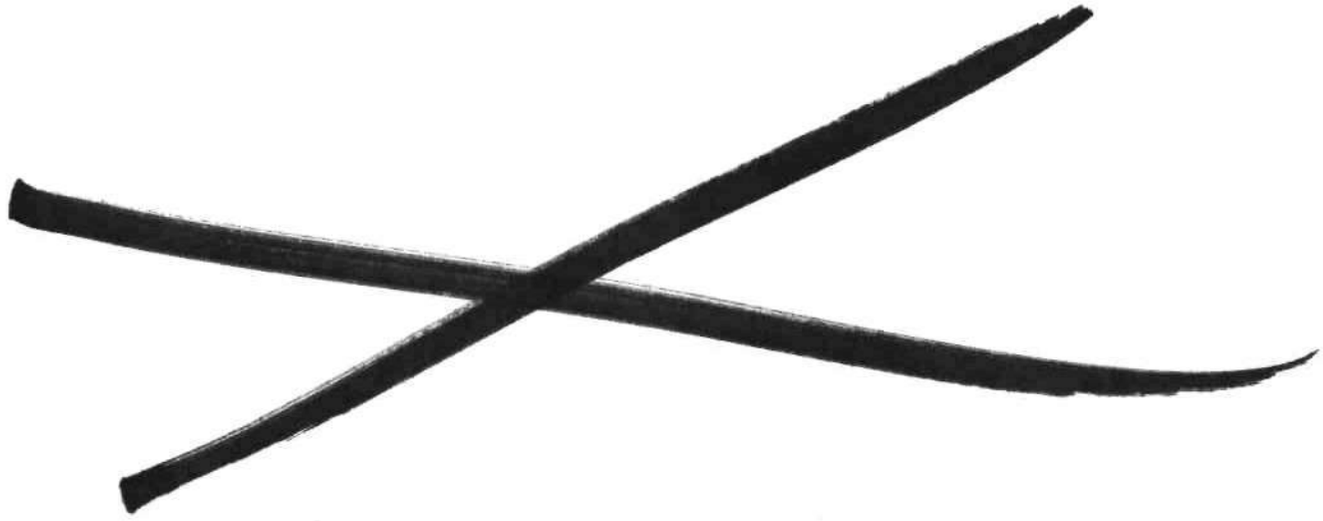
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Introduction to GaAs Semiconductors

The following information is an overview of the GaAs semiconductor segment option to the Dataquest Semiconductor Industry Service. Included are brief descriptions of the segment option and of the information available to the client.

STRUCTURE

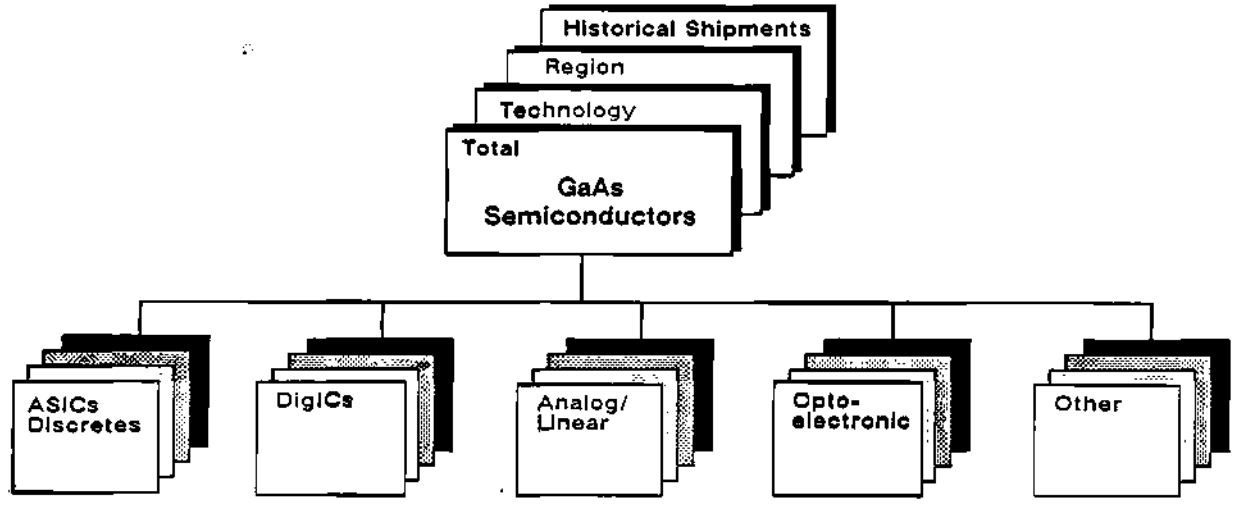
This notebook provides the most comprehensive set of information produced by Dataquest in the area of GaAs and related III–V compound semiconductors. It provides detailed analysis of this emerging industry, and gives worldwide perspective of the major issues and forces that are shaping its development.

GaAs Semiconductor Family Tree

Figure 1 shows the major components of the GaAs semiconductor family tree. Note that all top–level consumption and historical shipment data can be found in the "Executive Summary" section of this notebook. Clients who need information on silicon semiconductor consumption should refer to the regional and technology sections of the Semiconductor Industry Service (SIS) notebooks and to the end–use data in Dataquest's Semiconductor Applications Markets (SAM) binders.

Figure 1

GaAs Semiconductor Family Tree



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Introduction to GaAs Semiconductors

GaAs Semiconductor Segment Overview

Each product section in this notebook is designed to provide the client with in-depth data on the structure of the industry segment. Topics include:

- Executive summary—Provides the client with a brief overview of the factors affecting this segment
- Forecast—Summarizes Dataquest's forecast of this product set
- Product analysis—Examines product features, benefits, pricing, and related factors
- Competitive analysis—Discusses supplier behavior, market shares, and product positioning
- Emerging technology and trends—Identifies factors affecting the future direction of the product segment
- Applications and user issues—Provides insight from the user's point of view as to issues affecting product usage
- Historical shipment data—Summarizes estimated shipments by year

Company Profiles

This section of the segment provides information on almost all of the merchant market suppliers of GaAs and related III–V compound semiconductor suppliers in the free world. It includes more than 50 profiles on supplier companies. The companies range in size and product line depth from young start-up companies and joint ventures to large, vertically integrated systems houses that supply this market.

Newsletters

Dataquest's clients receive research newsletters and bulletins that discuss issues pertinent to the industry of interest. Clients choosing the GaAs semiconductor segment also receive newsletters that discuss GaAs products, applications, key industry events, and other GaAs device-related subjects.

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Inquiry Privilege

The registered Dataquest subscriber and one designated alternate have the privilege of direct access to Dataquest. Two forms of inquiry are available to the client:

- Access to the Semiconductor Inquiry Center (SIC)
- Access to the semiconductor research staff

We encourage our clients to call the SIC because these researchers are devoted to handling inquiries on a full-time basis and will provide assistance in finding or interpreting material. In addition, the client may be referred to a researcher who is a specialist for further clarification. Using this feature, clients may interact with industry experts on a one-on-one basis to discuss views and opinions about topics covered by the service.

FORECAST AND HISTORICAL SHIPMENT DATA

Each of the product sections in this notebook includes detailed estimates of consumption and historical shipments.

Annual Consumption Forecast

The consumption forecast, updated annually, spans two years of history and five years of forecasts. Dataquest segments markets and products as follows:

- Technology—Includes discretes and ICs, digital and analog/linear, with sub-categories where applicable
- Regions—Includes North America, Western Europe, Japan, and Rest of World (ROW)
- End use—Includes consumption estimates for:
  - EDP
  - Communications
  - Consumer
  - Industrial
  - Transportation
  - Military

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Historical Shipment Data

Dataquest currently estimates shipment revenue for approximately 100 semiconductor suppliers, including more than 30 GaAs device suppliers. These estimates include merchant as well as intracompany shipments (defined as shipments to an internal division). The estimates do not include companies that are all captive and build products only for internal consumption such as IBM or Unisys.

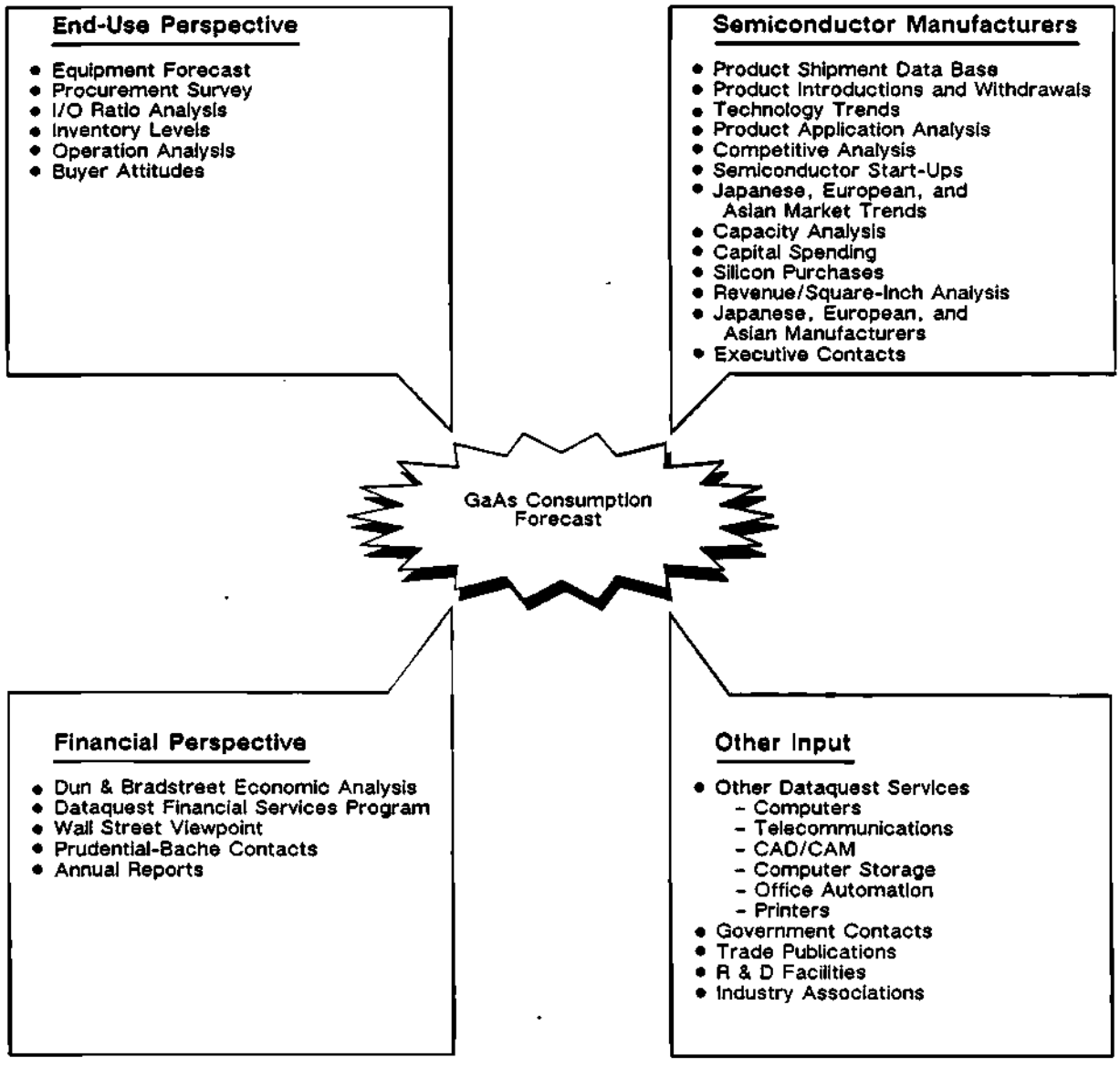
METHODOLOGY

Through extensive contacts in the semiconductor industry, Dataquest acquires information from all of the sources included in Figure 2. Together, these sources provide raw data, trend identification, and verification of Dataquest's analysis. Each type of source contributes different information from a unique perspective; collectively, they provide a comprehensive picture of the industry.

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Figure 2

Worldwide Input to Dataquest Semiconductor Forecasts



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Introduction to GaAs Semiconductors

Manufacturing Perspective

Dataquest's Semiconductor Information Group comprises seven different semiconductor information services. The combined worldwide research network of these services provides input to the forecasts based on all relevant aspects of the industry. Dataquest uses its extensive product shipment data base and information about new and obsolete products when compiling the annual consumption forecasts.

Executive level input from almost all semiconductor manufacturers in the free world provides insight into the industry environment, current business levels, and major competitors. Information regarding technology trends, capital spending, capacity utilization, and product acceptance is analyzed by Dataquest's industry experts in formulating the forecasts.

Other considerations are analyses of wafer starts, wafer consumption, and revenue per wafer. Our worldwide research offices and contacts in West Europe, Japan, and Asia provide primary input as well as checks and balances for each forecast cycle.

End-Use Perspective

Research about trends in the application and procurement of semiconductors is another cornerstone of our forecasts. The Semiconductor Application Markets service contributes this end-use analysis through equipment forecasts, procurement surveys, and I/O ratio analysis. The Semiconductor User Information Service studies buyer attitudes, changes in operation methods, inventory analysis, and short-term pricing trends.

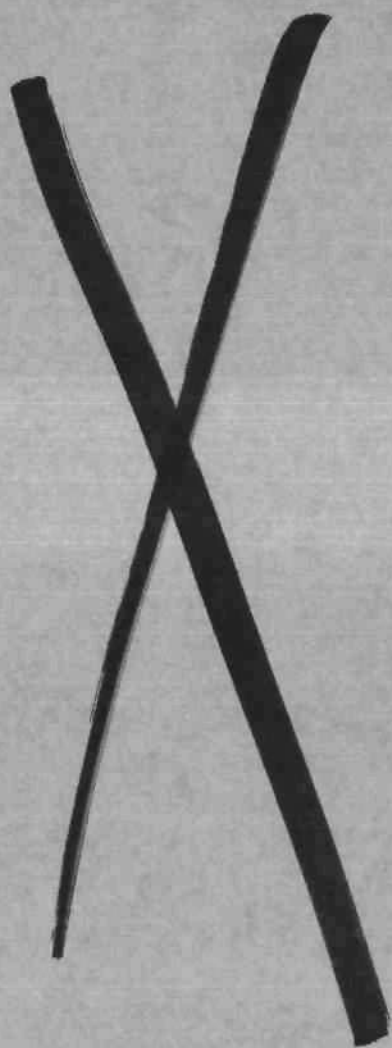
Financial Perspective

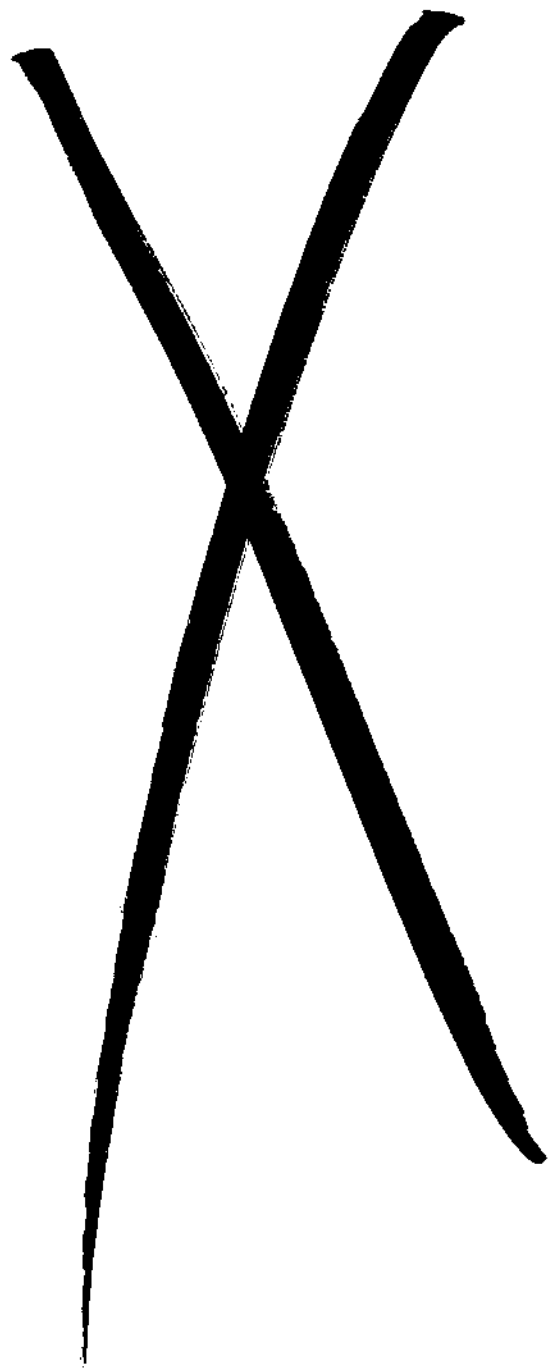
Dataquest's general economic outlook and financial viewpoint is based on business surveys and financial analyses from Dataquest's parent company, Dun & Bradstreet. In addition, Dataquest's Financial Services Program provides close contact with venture capitalists, fund managers, and financial institutions. Through our exclusive relationship with Prudential-Bache, Dataquest has access to Wall Street's attitudes about all areas of technology. These sources, combined with Dataquest's own research on financial and economic trends, provide one of the cornerstones of our forecasts.

Other Input

Close association with other Dataquest information services provides additional input to the forecast accuracy and quality. This includes analysis of key industries that consume semiconductors such as technical, business, and personal computers. In addition, input is solicited from services that analyze CAD/CAM, telecommunications, computer storage, printers, office automation, and graphics terminal industries. Dataquest analysts also attend industry trade shows and technical symposiums to monitor the latest product introductions and technology trends. Other input comes from government contracts and publications, industry associations, and trade publications.

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GaAs Semiconductors—Summary

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GaAs and other III-V compound semiconductors have moved rapidly from the laboratory to many commercial applications. After more than 20 years of military/government usage, discrete and SSI/MSI devices are being replaced by digital functions ranging in complexity to LSI/VLSI densities. Such functions include SRAMs, multipliers, gate arrays, and integrated optoelectronic devices. In the analog/linear area, microwave hybrids are being replaced, in many instances, by standard-cell-based MMICs capable of operation above 30 GHz. Users of supercomputers, telecommunications hardware, instrumentation, and consumer products are receiving major benefits in performance and improved functionality by taking advantage of this space-age technology. The GaAs semiconductor market is projected to exceed $5 billion by 1995; however, less than 30 percent of this value will be ICs.

This section is a brief summary of the information appearing throughout this volume. It is intended to give the user an overview of the gallium arsenide (GaAs) and related III-V compound semiconductor industry. The glossary (see "Glossary") may be helpful in clarifying terminology.

ADVANTAGES OF GaAs OVER SILICON

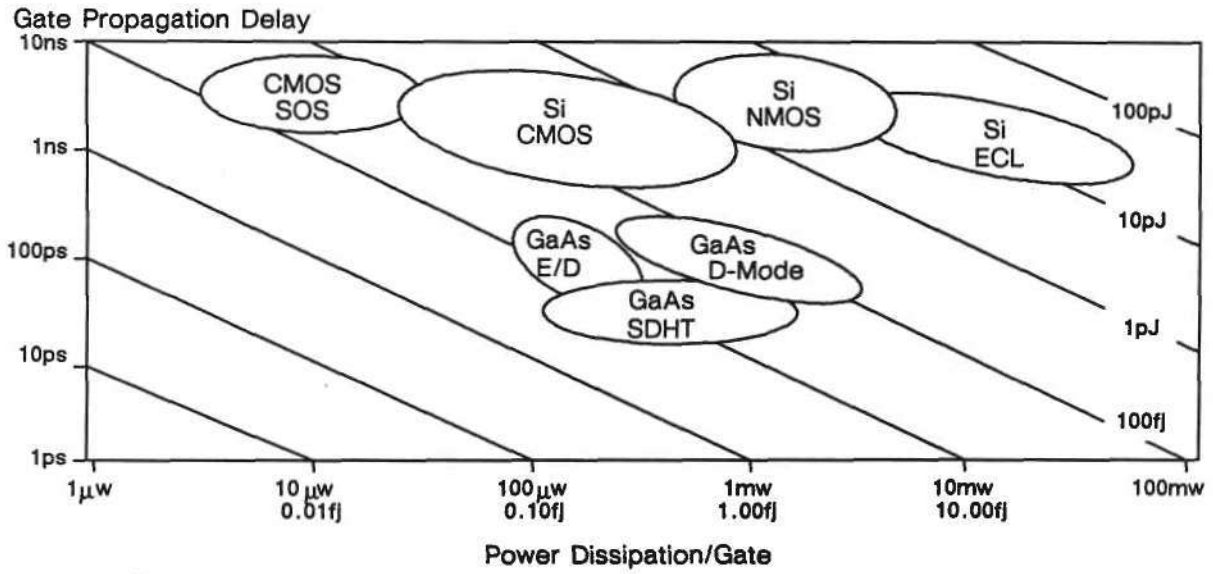
The following are advantages that GaAs semiconductors have over silicon:

- Circuit switching 3 to 10 times faster
- Speed/power product 5 to 6 times more efficient (refer to Figure 1)
- Manufacturing process less complex than those used in silicon IC fabrication
- Relative insensitivity to temperature and power supply variations
- Upper temperature limit of 350°C versus 175°C
- Superior levels of radiation tolerance
- Photonic operation including latching (memory) functions
- Integrated optoelectronics (electronic and photonic circuits) on a single chip
- Wider range of resistivity due to semi-insulating substrates

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Figure 1

GaAs Speed/Power Advantage



Source: GAIN Electronics

DISADVANTAGES OF GaAs VERSUS SILICON

The disadvantages of GaAs semiconductors compared with silicon are:

- Higher wafer cost
- Lower level of digital circuit integration at a given functional maturity
- Limited volume production parametric test capability

BRIEF CHRONOLOGY OF MAJOR GaAs DEVELOPMENTS—1952-1990

The III-V compound semiconductor technology is not new. The semiconducting properties of the compounds were researched more than 38 years ago, and GaAs ICs were in development in the late 1960s. A brief chronology follows (for a summary, see Figure 2):

- 1952—Welker reported semiconducting properties of III-V compounds
- 1956—Czochralski method used to prepare GaAs single crystals
- 1961—GaAs bipolar transistor with f_T= 730 MHz reported

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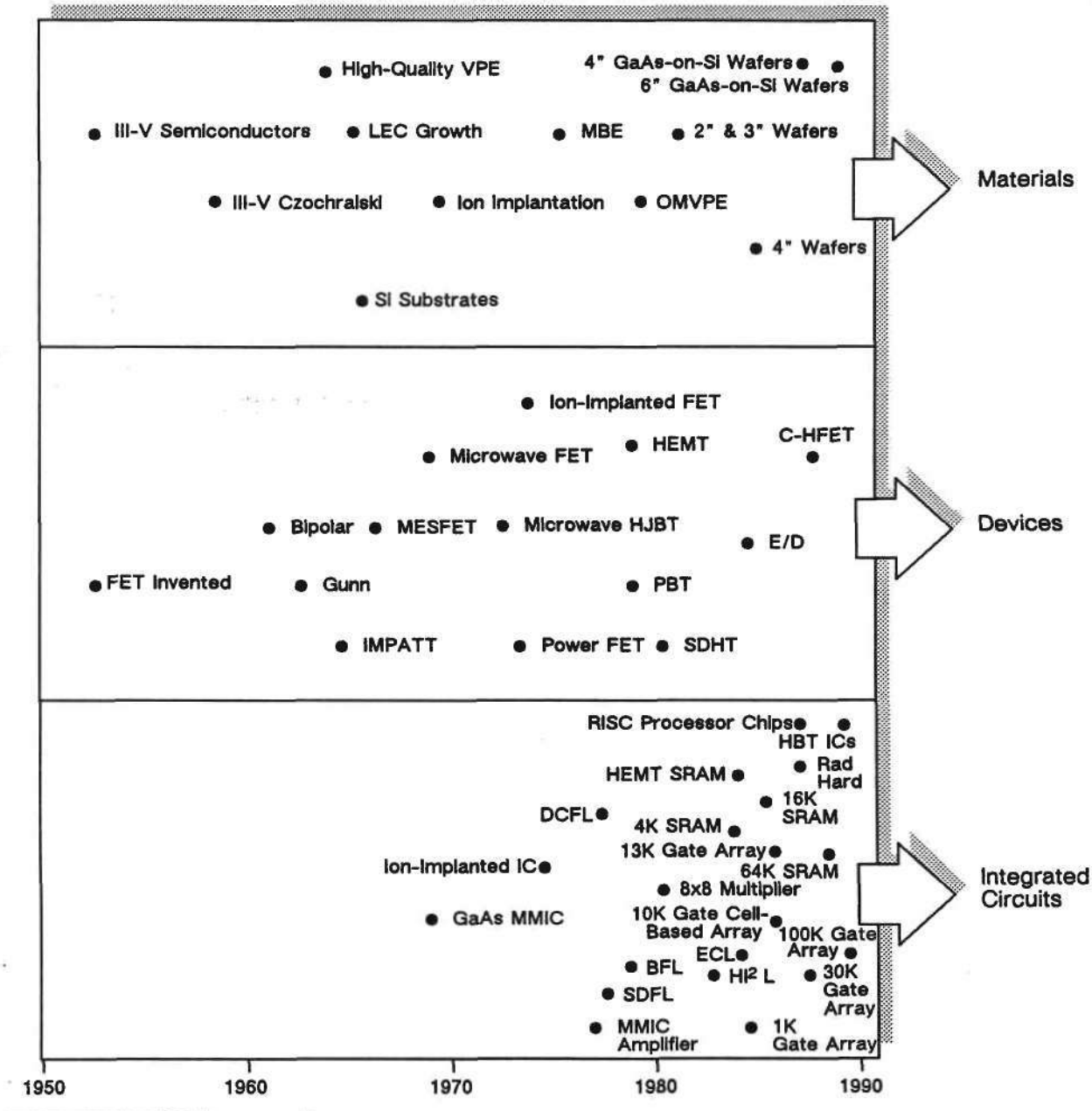
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- 1962—J.B. Gunn of IBM discovered the transferred electron effect
- 1966—GaAs oscillator reported by Bell Labs; GaAs Microwave Monolithic IC (MMIC) patent application
- 1973—First GaAs DigIC
- 1974—GaAs impact avalanche and transit (IMPATT) diodes and GaAs lasers fabricated by molecular beam epitaxy (MBE)
- 1978—33ps ring oscillator delay achieved
- 1980—8x8 Schottky Diode FET Logic (SDFL) multiplier
- 1981—2-inch and 3-inch GaAs wafers commercially available
- 1982—40+ GHz GaAs field-effect transfer (FET), 16x16 multiplier, 32-bit adder, 1,224 gate array
- 1983—4K SRAMs reported
- 1984—Sub-ns high-electron-mobility transistor (HEMT) 1K SRAM, 20-GHz monolithic voltage controlled oscillator (VCO), digital/analog ASIC array
- 1985—1.2-GHz GaAs frequency synthesizer, 42ps 2K gate array, 4K gate array tested at 385°C, 100-mips 8-bit microprocessor with RISC architecture and E/D process, 12-bit D/A converter with 1-GHz word rate, 115-GHz amplifier, 4-inch near defect-free (NDF) wafers announced
- 1986—NEC announced entry into GaAs digIC market, 4-inch NDF wafers shipped in production quantity, 600ps 1K SRAM, multiple-sourced 12x12 multiplier, 8-GHz 88-pin LCC package, 41-GHz amplifier with 135mW output power
- 1987—GaAs-on-Si wafers into beta-site tests, 6K E/D gate array, numerous multisourcing announcements, volume production of supercomputer ICs, CW operation of GaAs-on-Si lasers
- 1988—Commercialization of GaAs VLSI products, volume pricing parity between Si ECL and GaAs E/D MESFET gate arrays, GaAs ICs for TV and VCR tuners
- 1989—First samples of 30,528-gate GaAs VLSI, Honda develops in-house source of GaAs ICs for automotive applications, consolidations in MMIC industry in United States
- 1990—Lasers priced below US$1, TRW introduces HBT ICs to commercial market, first samples of 100,000-gate GaAs VLSI, single-chip radar transceiver developed

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Figure 2

GaAs Technology Evolution Timeline



Source: Dataquest (April 1991)

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GEOGRAPHIC DISTRIBUTION OF GaAs DEVICE SUPPLIERS

The greatest geographic concentration of semiconductor talent in the Free World is in the South San Francisco Bay Area, often referred to as Silicon Valley. While this may also be true of GaAs technology talent, other areas such as "Gallium Gardens" in New Jersey, "Gallium Gulch" in southern California, and "Gallium Springs" in Colorado are gaining recognition for their evolving infrastructures. The primary influences in recent years included AT&T and Rockwell, in much the same way that Fairchild spawned numerous start-ups in silicon technology in the 1960s.

The maps in Figures 3, 4, and 5 show the present dispersion of most of the GaAs companies in the Free World. Additional GaAs activities are under way in Eastern Europe; reporting on such activities exceeds the scope of this volume.

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Figure 3

U.S. Locations of GaAs Semiconductor Suppliers

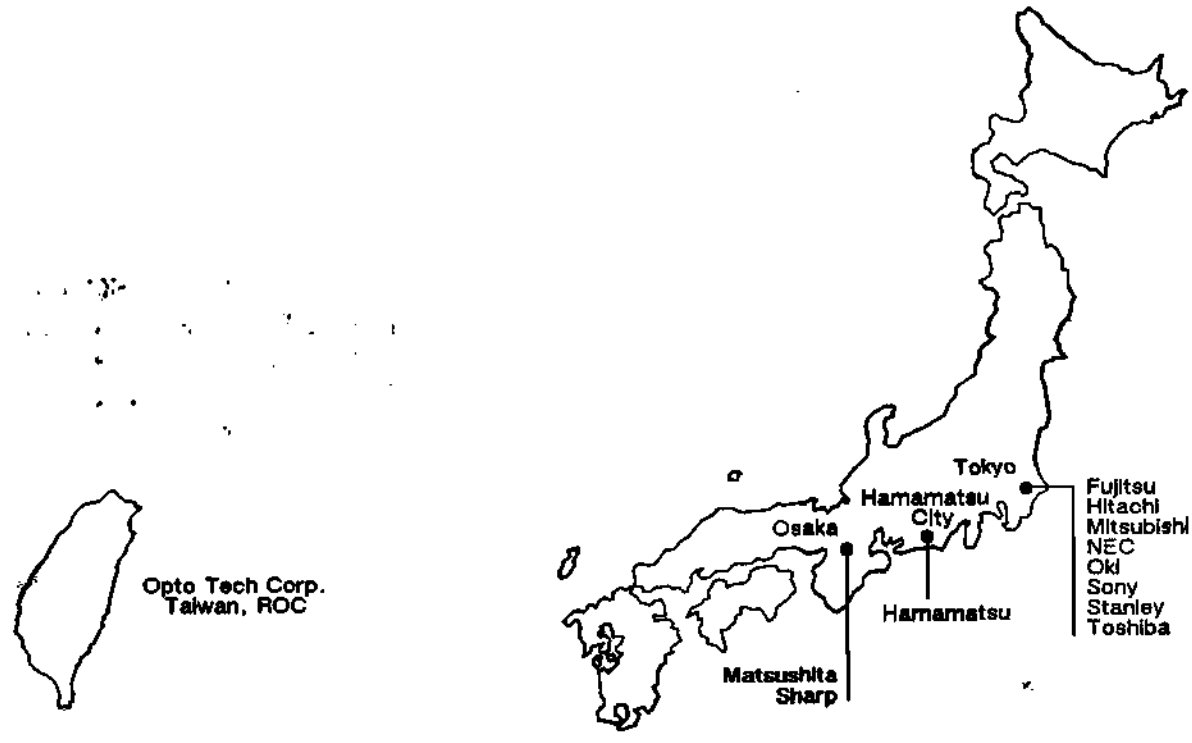


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Figure 4

Asian Locations of Semiconductor Suppliers



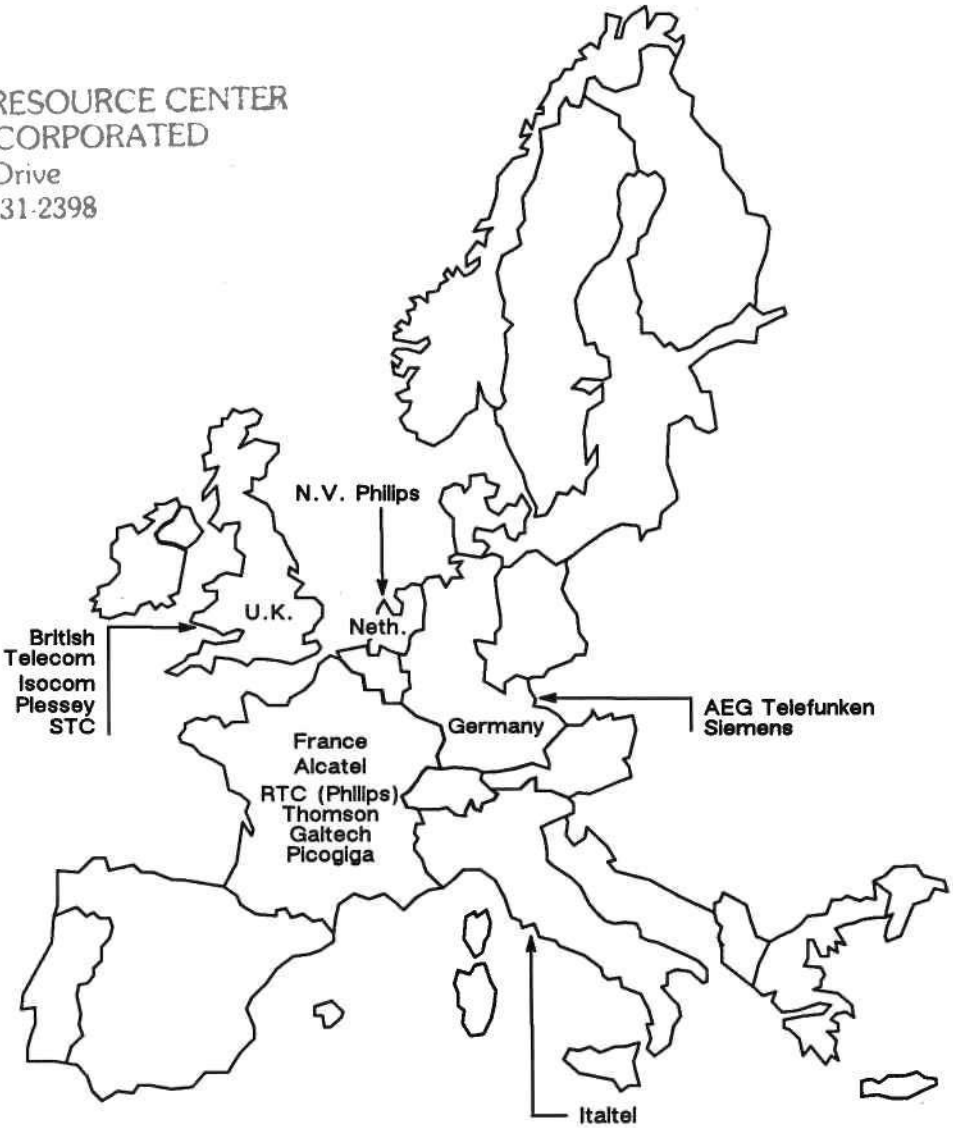
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Figure 5

Western European Locations of GaAs Semiconductor Suppliers

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STATE OF THE ART

GaAs and other III-V semiconductors are evolving more rapidly than did silicon devices in the 1960s. This is happening because, among other things, many techniques and methodologies developed during silicon industry evolution are readily adaptable to III-V technology. Device density and performance accomplishments in recent years are shown in Table 1.

Table 1

Recent Progress in GaAs ICs

Function		Company	Comments
Digital			
SRAMs	1Kx1	TI, others	GaAs-on-silicon
	64Kx1	NTT, others	Highest density reported
	16K	Rockwell	Rad hard, very low power
	1Kx1	Rockwell	600ps cycle time
Multipliers	16x16	Fujitsu	Highest density multiplier reported to date
	4x4	AT&T	Best speed/power to 1989 at 115ps and 0.34mW/gate
Gate Arrays	4K	TI	Tested at 385°C
	15K	GigaBit Logic	Standard-cell-based, E/D process
	100K	Vitesse	E/D process, cost-competitive with silicon ECL
	45K	Fujitsu	HEMT
Microprocessors	32-bit	TI; McDonnell Douglas	DARPA-sponsored
Analog			
A/D-D/As	12-bit DAC	HP	Highest resolution at 1-GHz word rate
MMICs	115 GHz	TI	Fastest GaAs amplifier reported to 1990
	41 GHz	TI	Best speed/power at 135mW output

Source: Dataquest (April 1991)

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The greatest potential for system performance improvement through the application of III-V FET technology will likely be realized with selectively doped heterojunction transistors (SDHT—also called HEMT) device structures. Although AT&T holds the basic patent, the first commercially available HEMT was Gould's H503, announced in 1985. GE (Syracuse, New York) has announced development of an HEMT structure with a current gain cutoff frequency of 80 GHz. The highest reported cutoff frequency for conventional GaAs FETs was over 70 GHz in mid-1990. In February 1991, Fujitsu reported developing a 64K SRAM and a 45K gate array, each using HEMT FET technology.

In the bipolar arena, HBT will offer superior speed for logic circuits up to LSI density by 1992.

APPLICATIONS

The unique properties of GaAs and other III-V compounds allow solutions to technical problems that were heretofore not economically solvable. Primary examples today are found in the fields of fiber-optic and satellite communications, supercom- puting, and high-speed test/measurement. Military/government applications, including aerospace, have provided the initial impetus for GaAs technology development. Among these are radar, satellite communications, electronic warfare, electronic counter-measures, surveillance, and high-speed signal processing.

The growing number of diverse applications for GaAs and other III-V compound semiconductors is discussed in the section "End Uses." As further cost improvements are realized, end uses will increasingly extend into the full spectrum of markets—local telecommunications, computer, instrumentation, CAD/CAE/CAM, artificial intelligence, robotics, military/aerospace, automotive, and consumer.

ASICS

ASIC technology provides a relatively inexpensive means of incorporating GaAs into an existing silicon subsystem or system design. The user may upgrade system performance in some cases by a factor of 2 to 3 by making relatively minor changes to existing hardware, such as incorporating GaAs into critical paths—e.g., clock distribution circuits and prescalers. As shown in Table 1, digital ASIC complexity is at the 100,000 gates-per-chip level, and will exceed 200,000 usable gates per chip by 1992.

GaAs suppliers that support ASIC and foundry work are offering a broadening range of customers the opportunity to efficiently incorporate added value into existing designs. Thus they may accelerate the transition from silicon to GaAs in very high-performance systems. GaAs ASICs are the focus of a special section of this module.

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GOVERNMENT ACTIVITIES

Major Free World governments investing in GaAs and related III-V compound semiconductor R&D include Japan, France, Germany, Greece, Italy, Spain, Canada, the United Kingdom, and the United States. Because of the strategic nature of various programs, the exact levels of funding are not available. Industry sources believe that the approximate range of annual investments by the governments of the named countries is $10 million to $100 million each.

In January 1990, the Japan National Supercomputer prototype unit was operating using GaAs chips in all critical speed areas. This is a MITI-sponsored project supported by Fujitsu, Hitachi, and others.

SUPPLIERS

Dataquest identified the following levels of industrial activity in GaAs and related compound technology in 1990:

- 44 merchant market suppliers of ICs
- 28 merchant suppliers of discretes
- 25 or more captive-only houses
- More than 30 companies supplying raw wafers, epi wafers, or both to the merchant market
- 15 merchant foundries
- More than 70 universities involved in III-V R&D, many with fab capability

In 1989, several supplier changes occurred. Tachonics ceased operations in October 1989. Adams-Russell was acquired by M/A-COM in mid-1989. Raytheon and Varian expanded their operations, and Gigabit Logic converted one of its production lines to 4-inch wafers.

In January 1991, TriQuint and GigaBit Logic announced plans to complete a merger by March 31, 1991. The merger was in progress at press time.

MARKETS AND OPPORTUNITIES

Initially, III-V compound semiconductor technology development and growth were stimulated by electronic warfare (EW), radar, SATCOM, and fiber-optic applications. These applications were initially analog/linear in nature, requiring microwave operation in many instances. More recent markets have evolved for GaAs and other III-V device usage in LANs, instrumentation, cellular radio, computers, automobiles, and TV reception. Industry sources (e.g., ANADIGICS Inc.) believe the market development sequence will approximate that shown in Table 2.

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Table 2

GaAs Market Evolution

TIME → / Military	Telecom	Bus/Inst.	EDP	Consumer
EW	Fiber Optics	Graphics	Supercomputers	DBS
C^3I	SATCOM	Instrumentation	Array Processors	HDTV
Radar	Radios	CAD/CAE	AI	PCs
Missiles	Modems	Medical	Superminis	Videotext
Simulators	LANs	Robotics	Mass Storage	Automotive

Source: ANADIGICS Inc.

TRENDS AND ISSUES

This section addresses current trends and issues in GaAs and related III-V compound materials, processing, chip functions, packaging, foundries, captive sources, government and university roles, standardization, testing, reliability, partnerships, second-sourcing, and market development.

Trends in III-V Materials

Availability of high-quality, low-defect-density GaAs substrates is considered a major limiting factor in the transition of GaAs technology from present density levels to LSI/VLSI complexities. State of the art in late 1990 was of the order of 2 to 200 dislocations/sq.cm., and much of the available material ranged up to 2,000 dislocations/sq.cm. or higher.

In December 1990, M/A-COM was considered the largest supplier of GaAs substrates in the United States. Japanese GaAs wafer suppliers included Sumitomo Electric Industries, Ltd., at 3,000 3- and 4-inch wafers/month; Shin-Etsu at 1,000 3-inch wafers/month; Mitsubishi-Monsanto Chemical Company at 2,000 3-inch wafers/month production; and others, including Nippon Mining and Showa Denko. Waeker (Germany) is the largest European supplier of GaAs wafers.

Processing

The trend in III-V compound chip fabrication for many types of ICs is toward use of ion implantation rather than epitaxial formation of active layers, for the following reasons:

- It eliminates the need for etching to obtain desired depth.
- Its precision surpasses that of etching procedures.
- Sharp carrier cutoff at the active layer-substrate interface is obtained.
- Circuit element isolation is possible by proton or oxygen ion bombardment.
- Device formation is simplified by selective ion implantation.

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- Some chip manufacturers now are using wafers with an epitaxial buffer layer as a means of reducing the back-gating effect, which has previously been a yield-limiting factor. MOVPE has proven acceptable, depending on process quality.

Functions

The trend in function evolution of GaAs ICs is to provide performance significantly above that possible with silicon technology at the highest density achievable within cost constraints of the application. Function density for GaAs digICs has outperformed Moore's Law in the recent past, according to industry sources. Gate array density now exceeds 100,000 gates per chip and is expected to triple that number by 1992.

Mergers, Acquisitions, and Agreements

A natural consequence of GaAs technology development in the United States is the increasing number of partnerships, agreements, mergers/acquisitions, joint ventures, and team efforts. The following paragraphs summarize some of the major such actions in this industry.

MIMIC Program

The DOD MIMIC (millimeter-microwave IC) initiative represents a major effort to incorporate the advantages of compound semiconductors into a variety of military applications. These applications include:

- Ultrareliable radar for the U.S. Air Force ATF
- Shared-aperture radar for the U.S. Navy ATA
- MILSTAR network communications terminals
- Smart munitions
- Wideband jammers
- Antiradiation missiles
- Other "brilliant" weapons

The MIMIC program entered Phase 0 early in 1987 with the award of 12 major and 4 smaller contracts to prime contractors. Additional awards went to Hittite Microwave ($500,000), Ball Aerospace ($497,000), E-Systems ($100,000), and Loral ($100,000). Funding for the remainder of the seven-year program recently was estimated at more than $530 million.

Phase I of MIMIC saw some realignment of the participants, as the program became more competitive and the number of teams decreased. Table 3 shows the prime contractors, approximate award amounts, responsible services, and other details of the Phase I awards.

Phase I teams include the following:

- AT&T, E-Systems, Hercules (Sperry Clearwater division), M/A-COM, Cascade Microtech, and Harris Microwave supporting Hughes/GE

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- Three divisions of ITT, Harris GSD, Pacific Monolithics, Alpha Industries, SRI, and Watkins-Johnson supporting ITT/Martin Marietta
- Aerojet General, Consilium, Compact, General Dynamics, Litton Airtron, Magnavox, Norden, and Teledyne supporting Raytheon/TI
- General Dynamics, Honeywell, and Kodak supporting TRW

The U.S. Department of Defense expects to make additional funding available for technology projects such as direct-write E-beam and MOMBE systems developments. Eliot D. Cohen of the Office of the Secretary of Defense stated to an audience at the MTT that the present demand estimate is 700 to 1,000 4-inch wafers per week by the mid-1990s to satisfy the currently projected MIMIC uses. This figure could increase substantially as new defense needs emerge.

Pacific Monolithics/TriQuint and Gazelle/TriQuint

TriQuint has performed well as Pacific Monolithics' and Gazelle's primary foundry, supplying processed wafers to mutually acceptable specifications. Dataquest believes that these relationships led to some of the specific teaming on the DOD MIMIC program (see Table 3), and to the DARPA contract with Gazelle.

Table 3

MIMIC Phase I Summary

Prime Contractors	Award ($M)	Service Branch	Freq. Range Upper Limit	Technologies	Applications
Hughes/GE	50	Air Force	To 30 GHz	MESFET, HEMT	Radar
ITT/Martin Marietta	49	Army	Above 30 GHz	SAGFET	Communications, smart munitions
Raytheon/TI	68	Navy	To 30 GHz	MESFET	Electronic warfare
TRW	58	Army	Above 30 GHz	MESFET, HBT, HEMT	Electronic warfare, smart munitions

Source: U.S. Department of Defense

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Pacific Monolithics/COMSAT Labs

In July 1987, Pacific Monolithics announced that it had signed an exclusive agreement with COMSAT Laboratories of Clarksburg, Maryland, to develop and pursue products and markets for power and millimeter-wave MMICs and to seek Phase I through III contracts under the DOD MIMIC program. Pacific will provide design and marketing skills; COMSAT will contribute 30-GHz MESFET foundry capability. The agreement is also intended as a vehicle for exploring additional business opportunities in monolithic and millimeter-wave devices.

Rockwell/IBM

Early in 1987, Rockwell International and IBM entered into an agreement for the cooperative development of high-speed digital and optoelectronic GaAs devices for future computers and telecommunications equipment. The program involves Rockwell's GaAs pilot line at Newbury Park, California; Rockwell development teams at Newbury Park and Thousand Oaks, California; and IBM development teams at East Fishkill and Yorktown Heights, New York. Dataquest believes that this agreement positions IBM to take a leadership role in GaAs digIC (digital integrated circuit) applications.

Cray/GigaBit Logic

For about five years, Cray Research Inc. has been working with GigaBit Logic Inc. to develop a reliable source of GaAs devices for use in a CRAY-3 computer. Early in 1987, Cray increased the amount of its order for GigaBit GaAs IC chips to be delivered in 1987 to $5.2 million. Cray Research participated in GigaBit Logic's third round of financing in May 1987, along with Analog Devices Inc., Digital Equipment Corporation, and others. In 1988, GigaBit shipped approximately $8 million of GaAs ICs to Cray. Late in 1988, Cray placed a $29 million order with GigaBit for 1989 delivery. However, less than $10 million of this order was shipped in 1989. In December 1989, Cray negotiated to move part of GigaBit's production facilities to Colorado Springs, Colorado. The move was completed in mid-1990.

AMD/Vitesse

In 1986, Advanced Micro Devices (AMD) and Vitesse agreed to a technology exchange involving AMD's 2900 bit-slice family and Vitesse's E/D MESFET GaAs technology. The effort resulted in Vitesse's announcement of its 29G01, 29G10, and other GaAs bit-slice products late in 1986.

Gazelle/TriQuint

A $17 million foundry agreement was announced by Gazelle and TriQuint in mid-1988. The agreement covers two-year shipments of wafers/chips for use in Gazelle's PLD products, including the factory-programmable GA22V10.

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GigaBit/Seattle Silicon

GigaBit Logic Inc. and Seattle Silicon Corporation developed a 4-bit ALU that is functionally equivalent to the 100181, a 100K ECL chip. Design engineering support was provided by the Washington Technology Center (WTC). The chip is 5.7 times faster than its silicon counterpart and consumes one-half the power.

Fujitsu/Vitesse

In November 1989, Fujitsu and Vitesse Semiconductor Corporation (VSC) jointly announced an alternate-sourcing agreement for the Vitesse "Fury" series of GaAs gate arrays. The announcement ended speculation as to which of the Japan-based computer houses would be the first to enter the merchant market for GaAs VLSI chips. Other likely entrants were (and still are) Hitachi, Mitsubishi, NEC, Oki, and Toshiba, all of which have concerted R&D in this area. The Fujitsu/VSC agreement includes arrays of 3,000 to 30,000 gates and mixed logic/SRAM chips as well as joint development of additional GaAs VLSI products.

Vitesse/Thomson CSF

In 1990, Vitesse and Thomson CSF (France) announced joint development of GaAs devices. The agreement includes provisions for Thomson to second-source Vitesse's "Fury" series of gate arrays.

MicroWave Technology Inc./Monolithic Microsystems Inc.

In June 1987, MicroWave Technology Inc. of Fremont, California, completed its acquisition of Monolithic Microsystems Inc. of Santa Cruz, California. Under the agreement, Monolithic Microsystems will become a wholly owned subsidiary of MicroWave Technology and will continue manufacturing at its present 8,200-square-foot facilities.

TRW/TriQuint

TRW Components International (a subsidiary of TRW Inc.) and TriQuint have agreed to jointly supply GaAs devices for space applications. The companies are working together on procedures for producing Class S-level GaAs components. TriQuint will provide foundry support.

Ciba-Geigy/Spectra-Physics

In June 1987, it was reported that Ciba-Geigy had signed a definitive agreement to acquire Spectra-Physics for $266 million. A prior lawsuit seeking to enjoin Ciba-Geigy's initial (reportedly hostile) takeover offer was reported as being dismissed without prejudice by the Delaware Federal Court. Dataquest believes that this acquisition will strengthen Ciba-Geigy's ability to participate in the GaAs industry infrastructure.

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Amoco/Spectra Diode/Kodak/Litton Airtron

Amoco Laser Company, a wholly owned subsidiary of Amoco Corporation, has formed a strategic alliance with Eastman Kodak, the Airtron Division of Litton Industries, and Spectra Diode Labs to support Amoco's laser systems product line. Kodak provides production support, Litton Airtron supplies wafers, and Spectra Diode makes the semiconductor lasers. Amoco intends to use this alliance to pursue communications, projection TV, reprography, and other commercial and military applications.

Thorn-EMI/Varian

TEV is a joint venture of Thorn-EMI Electronics (United Kingdom) and Varian Associates (United States). The company, based in the United Kingdom, supplies tubes for broadband EW and expendables for military applications. TEV also is developing 70mW to 80mW 90-GHz oscillators for missile-seeking mortars (smart munitions). The company is focusing on applications in earth resources satellites and SARs (synthetic aperture radars).

The Ford ASMMIC Team

Ford Aerospace and Communications Corporation recently described a team effort to enable insertion of microwave/millimeter wave ICs into widespread system applications. The team consists of Ford Aero; Singer Dalmo Victor Division; IBM Federal Systems Division; COMSAT; Pacific Monolithics; and TriQuint. The approach is called ASMMIC, for "application-specific MMIC."

GaAs IC designs based on this approach have been produced and tested to 28 GHz, and new designs to 100 GHz are in process. A reduction in system integration time by a factor of 3 is claimed for the approach. Typical applications include communications receivers, antennas, radar, and electronic support systems.

Other Supplier Agreements

Other agreements include M/A-COM/AT&T, TRW/FEI, AT&T/Hughes, several European companies, and others, many of which evolved from the U.S. DOD MIMIC program or the Europe 1992 intiative.

DATAQUEST CONCLUSIONS

In 1990, the GaAs IC business intensified, with the entry of Fujitsu in GaAs HEMT VLSI. Digital GaAs is now challenging ECL gate arrays at comparable prices, at densities to 100,000 gates per chip.

Dataquest believes that analog and linear GaAs and other III-V compound devices will displace silicon on a directly competitive basis only in those applications where GaAs offers a distinct advantage, such as a superior upper frequency limit, better radiation hardness, or higher operating temperature.

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Because many GaAs applications are in the design stage, GaAs IC sales are presently almost evenly divided between R&D and product sales. This proportion is expected to shift rapidly within this decade to at least 75 percent product sales in 1991.

The largest IC product market segment is analog, with sales of approximately $68 million in 1985, growing at more than 40 percent per year. The largest GaAs IC market segment is military/ government, followed by the communications and computer markets, which is expected to remain so into 1991.

Some industry sources believe that GaAs digICs have the potential to displace ECL in its entirety; however, Dataquest believes that ECL will continue to evolve (e.g., Motorola's ECLiPS family) and will remain more cost effective than GaAs ICs for some general-purpose logic applications into the 1990s.

The minimum investment required to start a GaAs device fab capability is in the range of $30 million to $40 million. To avoid this initial start-up cost, some companies are taking advantage of the present excess in foundry capacity. Fujitsu invested more than $200 million to develop GaAs IC production capability.

Japanese supplier presence in the merchant GaAs IC market is growing. Japanese companies, with strong MITI support, appear to be following the same III-V strategy as their silicon strategy, and their present positioning compares roughly with their position in silicon in the early 1970s.

The GaAs device industry will continue its consolidation in 1990, with pressure intensifying on wafer suppliers. Excess capacity will continue to shrink, and those companies without fab facilities have an excellent opportunity to acquire fab capability at a small fraction of the usual cost.

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Gallium Arsenide Technology Analysis

The following is a list of the material in this section:

- Gallium Arsenide--Executive Summary
- Gallium Arsenide--Forecast Summary

Gallium Arsenide--Executive Summary

GaAs and other III-V compound semiconductors have moved rapidly from the laboratory to many commercial applications. After more than 20 years of military/ government usage, discrete and SSI/MSI devices are being replaced by digital functions ranging in complexity to LSI/VLSI densities. Such functions include SRAMs, multipliers, gate arrays, and integrated optoelectronic devices. In the analog/linear area, microwave hybrids are being replaced, in many instances, by standard-cell-based MMICs capable of operation above 12 GHz. Users of supercomputers, telecommunications hardware, instrumentation, and consumer products are receiving major benefits in performance and improved functionality by taking advantage of this space-age technology. GaAs is projected to exceed $4 billion by 1992; however, less than 30 percent of this value will be ICs.

This section is a brief summary of the information appearing throughout this volume. It is intended to give the user an overview of the gallium arsenide (GaAs) and related III-V compound semiconductor industry. The glossary (Appendix G) may be helpful in clarifying terminology.

ADVANTAGES OF GaAs OVER SILICON

The following are advantages that GaAs semiconductors have over silicon:

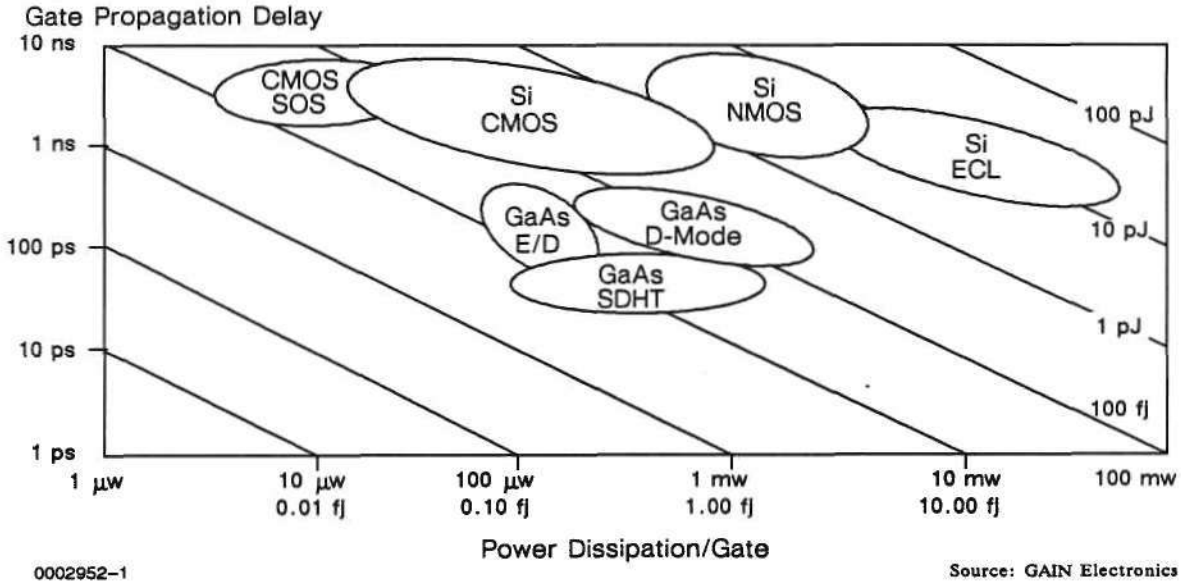
- Circuit switching 3 to 10 times faster
- Speed/power product 5 to 6 times more efficient (refer to Figure 1)
- Relative insensitivity to temperature and power supply variations
- Upper temperature limit of 350°C versus 175°
- Superior levels of radiation tolerance
- Integrated optoelectronics (electronic and photonic circuits) on a single chip
- Wider range of resistivity due to semi-insulating substrates

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Figure 1

GaAs Speed/Power Advantage



DISADVANTAGES OF GaAs VERSUS SILICON

The disadvantages of GaAs semiconductors compared with silicon are:

- Higher cost-per-circuit function
- Higher wafer cost (typically 20 times or more)
- Lower level of digital circuit integration at a given point in time
- Lack of volume production parametric test capability
- Design tasks more difficult; fewer expert designers

BRIEF CHRONOLOGY OF MAJOR GaAs DEVELOPMENTS—1952-1987

The III-V compound semiconductor technology is not new. The semiconducting properties of the compounds were researched more than 35 years ago, and GaAs ICs were in development in the late 1960s. A brief chronology follows (for a summary, see Figure 2):

- 1952—Welker reported semiconducting properties of III-V compounds
- 1956—Czochralski method used to prepare GaAs single crystals

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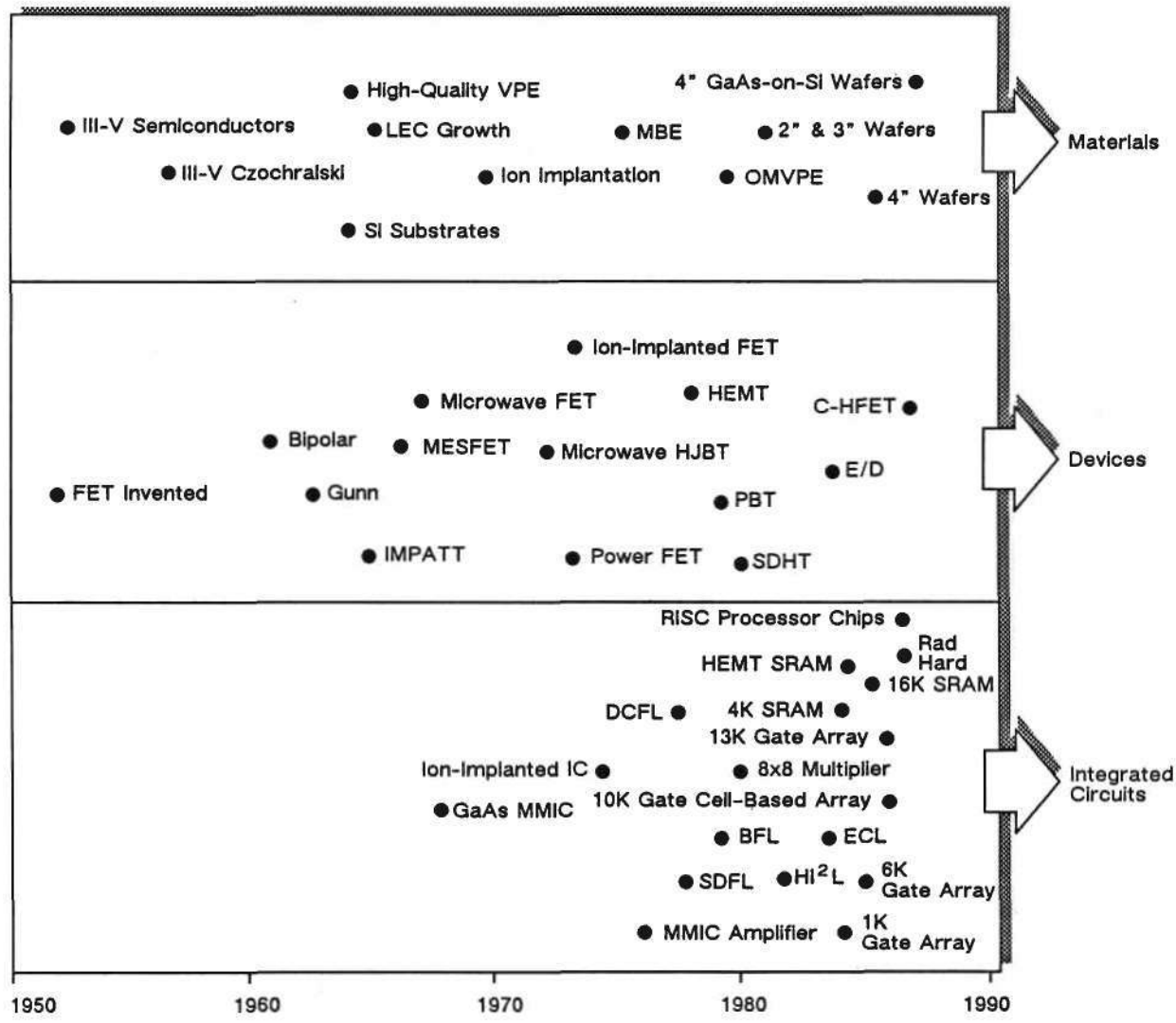
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- 1961—GaAs bipolar transistor with f_T= 730 MHz reported
- 1962—J.B. Gunn of IBM discovered the transferred electron effect
- 1966—GaAs oscillator reported by Bell Labs; GaAs Microwave Monolithic IC (MMIC) patent application
- 1973—First GaAs DigIC
- 1974—GaAs impact avalanche and transit (IMPATT) diodes and GaAs lasers fabricated by molecular beam epitaxy (MBE)
- 1978—33ps ring oscillator delay achieved
- 1980—8x8 Schottky Diode FET Logic (SDFL) multiplier
- 1981—2-inch and 3-inch GaAs wafers commercially available
- 1982—40+ GHz GaAs field-effect transfer (FET), 16x16 multiplier, 32-bit adder, 1,224 gate array
- 1983—4K SRAMs reported
- 1984—Sub-ns high-electron-mobility transistor (HEMT) 1K SRAM, 20-GHz monolithic Voltage Controlled Oscillator (VCO), digital/analog ASIC array
- 1985—1.2-GHz GaAs frequency synthesizer, 42ps 2K gate array, 4K gate array tested at 385°C, 100-mips 8-bit microprocessor with RISC architecture and E/D process, 12-bit D/A converter with 1-GHz word rate, 115-GHz amplifier, 4-inch near defect frep (NDF) wafers announced
- 1986—NEC announced entry into GaAs digIC market, 4-inch NDF wafers shipped in production quantity, 600ps 1K SRAM, multiple-sourced 12x12 multiplier, 8-GHz 88-pin LCC package, 41-GHz amplifier with 135mW output power
- 1987—GaAs-on-Si wafers into beta-site tests, 6K E/D gate array, numerous multisourcing announcements, volume production of supercomputer ICs, CW operation of GaAs-on-Si lasers

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Figure 2

GaAs Technology Evolution Time Line



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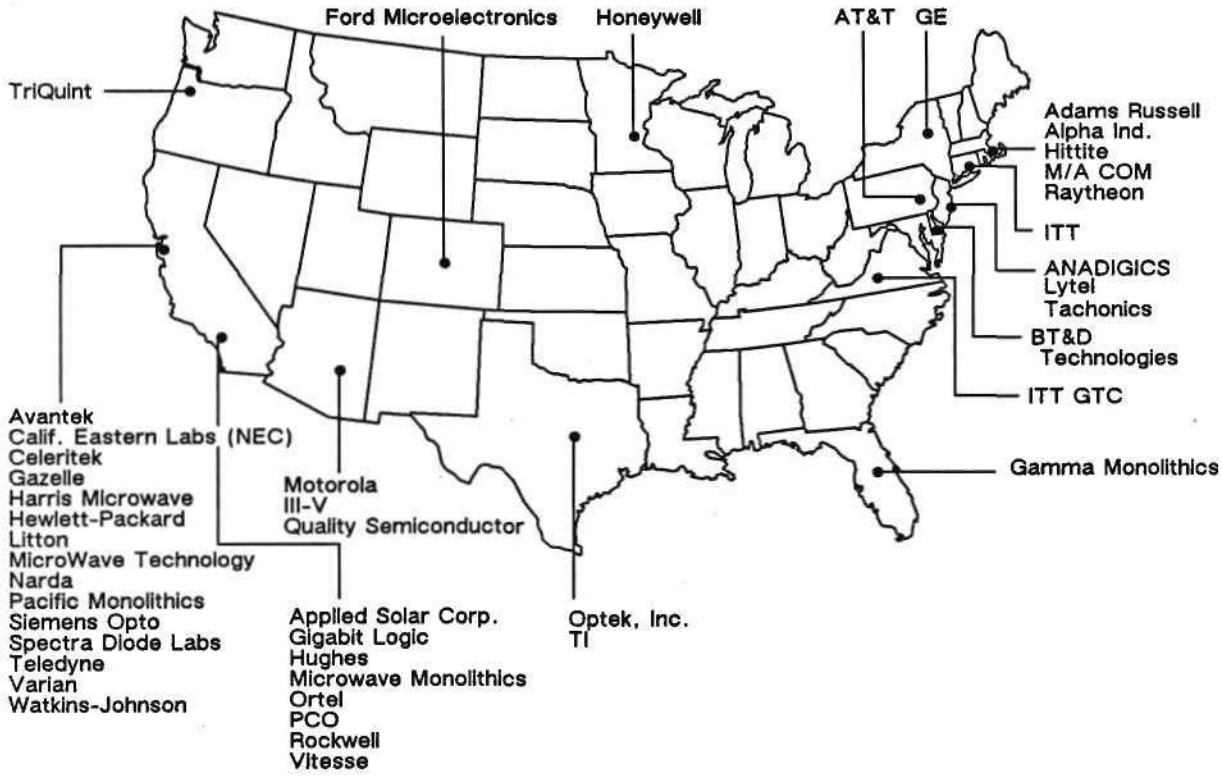
GEOGRAPHIC DISTRIBUTION OF GaAs DEVICE SUPPLIERS

The greatest geographic concentration of semiconductor talent in the Free World is in the South San Francisco Bay Area, often referred to as Silicon Valley. While this may also be true of GaAs technology talent, other areas such as "Gallium Gardens" in New Jersey, "Gallium Gulch" in southern California, and "Gallium Springs" in Colorado are gaining recognition for their evolving infrastructures. The primary influences in recent years included AT&T and Rockwell, in much the same way that Fairchild spawned numerous start-ups in silicon technology in the 1960s.

The maps in Figures 3, 4, and 5 show the present dispersion of most of the GaAs companies in the Free World. Additional GaAs activities are under way in Iron Curtain countries; reporting on such activities exceeds the scope of this volume.

Figure 3

U.S. Locations of GaAs Semiconductor Suppliers



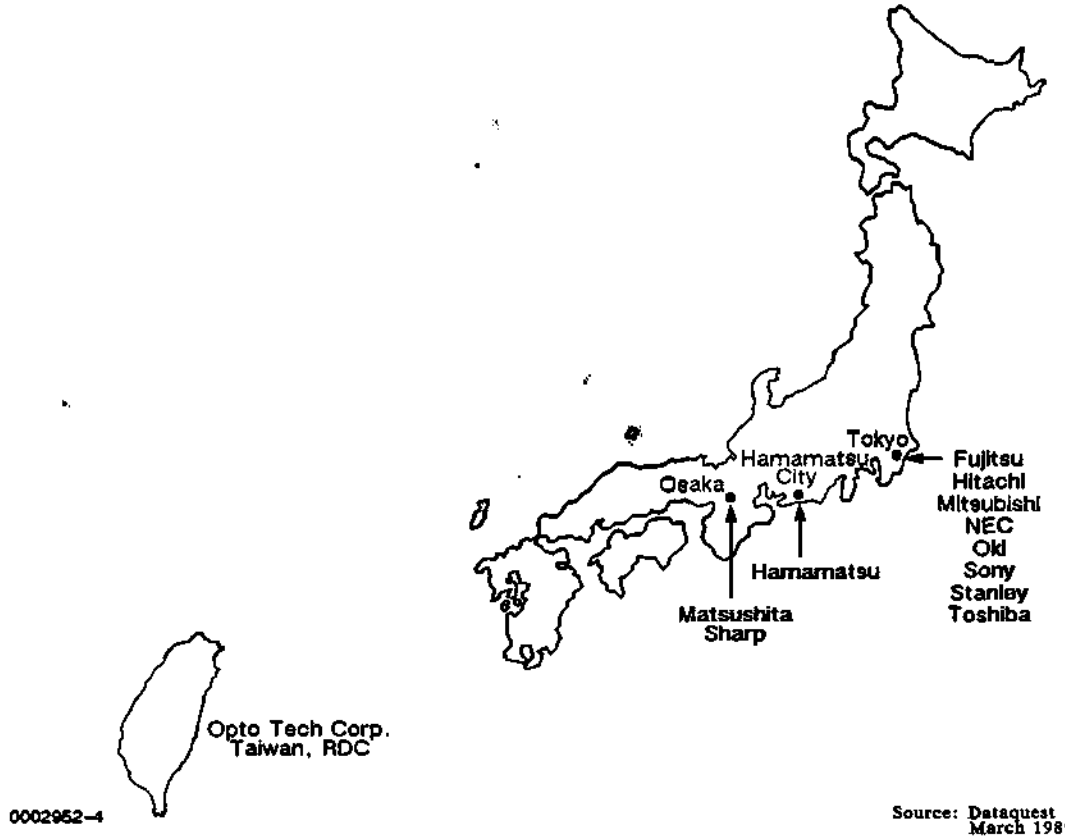
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Figure 4

Asian Locations of Semiconductor Suppliers

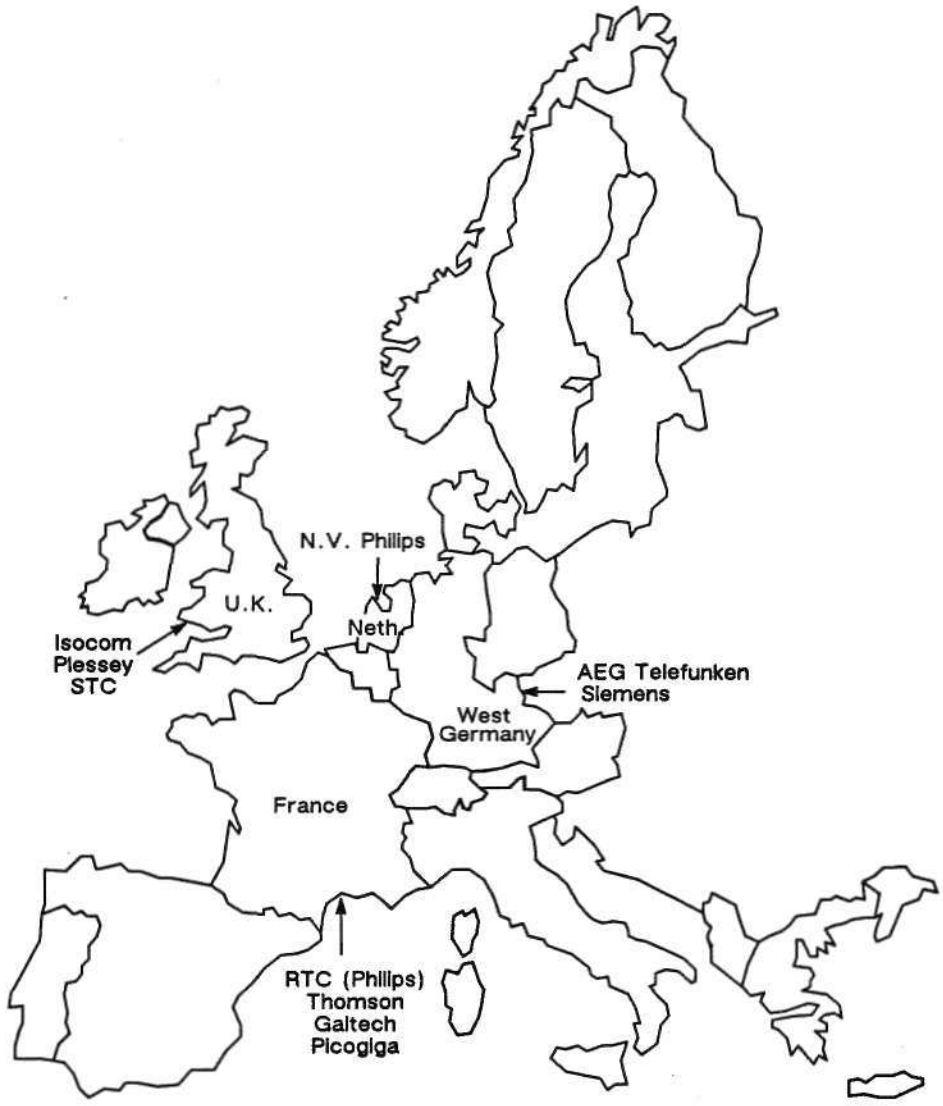


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Figure 5

Western European Locations of GaAs Semiconductor Suppliers



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STATE OF THE ART

GaAs and other III-V semiconductors are evolving more rapidly than did silicon devices in the 1960s. This is happening because, among other things, many techniques and methodologies developed during silicon industry evolution are readily adaptable to III-V technology. Device density and performance accomplishments in recent years are shown in Table 1.

Table 1

Recent Progress in GaAs ICs

Function		Company	Comments
Digital			
SRAMs	1Kx1	TI	Smallest cell reported to 11/85
	16Kx1	NEC	Highest density reported to 2/85
	16K	Rockwell	Rad hard, very low power
	1Kx1	Rockwell	600ps cycle time
Multipliers	16x16	Fujitsu	Highest density reported to date
	4x4	AT&T	Best speed/power to date at 115ps and 0.34mW/gate
Gate Arrays	4K	TI	Tested at 385°C
	2K	Fujitsu	Best reported t_{pd} at 42ps/gate
	6K	GAIN	E/D process, TTL/CMOS/ECL compatible
Analog			
A/D-D/As	12-bit DAC	HP	Highest resolution at 1-GHz word rate
MMICs	115GHz	TI	Fastest amplifier reported to date
	41GHz	TI	Best speed/power at 135mW output

Source: Aztek Associates

The greatest potential for system performance improvement through the application of III-V technology will likely be realized with selectively doped heterojunction transistors (SDHT--also called HEMT) device structures. Although AT&T holds the basic patent, the first commercially available HEMT was Gould's H503, announced in 1985. GE (Syracuse, New York) has announced development of an HEMT structure with a current gain cutoff frequency of 80 GHz. The highest reported cutoff frequency for conventional GaAs FETs was 50 GHz at press time.

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APPLICATIONS

The unique properties of GaAs and other III–V compounds allow solutions to technical problems that were heretofore not economically solvable. Primary examples today are found in the fields of fiber–optic and satellite communications, supercomputing, and high–speed test/measurement. Military/government applications, including aerospace, have provided the initial impetus for GaAs technology development. Among these are radar, satellite communications, electronic warfare, electronic countermeasures, surveillance, and high–speed signal processing.

The growing number of diverse applications for GaAs and other III–V compound semiconductors are discussed in the section "End Uses." As further cost improvements are realized, end uses will increasingly extend into the full spectrum of markets—local telecommunications, computer, instrumentation, CAD/CAE/CAM, artificial intelligence, robotics, military/aerospace, automotive, and consumer.

ASICs

ASIC technology provides a relatively inexpensive means of incorporating GaAs into an existing silicon subsystem or system design. The user may upgrade system performance in some cases by a factor of 2 to 3 by making relatively minor changes to existing hardware, such as incorporating GaAs into critical paths—e.g., clock distribution circuits and prescalers.

GaAs suppliers that support ASIC and foundry work are offering a broadening range of customers the opportunity to efficiently incorporate added value into existing designs. Thus they may accelerate the transition from silicon to GaAs in very high–performance systems. GaAs ASICs are the focus of a special section of this module.

GOVERNMENT ACTIVITIES

Major Free World governments investing in GaAs and related III–V compound semiconductor R&D include Japan, France, West Germany, Canada, the United Kingdom, and the United States. Because of the strategic nature of various programs, the exact levels of funding are not available. Industry sources believe the approximate range of annual investments by the governments of the named countries is $10 million to $100 million each.

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SUPPLIERS

Dataquest identified the following levels of industrial activity in GaAs and related compound technology in 1987:

- 30 merchant market suppliers of ICs
- 27 merchant suppliers of discretes
- 23 captive-only houses
- 25 wafer producers supplying to the merchant market
- 16 merchant foundries
- 6 start-ups not shipping in 1987 with near-future entry plans
- More than 70 universities involved in III-V R&D, many with fab capability

MARKETS AND OPPORTUNITIES

Initially, III-V compound semiconductor technology development and growth were stimulated by electronic warfare (EW), radar, SATCOM, and fiber-optic applications. These applications were initially analog/linear in nature, requiring microwave operation in many instances. More recent markets have evolved for GaAs and other III-V device usage in LANs, instrumentation, cellular radio, supercomputers, compact disks, and TV reception. Industry sources (e.g., ANADIGICS, Inc.) believe the market development sequence will approximate that shown in Table 2.

Table 2

GaAs Market Evolution

TIME Military	Telecom	Bus/Inst.	EDP	Consumer
EW	Fiber Optics	Graphics	Supercomputers	DBS
C^3I	SATCOM	Instrumentation	Array Processors	HDTV
Radar	Radios	CAD/CAE	AI	PCs
Missiles	Modems	Medical	Super minis	Videotext
Simulators	LANs	Robotics	Mass Storage	Automotive

Source: ANADIGICS, Inc.

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TRENDS AND ISSUES

This section addresses current trends and issues in GaAs and related III–V compound materials, processing, chip functions, packaging, foundries, captive sources, government and university roles, standardization, testing, reliability, partnerships, second–sourcing, and market development.

Trends in III–V Materials

Availability of high–quality, low–defect–density GaAs substrates is considered a major limiting factor in the transition of GaAs technology from present density levels to LSI/VLSI complexities. State of the art in late 1986 was of the order of 100 to 200 dislocations/sq.cm., and much of the available material ranged up to 2,000 dislocations/sq.cm. or much higher. We believe that the methodologies then in use for minimizing dislocation density created other problems for device suppliers during the ion implantation steps of the device manufacturing process.

In November 1986, M/A–COM was considered the largest supplier of GaAs substrates in the United States. Japanese GaAs wafer suppliers included Sumitomo Electric Industries, Ltd., at 3,000 3–inch wafers/month; Shin–Etsu at 500 3–inch wafers/month, with plans to increase production; Mitsubishi–Monsanto Chemical Company at 2,000 3–inch wafers/month production; and others, including Nippon Mining and Showa Denko, to increase production soon.

In December 1985, Mitsubishi–Monsanto announced that it had developed the first near–dislocation–free (NDF) 4–inch GaAs wafer. The company presently produces 2–inch and 3–inch wafers, and it plans to begin quantity production of 4–inch wafers in 1987. Westinghouse reported In–doped NDF wafers in October 1986.

Varian is considered a leader in InP devices. Varian has marketed InP MMIC and discrete products, and the company developed an InP VCO chip for introduction in 1986.

Table 3 presents a compilation of the major merchant market suppliers of III–V compound wafers. It shows the various wafer sizes and growth methods in use at the present time. In addition, several companies including start–ups Emcore, OMVPE Technologies, and United Epitaxial Technologies Inc., offer epitaxial GaAs wafers and GaAs wafers that incorporate indium and phosphorus dopants.

Table 3

III-V Wafer Suppliers

Suppliers	Materials	Wafer Diameter (Inches)	Growth Method
Airtron (Litton Ind.)	GaAs	2, 2.5, 3	LEC
Bertram Labs Inc.	GaAs	2	HB
Boliden Finemet AB	GaAs	2, 3	HPLEC
Cominco Electr. Materials Inc.	GaAs, GaSb, InSb, InAs	2, 3, 4	HPLEC
Commerc. Crystal Labs., Inc.	GaAs, GaP, InP	2	LEC, HB
Dowa Mining	GaAs, InP	2	HB
Furukawa	GaAs, InP	2, 3	LEC
Galaris Corp.	GaAs	2	HB
GVI Inc.	GaAs		
Hitachi Cable	GaAs, InP	2, 3	LEC
ICI Wafer Technology, Ltd.	GaAs, InP	2, 3	LEC
M/A-COM Inc.	GaAs	2, 3	LEC
Metalspecialties Inc.	GaAs, GaP, GaSb, InAs, InP, InSb	1.5, 2, 2.5, 3	LEC, HB
Mitsubishi Metal Corp.	GaAs	2, 3	LEC, HB
Mitsubishi-Monsanto	GaAs	2, 3, 4	LEC
Morgan (Ethyl Corp.)	GaAs	2, 3	HPLEC
Nippon Mining	GaAs, InP	2, 3	LEC

(Continued)

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Table 3 (Continued)

III-V Wafer Suppliers

Suppliers	Materials	Wafer Diameter (Inches)	Growth Method
Shin-Etsu Handotai	GaAs	2, 3	LEC
Showa Denko	GaAs, InP	2, 3	Magnetic LEC
Siemens Comp. Inc. Opto. Div.	GaAs	1.6- 3	HB
Spectrum Technologies Inc.	GaAs	2, 3	LEC
Sumitomo Electric	GaAs, GaP, InP, InSb, InAs, GaSb	0.8- 3	LEC, HB
Sumitomo Metal & Mining	GaAs, CdTe, GaP	2	LEC

Source: Dataquest March 1989

Processing

The trend in III-V compound chip fabrication is toward use of ion implantation rather than epitaxial formation of active layers, for these reasons:

- It eliminates the need for etching to obtain desired depth.
- Its precision surpasses that of etching procedures.
- Sharp carrier cutoff at the active layer-substrate interface is obtained.
- Circuit element isolation is possible by proton or oxygen ion bombardment.
- Device formation is simplified by selective ion implantation.

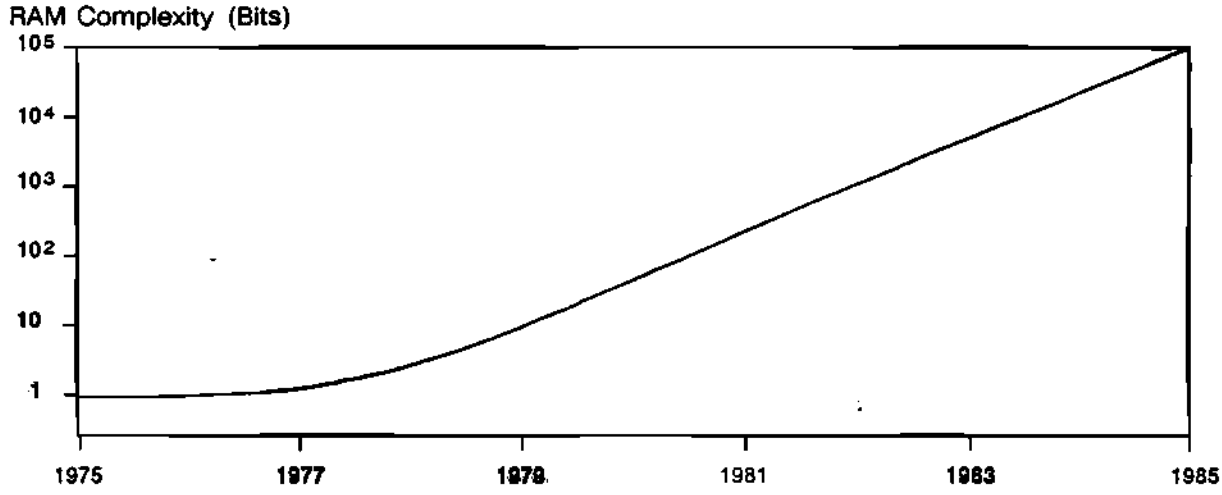
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Functions

The trend in function evolution of GaAs ICs is to provide performance significantly above that possible with silicon technology at the highest density achievable within cost constraints of the application. Function density for GaAs digICs (see Figure 6) has outperformed Moore's Law in the recent past, according to industry sources.

Figure 6

GaAs RAM Functional Density versus Time



0002952-6

Source: Dataquest March 1989

Mergers, Acquisitions, and Agreements

A natural consequence of GaAs technology development in the United States is the increasing number of partnerships, agreements, mergers/acquisitions, joint ventures, and team efforts. The following paragraphs summarize some of the major such actions in this industry.

MIMIC Program

The DOD MIMIC (millimeter-microwave IC) initiative represents a major effort to incorporate the advantages of compound semiconductors into a variety of military applications. These applications include:

- Ultrareliable radar for the U.S. Air Force ATF
- Shared-aperture radar for the U.S. Navy ATA

- MILSTAR network communications terminals
- Smart munitions
- Wideband jammers
- Antiradiation missiles
- Other "brilliant" weapons

The MIMIC program entered Phase 0 early in 1987 with the award of 12 major and 4 smaller contracts to prime contractors. Table 4 shows a compilation of the responsible services, prime contractors, approximate award amounts, and team members involved in the major Phase 0 contracts. Additional awards went to Hittite Microwave ($500,000), Ball Aerospace ($497,000), E-Systems ($100,000), and Loral ($100,000). Funding for the remainder of the seven-year program recently was estimated at more than $530 million. Dataquest believes that Phase I of MIMIC will see some realignment of the participants, as the program becomes more competitive and the number of teams decreases.

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Table 4

MIMIC Phase 0

Service	Army			
Prime Contractor	Eaton	ITT	Martin Marietta	TRW
Award ($K)	886	995	986	1,000
Team Members:				
Adams Russell				
Aerojet				
Airtron (Litton)				
Alpha Industries			X	
AT&T				
Avantek				
Cascade			X	
Cominco				
Compact Software				
Consilium				
Cornell University				
EEsof			X	
General Dynamics				X
General Electric				
Harris			X	
Honeywell				X
Lockheed				
M/A-COM				
Magnavox				
Motorola				
Norden (United Technologies)				
Pacific Monolithics		X		
Rockwell				
Singer				

(Continued)

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Table 4 (Continued)

MIMIC Phase 0

Service	Army			
Prime Contractor	Eaton	ITT	Martin Marietta	TRW
Team Members				
Spectrum			X	
Teledyne Ryan				
Texas Instruments			X	
TriQuint				
Varian				
Watkins-Johnson		X		

Service	Navy			
Prime Contractor	Bendix	Ford	Raytheon/TI	Sandecs
Award ($K)	751	1,000	999	981
Team Members:				
Adams Russell				X
Aerojet			X	
Airtron (Litton)			X	
Alpha Industries				
AT&T				
Avantek				
Cascade				
Cominco				
Compact Software			X	
Consilium			X	
Cornell University				
EEsof				
General Dynamics			X	
General Electric				
Harris				
Honeywell				
Lockheed				X
M/A-COM		X		

(Continued)

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Table 4 (Continued)

MIMIC Phase 0

Service	Navy			
Prime Contractor	Bendix	Ford	Raytheon/TI	Sandecs
Team Members				
Magnavox			X	
Motorola				X
Norden (United Technologies)			X	
Pacific Monolithics	X	X		
Rockwell				
Singer		X		
Spectrum				
Teledyne Ryan			X	
Texas Instruments				
TriQuint	X	X		
Varian				X
Watkins-Johnson				

Service	Air Force			
Prime Contractor	Harris	Hughes	UNISYS	Westinghouse
Award ($K)	748	998	953	989
Team Members:				
Adams Russell				
Aerojet				
Airtron (Litton)				
Alpha Industries			X	
AT&T		X		
Avantek				X
Cascade				
Cominco				X
Compact Software				
Consilium				
Cornell University	X			
EEsof	X			X

(Continued)

Table 4 (Continued)

MIMIC Phase 0

Service	Air Force			
Prime Contractor	Harris	Hughes	UNISYS	Westinghouse
Team Members:				
General Dynamics				
General Electric	X	X		
Harris		X		
Honeywell				
Lockheed				
M/A-COM				
Magnavox				
Motorola				
Norden (United Technologies)				
Pacific Monolithics				
Rockwell				X
Singer				
Spectrum				
Teledyne Ryan				
Texas Instruments				
TriQuint	X		X	X
Varian			X	
Watkins-Johnson				

Source: Dataquest
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Pacific Monolithics/TriQuint

TriQuint has performed well as Pacific Monolithics' primary foundry, supplying processed wafers to mutually acceptable specifications. Dataquest believes that this relationship led to some of the specific teaming on the DOD MIMIC program (see Table 4).

Pacific Monolithics/COMSAT LABS

In July 1987, Pacific Monolithics announced that it had signed an exclusive agreement with COMSAT Laboratories of Clarksburg, Maryland, to develop and pursue products and markets for power and millimeter-wave MMICs, and to seek Phase I through III contracts under the DOD MIMIC program. Pacific will provide design and marketing skills; COMSAT will contribute 30-GHz MESFET foundry capability. The agreement is also intended as a vehicle for exploring additional business opportunities in monolithic and millimeter-wave devices.

Rockwell/IBM

Early in 1987, Rockwell International and IBM entered into an agreement for the cooperative development of high-speed digital and optoelectronic GaAs devices for future computers and telecommunications equipment. The program involves Rockwell's GaAs pilot line at Newbury Park, California; Rockwell development teams at Newbury Park and Thousand Oaks, California; and IBM development teams at East Fishkill and Yorktown Heights, New York. Dataquest believes that this agreement positions IBM to take a leadership role in GaAs digIC (digital integrated circuit) applications.

Cray/GigaBit

For about three years, Cray Research, Inc., has been working with GigaBit Logic, Inc., to develop a reliable source of GaAs devices for use in a Cray-3 computer. Early in 1987, Cray increased the amount of its order for GigaBit GaAs IC chips to be delivered in 1987 to $5.2 million. Dataquest believes that this agreement allows Cray to redirect its internal GaAs capability toward development of HEMT, E/D MESFET, or other high-speed technology. Cray Research participated in GigaBit Logic's third round of financing in May 1987, along with Analog Devices, Inc.; Digital Equipment Corporation; and others.

AMD/Vitesse

In 1986, AMD and Vitesse agreed to a technology exchange involving AMD's 2900 bit-slice family and Vitesse's E/D MESFET GaAs technology. The effort resulted in Vitesse's announcement of its 29G01, 29G10, and other GaAs bit-slice products late in 1986.

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Gallium Arsenide--Executive Summary

GigaBit/Seattle Silicon

GigaBit and Seattle Silicon Corporation have developed a 4-bit ALU that is functionally equivalent to the 100181, a 100K ECL chip. Design engineering support was provided by the Washington Technology Center (WTC). The chip is 5.7 times faster than its silicon counterpart and consumes half the power.

GigaBit/Prisma Corporation

In July 1987, GigaBit and Prisma Corporation announced an agreement to produce a complete family of custom GaAs logic and memory digICs for use in Prisma's new family of real-time supercomputers. The machine architecture is based on a 32-bit RISC structure. Under the agreement, Prisma will design the ICs to GigaBit's newly released HME/D (high-margin enhancement/depletion) process, which is characterized by sub-100ps gate delays at power levels significantly lower than those of silicon ECL gates.

Ford/Vitesse

Ford Microelectronics, Colorado Springs, Colorado, and Vitesse Semiconductor Corporation, Camarillo, California, are establishing an E/D self-aligned gate GaAs IC alternate-source agreement and capability. Initially, the agreement includes custom and semicustom circuits, but it may be extended to standard products. Dataquest believes that Ford has successfully processed wafers containing gate array chips to mutually agreed-upon design rules.

On October 14, 1987, Ford Microelectronics, Inc., and Vitesse Semiconductor Corporation announced what both companies consider to be the first agreement among commercial GaAs manufacturers to provide alternate sourcing for foundry production of custom LSI GaAs E/D MESFET ICs. Ford Microelectronics' president, John R. Wallace, stated, "The agreement between Ford and Vitesse allows customers a choice of vendors and the opportunity for backup supplies." Both companies project that their GaAs technology will be used to achieve lower power, higher speed, and increased functionality in less space and at lower cost.

Microwave Technology, Inc./Monolithic Microsystems, Inc.

In June 1987, Microwave Technology, Inc., of Fremont, California, completed its acquisition of Monolithic Microsystems, Inc., of Santa Cruz, California. Under the agreement, Monolithic Microsystems will become a wholly owned subsidiary of Microwave Technology and will continue manufacturing at its present 8,200-square-foot facilities.

Gallium Arsenide--Executive Summary

TRW/TriQuint

TRW Components International (a subsidiary of TRW, Inc.) and TriQuint have agreed to jointly supply GaAs devices for space applications. The companies are working together on procedures for producing Class S-level GaAs components. TriQuint will provide foundry support.

Ciba-Geigy/Spectra-Physics

In June 1987, it was reported that Ciba-Geigy had signed a definitive agreement to acquire Spectra-Physics for $266 million. A prior lawsuit seeking to enjoin Ciba-Geigy's initial (reportedly hostile) takeover offer was reported as being dismissed without prejudice by the Delaware Federal Court. Dataquest believes that this acquisition will strengthen Ciba-Geigy's ability to participate in the GaAs industry infrastructure.

California Micro Devices/Tachonics

A June 1987 announcement stated that California Micro Devices, Milpitas, California, has formed an alliance with Tachonics, Plainsboro, New Jersey, to produce a family of GaAs ASICs for military applications. Tachonics is a subsidiary of Grumman Aerospace Corporation of Bethpage, New York.

Amoco/Spectra Diode/Kodak/Litton Airtron

Amoco Laser Company, a wholly owned subsidiary of Amoco Corporation, has formed a strategic alliance with Eastman Kodak, the Airtron Division of Litton Industries, and Spectra Diode Labs to support Amoco's laser systems product line. Kodak provides production support, Litton Airtron supplies wafers, and Spectra Diode makes the semiconductor lasers. Amoco intends to use this alliance to pursue communications, projection TV, reprography, and other commercial and military applications.

Thorne-EMI/Varian

TEV is a joint venture of Thorne-EMI Electronics (United Kingdom) and Varian Associates (United States). The company, based in the United Kingdom, supplies tubes for broadband EW and expendables for military applications. TEV also is developing 70mW to 80mW 90-GHz oscillators for missile-seeking mortars (smart munitions). The company is focusing on applications in earth resources satellites and SARs (synthetic aperture radars).

The Ford ASMMIC Team

Ford Aerospace and Communications Corporation recently described a team effort to enable insertion of microwave/millimeter wave ICs into widespread system applications. The team consists of Ford Aero; Ford Microelectronics, Inc.; Singer Dalmo Victor Division; IBM Federal Systems Division; COMSAT; Pacific Monolithics; and TriQuint. The approach is called ASMMIC, for "application-specific MMIC."

GaAs IC designs based on this approach have been produced and tested to 28 GHz, and new designs to 100 GHz are in process. A reduction in system integration time by a factor of three is claimed for the approach. Typical applications include communications receivers, antennas, radar, and electronic support systems.

GigaBit and Tachonics

On October 21, 1987, GigaBit Logic Inc. and Tachonics Corporation announced their agreement to second-source GaAs digital ICs developed by both companies. The two companies reported that their agreement includes:

- Transfer of logic design data bases, schematics, and test specifications
- Full support by both companies of Daisy, Mentor, and VLSI Technology workstations
- Codevelopment of cell libraries for future processes

DATAQUEST CONCLUSIONS

Dataquest believes that GaAs and other III-V compound devices will displace silicon on a directly competitive basis only in those applications where GaAs offers a distinct advantage, such as a superior upper frequency limit, better radiation hardness, or higher operating temperature.

Because many GaAs applications are in the design stage, GaAs IC sales are presently almost evenly divided between R&D and product sales. This is expected to shift rapidly within this decade to at least 70 percent product sales by 1990.

The largest IC product market segment is analog, with sales of approximately $68 million in 1985, growing at more than 50 percent per year. The largest GaAs IC market segment is military/government, followed by the communications market, which is expected to remain so into 1989 and 1990.

Some industry sources believe that GaAs digICs have the potential to displace ECL in its entirety; however, Dataquest believes that ECL will continue to evolve (e.g., Motorola's ECLiPS family) and will remain more cost effective than GaAs ICs for many general-purpose logic applications into the 1990s.

The minimum investment required to start a GaAs device fab capability is in the range of $20 million. To avoid this initial start-up cost, some companies are taking advantage of the present excess in foundry capacity. Many companies have invested more than $30 million to develop GaAs IC production capability.

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Gallium Arsenide--Executive Summary

Japanese supplier presence in the merchant GaAs IC market is presently limited to NEC's MMICs and digICs. Japanese companies, with strong MITI support, appear to be following the same III-V strategy as their silicon strategy, and their present positioning compares roughly to their position in silicon in the early 1970s.

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GaAs Semiconductors--Markets

Table 1

Worldwide GaAs Merchant Consumption Forecast by Technology (Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR 1987-1991
Analog									
GaAs ICs	39	80	117	173	227	306	397	551	33.6%
Devices	19	40	66	123	177	256	372	531	44.1%
NRE	20	40	51	50	50	50	25	20	
Digital ICs	11	26	51	91	142	232	403	617	61.4%
Devices	1	6	16	59	112	207	383	597	78.4%
NRE	10	20	35	32	30	25	20	20	
Discrete Opto	1,282	1,276	1,629	1,728	2,087	2,014	2,260	2,650	11.3%
Integrated Opto	8	20	28	43	67	104	162	202	47.2%
Microwave Discrete	131	180	228	273	341	410	450	494	16.0%
Total	1,471	1,582	2,053	2,308	2,864	3,066	3,672	4,514	18.3%

Columns may not add to totals shown because of rounding.

Assumptions:

- Sustained materials, quality improvements, and open-market availability of DF wafers
- No predatory pricing by major suppliers
- Successful MIMIC program funded in excess of $120 million over 5 years

Source: Dataquest
March 1988

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GaAs Semiconductors--Markets

Table 2a

Worldwide GaAs Consumption Forecast by End Use (Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR 1987-1991
Total Available Market	1,471	1,580	2,053	2,308	2,864	3,066	3,672	4,514	18.3%
EDP	527	473	576	646	759	767	882	1,036	12.5%
Computers, business machines including mail and POS, printers, optical storage, other									
Communications	312	303	418	472	577	639	788	952	19.2%
Long lines (microwave and fiberoptic), LANs, satcom, digital radio, fax, other									
Industrial	233	278	352	414	510	553	651	823	18.7%
Medical, instrumentation, security, process control including robotics and vision systems, other									
Consumer	235	285	404	446	537	567	704	909	19.5%
TVs, video and audio disks, CDs, VCRs, cameras, toy/hobby products, home/auto security, radar detectors, other									
Military	115	157	188	224	271	325	389	476	20.7%
EW, ECM, guidance and navigation, sensors, other									
Transportation	50	84	115	185	214	215	257	318	14.5%

Columns may not add to totals shown because of rounding.

Source: Dataquest
March 1988

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GaAs Semiconductors--Markets

Table 2b

Worldwide GaAs Consumption Forecast by End Use
(Percent)

Category	1984	1985	1986	1987	1988	1989	1990	1991
Total Available Market	100	100	100	100	100	100	100	100
EDP	36	30	28	27	27	25	24	23
Communications	21	19	20	21	20	21	21	21
Industrial	16	18	17	17	18	17	18	18
Consumer	16	18	20	19	19	19	19	20
Military	8	10	9	9	9	11	11	11
Transportation	3	5	6	8	7	7	7	7

Source: Dataquest
March 1988

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Table 3a

North American GaAs Consumption Forecast by End Use (Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR 1987-1991
Total Available Market	615	583	745	908	1,165	1,190	1,439	1,723	17.4%
EDP	249	194	233	287	332	307	343	369	6.5%
Computers, business machines including mail and POS, printers, optical storage, other									
Communications	136	122	194	232	277	301	384	438	17.2%
Long lines (microwave and fiber optic), LANs, satcom, digital radio, fax, other									
Industrial	102	110	140	173	221	234	272	346	19.0%
Medical, instrumentation, security, process control including robotics and vision systems, other									
Consumer	39	31	34	78	82	61	87	129	13.4%
TVs, video and audio disks, CDs, VCRs, cameras, toy/hobby products, home/auto security, radar detectors, other									
Military	73	99	113	139	173	213	264	324	23.8%
EW, ECM, guidance and navigation, sensors, other									
Transportation	17	27	31	76	80	74	89	117	11.4%
Includes aftermarket									

Columns may not add to totals shown because of rounding.

Source: Dataquest
March 1988

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Table 3b

North American GaAs Consumption Forecast by End Use
(Percent)

Category	1984	1985	1986	1987	1988	1989	1990	1991
Total Available Market	100	100	100	100	100	100	100	100
EDP	40	33	31	32	29	26	24	22
Communications	22	21	26	26	24	26	27	25
Industrial	17	19	19	19	19	20	19	20
Consumer	6	5	5	9	7	5	6	7
Military	12	17	15	15	15	17	18	19
Transportation	3	5	4	8	7	6	6	7

Source: Dataquest
March 1988

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Table 4a

West European GaAs Consumption Forecast by End Use (Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR 1987-1991
Total Available Market	222	288	361	406	478	559	678	813	19.0%
EDP	59	64	74	78	92	108	135	159	19.5%
Computers, business machines including mail and POS, printers, optical storage, other									
Communications	45	53	62	70	84	101	122	149	20.8%
Long lines (microwave and fiberoptic), LANs, satcom, digital radio, fax, other									
Industrial	35	49	60	68	82	94	116	139	19.6%
Medical, instrumentation, security, process control including robotics and vision systems, other									
Consumer	43	55	74	76	89	104	129	155	19.5%
TVs, video and audio disks, CDs, VCRs, cameras, toy/hobby products, home/auto security, radar detectors, other									
Military	24	38	47	54	61	73	78	94	14.9%
EW, ECM, guidance and navigation, sensors, other									
Transportation	16	29	44	60	74	79	97	117	18.2%

Columns may not add to totals shown because of rounding.

Source: Dataquest
March 1988

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Table 4b

West European GaAs Consumption Forecast by End Use
(Percent)

Category	1984	1985	1986	1987	1988	1989	1990	1991
Total Available Market	100	100	100	100	100	100	100	100
EDP	27	23	21	20	19	19	20	20
Communications	21	18	17	17	18	18	18	18
Industrial	15	17	17	17	17	17	17	17
Consumer	19	19	21	19	19	19	29	19
Military	11	13	12	13	13	13	12	12
Transportation	7	10	12	14	14	14	14	14

Source: Dataquest
March 1988

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Table 5a

Asian GaAs Consumption Forecast by End Use
(Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR 1987-1991
Total Available Market	634	709	947	994	1,221	1,317	1,555	1,978	18.8%
EDP	219	215	269	281	335	352	404	508	16.0%
Computers, business machines including mail and POS, printers, optical storage, other									
Communications	131	128	162	170	216	237	282	365	21.0%
Long lines (microwave and fiberoptic), LANs, satcom, digital radio, fax, other									
Industrial	96	119	152	173	207	255	263	338	18.2%
Medical, instrumentation, security, process control including robotics and vision systems, other									
Consumer	153	199	296	292	366	402	488	625	21.0%
TVs, video and audio disks, CDs, VCRs, cameras, toy/hobby products, home/auto security, radar detectors, other									
Military	18	20	28	31	37	39	47	58	17.0%
EW, ECM, guidance and navigation, sensors, other									
Transportation	17	28	40	49	60	62	71	84	14.4%

Columns may not add to totals shown because of rounding.

Source: Dataquest
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Table 5b

Asian GaAs Consumption Forecast by End Use
(Percent)

Category	1984	1985	1986	1987	1988	1989	1990	1991
Total Available Market	100	100	100	100	100	100	100	100
EDP	35	31	28	29	28	27	26	26
Communications	21	18	17	17	18	18	18	18
Industrial	15	17	17	17	17	17	17	17
Consumer	23	27	31	30	30	31	31	32
Military	3	3	3	3	3	3	3	3
Transportation	3	4	4	4	4	4	4	4

Source: Dataquest
March 1988

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GaAs Semiconductors--Markets

Table 6a

GaAs Shipments by Region
(Millions of Dollars)

Region	1984	1985	1986
North America	588	580	710
Western Europe	147	177	228
Japan	732	818	1,107
ROW	4	5	8
Total	1,471	1,580	2,053

Table 6b

GaAs Shipments by Region
(Percent)

Region	1984	1985	1986
North America	40.0	36.7	34.6
Western Europe	10.0	11.2	11.1
Japan	49.8	51.8	53.9
ROW	0.2	0.3	0.4
Total	100.0	100.0	100.0

Source: Dataquest
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GaAs Semiconductors--Markets

Table 7a

GaAs Consumption Forecast by Region
(Millions of Dollars)

Region	1984	1985	1986	1987	1988	1989	1990	1991
North America	615	583	745	908	1,165	1,190	1,439	1,723
Western Europe	222	288	361	406	478	559	678	813
Japan	520	581	772	805	983	1,059	1,248	1,579
ROW	114	128	175	189	238	258	307	399
Total	1,471	1,580	2,053	2,308	2,864	3,066	3,672	4,514

Table 7b

GaAs Consumption Forecast by Region
(Percent)

Region	1984	1985	1986	1987	1988	1989	1990	1991
North America	41.8	36.9	36.3	39.3	40.7	38.8	39.1	38.2
Western Europe	15.1	18.2	17.6	17.6	16.7	18.2	18.5	18.0
Japan	35.4	36.8	37.6	34.9	34.3	34.6	34.0	35.0
ROW	7.7	8.1	8.5	8.2	8.3	8.4	8.4	8.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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GaAs and Related Semiconductor Shipment and Consumption Forecast

March 1992

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Market Statistics

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Gallium Arsenide Semiconductors *Worldwide*

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Gallium Arsenide and Related Semiconductor Revenue and Shipment Forecast

March 1992

Source: Dataquest

Market Statistics

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Gallium Arsenide and Related Semiconductor Consumption and Shipment Forecast

Introduction

Gallium arsenide (GaAs) and related semiconductor consumption and shipment data comprise a set of detailed tables that estimate the size of the semiconductor total available market (TAM) worldwide and for four major geographical regions. Historical data begin with 1986 and end with 1991, while forecast data provide annual market size estimates for 1992 through 1996. The following list of tables details the type of data, region, time period, and units of measure.

Each table gives estimates of GaAs and related semiconductor revenue or shipments listed by the major semiconductor device product categories. In these tables, semiconductor components are divided into three major product groups: integrated circuits, discrete devices, and optoelectronic devices. These groups are divided into a number of subgroups, some of which are segmented further.

Definitions and Conventions

Dataquest uses a common manufacturer base for all data tables. This base includes all suppliers to the merchant semiconductor market. It includes aggregate revenue estimates for North American companies that manufacture devices solely for the benefit of the parent company, such as Delco, IBM, and Unisys. Also included are companies that actively market semiconductor devices to the merchant market as well as to other divisions of their own companies. For such companies, both external and internal shipments are included. Devices that are used internally are valued at current market prices.

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7	Total GaAs	Worldwide	1990-1996	Dollars

NA = Not available
Dataquest (March 1992)

Consumption—Dataquest defines consumption as the purchase of a semiconductor device or devices. This definition must be differentiated from actual use of the device in a final product. A regional market size includes all devices sold to or within, or shipped to or within, that region (that is the TAM of that region).

Hybrids—In earlier consumption data, hybrid devices were included as a separate segment of integrated circuits. Hybrid devices manufactured by semiconductor companies are now included in the most appropriate product segment, usually the analog segment.

The manufacturer base, product group definitions, and guidelines for including value of output that we have used in our tables may differ from those used in other studies of this type. Our base is nearly the same as that used by the World Semiconductor Trade Statistics (WSTS) program, with the following exceptions:

- Dataquest includes all of AT&T's semiconductor revenue, both merchant and captive.
- Dataquest includes—and has always included—nonrecurring engineering (NRE) charges associated with application-specific integrated circuit (ASIC) revenue. (This applies to both the bipolar digital and MOS digital logic categories.)
- Dataquest includes the revenue generated by sales of standalone circuit design software, sold by certain U.S. manufacturers of ASIC logic devices.
- Dataquest includes Signetics revenue with that of its parent company, Netherlands-based N.V. Philips.
- Dataquest includes revenue for Taiwanese semiconductor manufacturers.
- Dataquest includes revenue for three Japanese companies not included by WSTS until 1990: NMB Semiconductor, Seiko-Epson, and Yamaha.
- As noted herein, Dataquest includes hybrid revenue in the analog category.

Regions—North America is defined as including both the United States and Canada. Latin America, including Mexico, is considered part of the Asia/Pacific-ROW category. Asia/Pacific includes South Korea, Taiwan, Hong Kong,

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Singapore, and China. Western Europe includes Austria, Belgium, Germany, France, Italy, Luxembourg, the Netherlands, the Scandinavian countries (Denmark, Finland, Norway, Sweden), Spain, the United Kingdom, and the rest of Europe. Japan, the fourth region, is the only single-country region.

Data Sources

The historical information presented in the consumption and shipment data has been consolidated from a variety of sources, each of which focuses on a specific part of the market. These sources include the following:

- WSTS data and Dataquest's estimates of regional company sales are used to determine shipments to North America.
- Japanese trade statistics compiled and published by the Ministry of Finance (MOF) and the Ministry of International Trade and Industry (MITI), WSTS data, and Dataquest's estimates of regional company sales are used to determine shipments to Japan.
- For Western European markets, marketing statistics from WSTS data and Dataquest's estimates of regional company sales are used to determine market size.
- In Asia/Pacific-ROW, the major published sources used to estimate market size are WSTS data and Dataquest's estimates of company shipments into the region.

Dataquest believes that the estimates presented here are the most accurate and meaningful generally available today. The sources of the data and the guidelines for the forecasts presented in the tables are as follows:

- Dataquest's own forecasts of electronic equipment production and semiconductor I/O ratios
- Unit shipments or revenue (or both) published by major industry participants, both in the United States and abroad
- Estimates presented by knowledgeable and reliable industry spokespersons
- Government data or trade association data such as those from the Electronics Industry Association (EIA), MITI, WSTS, and the U.S. Department of Commerce
- Published product literature and price lists
- Interviews with knowledgeable manufacturers, distributors, and users
- Relevant projected world economic data

Accuracy

The tables presented here represent Dataquest estimates that we believe are reasonably accurate. Where we have no reasonable estimate, none is given. A zero in a table represents an estimate.

Valuation of Consumption

Regional market size is expressed in U.S. dollars (with the Japanese market also expressed in yen). To make the tables in this study useful in comparing different regions, it is necessary to express all values in a common currency, and we chose the U.S. dollar for convenience. However, the choice of the U.S. dollar (or any single currency, for that matter) as the currency basis for the tables brings with it some problems that require the readers' careful consideration in interpreting the data.

Inflation

All countries that participate significantly in international semiconductor markets suffered from an overall price inflation in the 1980s, continuing into the 1990s. As a consequence, the dollar in a given year is not truly comparable with the dollar in any preceding year. Consumer and wholesale price indices and GNP deflators all measure price changes in various composite "market baskets" of goods. However, there is no price index that measures price changes of material, equipment, and labor inputs to the semiconductor industry. Indeed, the "mix" is changing so rapidly that what is used this year was sometimes unavailable last year, at any price. Nor is there a composite price index that measures price changes in aggregate semiconductor product. In an industry noted for its deflationary trends, this latter effect would tend to make the component purchaser's dollar worth more as time passed, in terms of purchasing ability.

We have made no adjustments in the historical data to account for these inflationary and

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deflationary effects. The data are expressed in current dollars (dollars that include the inflation rate and exchange rates of the given year) for all historical data; comparisons between different years must be interpreted accordingly.

Exchange Rates

Construction of the West European tables involves combining data from many countries, each of which has different and changing exchange rates. Dataquest uses Annual Foreign Exchange Rates for each year as published by The International Monetary Fund and *The Wall Street Journal.* As far as possible, we prepare our estimates in terms of local currencies before conversion to U.S. dollars. The exchange rates for major currencies can be found in Table 0 at the end of this introduction.

Japanese market size is originally expressed in yen. The Japanese data published in this study are expressed in both dollars (Tables 3a, 3b, 3c, and 3d) and in yen (Tables 4a, 4b, 4c, and 4d). The yen/dollar exchange rate used for each year can be found in Table 0. Because of the fluctuations in the exchange rate for the yen, the dollar values given tend to distort the growth rate of the Japanese market, but they do provide a useful basis for regional market size comparisons. However, the data in yen give a better picture of the real growth in the Japanese market.

Table 0
Foreign Exchange Rates

Year	Yrly/Qtrly	Japan (Yen per U.S.$)	France (U.S.$ per Franc)	Germany (U.S.$ per Deutsche Mark)	United Kingdom (U.S.$ per Pound Sterling)
1970	YR	358	0.18	0.27	2.38
1971	YR	343	0.18	0.29	2.44
1972	YR	302	0.20	0.31	2.50
1973	YR	269	0.22	0.37	2.44
1974	YR	292	0.21	0.39	2.33
1975	YR	297	0.23	0.41	2.22
1976	YR	296	0.21	0.40	1.82
1977	YR	269	0.20	0.43	1.75
1978	YR	210	0.22	0.50	1.92
1979	YR	219	0.24	0.55	2.13
1980	YR	227	0.24	0.55	2.33
1981	YR	221	0.18	0.44	2.04
1982	YR	248	0.15	0.41	1.75
1983	YR	235	0.13	0.39	1.52
1984	YR	237	0.11	0.35	1.33
1985	YR	238	0.11	0.34	1.30
1986	YR	167	0.14	0.46	1.47
1987	YR	144	0.17	0.56	1.64
1988	YR	130	0.17	0.57	1.79
1989	YR	138	0.16	0.53	1.50
1990	YR	144	0.18	0.62	1.79
1991	YR	129	0.18	0.61	1.77

Source: The International Monetary Fund, *Financial Times,* Dataquest (March 1992)

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Market Share

As mentioned previously, historical data are expressed in current dollars or dollars that include the given year's inflation rate and exchange rates. However, the revenue forecasts use constant dollars and exchange rates, with no allowance for inflation or variations in the rates of exchange between countries. All estimates for 1992 and beyond are made as if 1991 monetary conditions will continue through 1996 and, therefore, show the absolute year-to-year growth during this period.

Historical Shipment Data

Analog/Linear GaAs ICs

Tables 2a through 2e summarize shipment revenue estimates for analog/linear GaAs ICs. Estimates for NRE charges are separated from device shipment figures.

Digital GaAs ICs

Digital GaAs ICs (digICs) grew by approximately 18 percent in 1991, to $192 million worldwide. NRE charges decreased by $1 million to $45 million. The majority of the shipments were made by U.S. companies, with major gains made by the Japanese suppliers. Tables 3a through 3e summarize shipment revenue estimates for GaAs digICs. NRE charges are listed separately.

III-V Optoelectronics

This section presents historical shipment data for the GaAs and Other III-V semiconductor optoelectronic device market from 1986 through 1991. Tables 4a through 4f show estimated shipment revenue by product category and by major geographic regions of origin. Where an estimate is not yet available, none is given.

GaAs Discretes

Tables 5a through 5e summarize shipment revenue estimates for GaAs uWave/mmWave discretes by geographic region.

GaAs ASICs

Tables 6a through 6d summarize historical shipment estimates for GaAs digital and analog/linear ASICs. In the tables, estimated NRE charges are shown separate from device shipment figures.

The worldwide market for compound ICs, discretes, and other optoelectronic semiconductors grew to almost $4 billion in 1991. The predominant devices were discrete optoelectronics; ICs now comprise 14 percent of these figures (including NRE costs). The growth in GaAs ICs was sufficient to boost overall market growth rate to nearly 15 percent from 1990 to 1991.

The GaAs semiconductor industry has been adversely affected by such factors as the following:

- Failure of supercomputer manufacturers to produce their latest developments
- Overly optimistic business plans at several start-ups
- Reduction in U.S. defense spending and lack of U.S. government technology policy
- Long progression of poor yields and non-worst-case designs
- "Boom and bust" cycles in the personal computer industry

Since 1986, industry participants have been attacking these problems, and each year, some progress is evident. Japanese suppliers are now well positioned to take advantage of opportunities in this market, as evidenced by Fujitsu's introduction of its GaAs 64K SRAM and HEMT gate arrays.

Table 7 is a summary of Dataquest's forecast of the GaAs semiconductor market through 1996. The market is expected to grow at a compound annual rate of 10.2 percent, driven primarily by the emerging markets for linear, digital, and optoelectronic ICs. Together, these three segments are expected to exceed shipments of $1 billion by 1994.

While the linear IC segment is the largest of the three GaAs IC product families at present,

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digital device sales are expected to experience the highest growth rate, with more than 29.1 percent growth through 1996. Combined with the NRE costs, the digital segment growth rate is forecast at 24 percent. Analog/linear ICs will grow rapidly at expected compound annual growth rates (CAGRs) of 20.7 percent (devices) and 18.9 percent (overall, including NRE) rates. The 1991 through 1993 growth of more than $320 million in the IC segments will depend largely on continued market development and pervasiveness, similar to that experienced during the late 1980s in the supercomputer, graphics processor, and optical communications hardware segments.

The optoelectronics device market and microwave discrete markets temper the overall GaAs market dramatically. Discrete opto devices are growing less rapidly than the IC segments, at 7.9 percent CAGR through 1996. Growth in discrete microwave devices is expected to be less than 8 percent per year and may decrease faster than shown as MMICs replace many hybrid module designs.

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Table 1a
GaAs Semiconductor Market Share Estimates—North American Suppliers
(Millions of Dollars)

Company	1985	1986	1987	1988	1989	1990	1991
Adams Russell[1]	10	13	15	18	NA	0	0
Alpha Industries	11	13	17	24	24	22	22
Avantek[2]	17	19	22	26	21	27	NA[2]
Dexcel (Gould)[3]	8	13	0	0	0	0	0
GE	20	32	16	20	0	0	0
GigaBit Logic[4]	7	8	10	12	17	12	NA[4]
GI Opto Division[5]	38	34	28	0	0	0	0
Harris Microwave	4	6	7	8	26	24	21
Hewlett-Packard	166	166	186	223	224	260	310
Honeywell	31	35	30	30	31	28	28
Hughes	9	15	17	21	23	28	31
Litton	NA	NA	20	24	25	25	33
M/A-COM	29	38	35	35	44[6]	36[6]	35
Microwave Monolithics	3	5	6	6	7	8	8
MicroWave Technology Inc.	3	5	6	6	7	11	12
Motorola	17	18	24	24	25	30	38
Narda	15	16	18	19	18	17	15
Optek	NA	NA	NA	NA	77	66	52
Pacific Monolithics	7	8	10	12	13	14	16
Quality Technologies	0	0	0	40	38	34	35
Rockwell	8	15	21	28	25	25	27
Spectra Diode Labs	5	8	10	12	10	10	10
Teledyne	5	7	8	9	9	11	12
Texas Instruments	33	34	39	41	42	45	82
TriQuint	7	10	11	14	15	18	35
TRW	46	38	43	0	6	17	26
Vitesse	-	2	2	3	8	17	28
Others	55	110	60	62	105	95	NA
Total	554	649	661	717	840	880	NA

[1]Acquired by M/A-COM in 1989
[2]Acquired by Hewlett-Packard in 1991
[3]Acquired by Litton in 1987
[4]Acquired by TriQuint in 1991
[5]Acquired by Quality Technologies in 1988
[6]Includes Adams Russell
NA = Not available
Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

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Table 1b
GaAs Semiconductor Market Share Estimates—Western European Suppliers
(Millions of Dollars)

Company	1985	1986	1987	1988	1989	1990	1991
ASEA-Brown Boveri	5	6	8	9	9	10	NA
Isocom	15	22	25	27	NA	NA	NA
Litronix[1]	NA	NA	NA	NA	NA	NA	NA
Microwave Semiconductor[2]	NA	NA	NA	NA	0	0	0
Philips	25	35	26	27	29	38	45
Plessey[2]	10	21	24	29	28	0	0
Siemens	75	77	85	105	120	138	197
Telefunken Electronic	41	58	77	82	86	87	93
Thomson-CSF	4	5	7	10	15	33	45
Others	2	4	15	18	10	31	10
Total	177	228	267	298	297	337	360

[1]Included in Siemens data (Microwave Semiconductor ceased operations in 1988.)
[2]Includes Plessey Three-Five through 1989 (GEC-Marconi acquired Plessey in 1989.)
NA = Not available (separately)
Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 1c
GaAs Semiconductor Market Share Estimates—Japanese Suppliers
(Millions of Dollars)

Company	1985	1986	1987	1988	1989	1990	1991
Calif. Eastern Labs (NEC)	14	18	20	23	26	35	45
Fuji Electric	10	7	4	4	5	5	5
Fujitsu	55	76	88	131	136	144	171
Hitachi	55	65	71	80	78	85	94
Matsushita	104	133	160	197	326	335	412
Mitsubishi	32	56	55	57	61	62	79
NEC	50	65	75	108	140	149	180
Oki	14	24	32	44	43	43	47
Rohm	34	56	70	114	102	105	130
Sanken	6	10	13	19	18	19	22
Sanyo	40	49	85	62	160	170	236
Sharp	148	197	222	284	328	339	432
Sony	55	115	138	217	249	270	339
Toshiba	126	147	170	255	312	317	367
Others	75	30	52	82	97	74	NA
Total	818	1,048	1,255	1,677	2,081	2,152	NA

Source: Dataquest (March 1992)

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Table 1d
GaAs Semiconductor Market Share Estimates—Asia/Pacific Suppliers
(Millions of Dollars)

Company	1988	1989	1990	1991
AMPi	NA	NA	1	0
KEC	5	7	7	8
Kingbright	NA	NA	7	7
Ledtech	NA	NA	7	7
Liteon	NA	NA	6	16
Total	5	7	28	38

NA = Not available
Source: Dataquest (March 1992)

Table 2a
Estimated Worldwide Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Analog/Linear ICs	107	138	157	187	242	308
NRE	51	53	50	45	48	47
MMIC amps	17	21	28	31	42	54
ASICs	24	42	51	78	114	164
Others	15	22	28	33	38	43

Source: Dataquest (March 1992)

Table 2b
Estimated North American Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Analog/Linear ICs	101	124	137	159	180	215
NRE	50	51	48	43	38	35
MMIC amps	14	17	22	24	27	29
ASICs	22	37	43	66	88	123
Others	15	19	24	26	27	28

Source: Dataquest (March 1992)

Table 2c
Estimated Western European Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Analog/Linear ICs	5	11	15	17	30	42
NRE	1	2	2	2	6	7
MMIC amps	2	3	4	4	5	7
ASICs	2	4	6	8	14	22
Others	0	2	3	3	5	6

Source: Dataquest (March 1992)

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Table 2d
Estimated Japanese Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Analog/Linear ICs	1	3	5	11	32	51
NRE	0	0	0	0	4	5
MMIC amps	1	1	2	3	10	18
ASICs	0	1	2	4	12	19
Others	0	1	1	4	6	9

Source: Dataquest (March 1992)

Table 2e
Estimated Japanese Analog/Linear GaAs Merchant Shipments
(Billions of Yen)

Category	1986	1987	1988	1989	1990	1991
Analog/Linear ICs	0.1	0.4	0.65	1.52	4.32	6.48
NRE	0	0	0	0	0.54	0.64
MMIC amps	0.1	0.1	0.23	0.41	1.35	2.29
ASICs	0	0.1	0.23	0.55	1.62	2.41
Others	0	0.1	0.19	0.55	0.81	1.14

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 3a
Estimated Worldwide GaAs DigIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Digital ICs	51	71	86	117	163	192
NRE	30	36	35	29	46	45
Standard Logic	5	7	11	12	13	10
RAMs	4	5	7	8	10	8
ASICs	12	23	33	68	94	129

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 3b
Estimated North American GaAs DigIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Digital ICs	47	60	69	92	107	125
NRE	29	33	32	26	28	26
Standard Logic	4	5	7	8	6	2
RAMs	4	5	7	7	8	3
ASICs	10	17	23	51	66	94

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

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Table 3c
Estimated Western European GaAs DigIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Digital ICs	3	5	8	11	18	22
NRE	1	2	2	2	8	9
Standard Logic	0	0	1	1	1	1
RAMs	0	0	0	0	0	0
ASICs	2	3	5	8	9	12

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 3d
Estimated Japanese GaAs DigIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Digital ICs	1	6	9	14	38	45
NRE	0	1	1	2	10	10
Standard Logic	1	2	3	3	6	7
RAMs	0	0	0	1	3	5
ASICs	0	3	5	9	19	23

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 3e
Estimated Japanese GaAs DigIC Merchant Shipments by Technology
(Billions of Yen)

Category	1986	1987	1988	1989	1990	1991
Digital ICs	0.1	0.8	1.1	1.9	5.1	5.7
NRE	0	0.1	0.1	0.1	1.4	1.3
Standard Logic	0.1	0.3	0.4	0.4	0.8	0.8
RAMs	0	0	0	0.1	0.4	0.6
ASICs	0	0.4	0.6	1.2	2.6	2.9

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

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Table 4a
Estimated Worldwide Optoelectronic Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Total Optoelectronics	1,486	1,709	2,179	2,627	2,687	3,072
LEDs and LED Arrays	662	509	585	647	669	791
Optocouplers, Isolators, Interruptors	273	329	448	541	552	593
Lasers/Transmitters	325	376	411	558	577	643
Detectors	87	108	129	161	156	160
Photovoltaic Cells	85	104	115	152	162	170
Others (including CCD and OEICs)	54	283	491	568	571	715

Source: Dataquest (March 1992)

Table 4b
Estimated North American Optoelectronic Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Total Optoelectronics	373	383	425	458	457	541
LEDs and LED Arrays	120	114	123	105	98	96
Optocouplers, Isolators, Interruptors	96	103	108	118	112	116
Lasers, Transmitters, Detectors, Photovoltaic, Others	157	166	194	235	247	329

Source: Dataquest (March 1992)

Table 4c
Estimated Western European Optoelectronic Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Total Optoelectronics	206	230	238	244	267	272
LEDs and LED Arrays	109	133	136	137	152	153
Optocouplers, Isolators, Interruptors	31	37	40	38	41	42
Lasers, Transmitters, Detectors, Photovoltaic, Others	66	60	62	69	74	77

Source: Dataquest (March 1992)

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Table 4d
Estimated Japanese Optoelectronic Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Total Optoelectronics	905	1,093	1,511	1,918	1,935	2,227
LEDs and LED Arrays	402	262	323	401	405	526
Optocouplers, Isolators, Interruptors	142	93	299	383	391	426
Lasers, Transmitters, Detectors, Photovoltaic, Others	361	738	889	1,134	1,139	1,274

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 4e
Estimated Japanese GaAs Merchant Shipments by Technology
(Billions of Yen)

Category	1986	1987	1988	1989	1990	1991
Total Optoelectronics	151.2	174.9	193.4	264.7	267.0	287.0
LEDs and LED Arrays	67.1	41.9	41.3	55.3	55.8	68.8
Optocouplers, Isolators, Interruptors	23.7	14.9	38.3	52.9	54.0	55.2
Lasers, Transmitters, Detectors, Photovoltaic, Others	60.3	118.1	113.8	156.5	157.2	162.8

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 4f
Estimated Asia/Pacific Optoelectronic Merchant Shipments by Technology
(Millions of Dollars)

Category	1988	1989	1990	1991
Total Optoelectronics	5	7	28	32
LEDs and LED Arrays	3	4	14	16
Optocouplers, Insolaters, Interruptors	1	2	8	8
Lasers, Transmitters, Detectors, Others	1	1	6	8

Source: Dataquest (March 1992)

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Table 5a
Estimated Worldwide GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Other Discretes	228	222	243	291	305	331
SS Transistors	141	135	150	181	188	199
Power Transistors	73	72	77	92	98	110
Hall Elements, Others	14	15	16	18	19	22

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 5b
Estimated North American GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Other Discretes	112	118	117	131	136	154
SS Transistors	54	61	58	59	60	69
Power Transistors	56	55	57	69	73	80
Hall Elements, Others	2	2	2	3	3	5

Source: Dataquest (March 1992)

Table 5c
Estimated Western European GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Other Discretes	14	16	19	22	22	24
SS Transistors	7	8	10	11	11	11
Power Transistors	5	6	7	8	8	10
Hall Elements, Others	2	2	2	3	3	3

Source: Dataquest (March 1992)

Table 5d
Estimated Japanese GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Other Discretes	102	88	107	138	147	153
SS Transistors	80	66	82	111	117	119
Power Transistors	12	11	13	15	17	20
Hall Elements, Others	10	11	12	12	13	14

Source: Dataquest (March 1992)

Table 5e
Estimated Japanese GaAs uWave/mmWave Discretes Merchant Shipments
(Billions of Yen)

Category	1986	1987	1988	1989	1990	1991
Other Discretes	17.0	12.7	13.9	19.0	19.8	19.4
SS Transistors	13.4	9.5	10.7	15.3	15.8	15.1
Power Transistors	2.0	1.6	1.7	2.1	2.3	2.5
Hall Elements, Others	1.7	1.6	1.5	1.7	1.8	1.8

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

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Table 6a
Estimated Worldwide GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Total GaAs ASICs	117	154	169	220	302	385
Digital GaAs ASICs	42	59	68	97	140	174
NRE	30	36	35	29	46	45
Devices	12	23	33	68	94	129
Analog/Linear GaAs ASICs	75	95	101	123	162	211
NRE	51	53	50	45	48	47
Devices	24	42	51	78	114	164

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (March 1992)

Table 6b
Estimated North America GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Total GaAs ASICs	111	138	146	186	220	278
Digital GaAs ASICs	39	50	55	77	94	120
NRE	29	33	32	26	28	26
Devices	10	17	23	51	66	94
Analog/Linear GaAs ASICs	72	88	91	109	126	158
NRE	50	51	48	43	38	35
Devices	22	37	43	66	88	123

Source: Dataquest (March 1992)

Table 6c
Estimated Western European GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Total GaAs ASICs	6	9	15	20	37	50
Digital GaAs ASICs	3	4	7	10	17	21
NRE	1	2	2	2	8	9
Devices	2	2	5	8	9	12
Analog/Linear GaAs ASICs	3	5	8	10	20	29
NRE	1	3	2	2	6	7
Devices	2	2	6	8	14	22

Source: Dataquest (March 1992)

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Table 6d
Estimated Japanese GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1986	1987	1988	1989	1990	1991
Total GaAs ASICs	0	5	8	14	45	57
Digital GaAs ASICs	0	4	6	10	29	33
NRE	0	1	1	1	10	10
Devices	0	3	5	9	19	23
Analog/Linear GaAs ASICs	0	1	2	4	16	24
NRE	0	0	0	0	4	5
Devices	0	1	2	4	12	19

Source: Dataquest (March 1992)

Table 7
Worldwide GaAs Semiconductor Merchant Consumption Forecast
(Millions of Dollars)

	1990	1991	1992	1993	1994	1995	1996	CAGR (%) 1991-1996
Total	3,397	3,903	4,280	4,825	5,434	5,951	6,347	10.2
Analog/Linear ICs	242	308	387	474	588	659	732	18.9
Devices	194	261	338	422	535	602	670	20.7
NRE	48	47	49	52	53	57	62	5.7
Digital ICs	163	192	241	318	402	497	563	24.0
Devices	117	147	201	283	367	462	528	29.1
NRE	46	45	40	35	35	35	35	-4.9
Optoelectronics	2,687	3,072	3,298	3,657	4,024	4,348	4,574	8.3
Discretes and CCDs	2,615	2,988	3,201	3,532	3,872	4,178	4,380	7.9
OEICs	72	84	97	125	158	170	194	18.2
Microwave/Millimeterwave Discretes	305	331	354	376	410	447	478	7.6

Note: Data include intracompany consumption for merchant suppliers and exclude intracompany consumption by full captives. Optoelectronics include silicon IR emitters, silicon photodetectors, and laser drivers.
Source: Dataquest (March 1992)

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0012815

GaAs Semiconductors—Forecast

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The worldwide market for compound ICs, discretes, and other optoelectronic semiconductors grew slightly to almost $3.4 billion in 1990. The predominant devices were discrete optoelectronics; ICs now comprise 14 percent of these figures (including NRE costs). The growth in ICs and microwave/millimeter-wave discretes was sufficient to boost overall market growth rate to more than 5 percent from 1989 to 1990, although the optoelectronics device market was essentially flat.

The GaAs semiconductor industry has been adversely affected by such factors as the following:

- Failure of supercomputer manufacturers to produce their latest developments
- Overly optimistic business plans at several start-ups
- Reduction in U.S. defense spending and lack of U.S. government technology policy
- Long progression of poor yields and non-worst-case designs
- "Boom and bust" cycles in the personal computer industry

Since 1986, industry participants have been attacking these problems, and each year, some progress is evident. Japanese suppliers are now well positioned to take advantage of opportunities in this market, as evidenced by Fujitsu's introduction of its GaAs 64K SRAM.

Table 1 is a summary of Dataquest's forecast of the GaAs semiconductor market through 1995. The market is expected to grow at a compound annual rate of 12.1 percent, driven primarily by the emerging markets for linear, digital, and optoelectronic ICs. Together, these three segments are expected to exceed shipments of $1 billion by 1994.

While the linear IC segment is the largest of the three GaAs IC product families at present, digital device sales are expected to experience the highest growth rate, with more than 39 percent growth through 1995. Combined with the NRE costs, the digital segment growth rate is forecast at 32 percent. Analog/linear ICs will grow rapidly at expected compound annual growth rates (CAGRs) of 27 percent (devices) and 23 percent (overall, including NRE) rates. The 1991 through 1993 growth of more than $440 million in the IC segments will depend largely on continued market development and pervasiveness, similar to that experienced during 1986 through 1988 in the supercomputer, graphics processor, and optical communication hardware segments.

The optoelectronics device market and microwave discrete markets temper the overall GaAs market dramatically. Discrete opto devices are growing less rapidly than the IC segments, at 8.9 percent CAGR through 1995. Growth in discrete microwave devices is expected to be less than 9 percent per year and may decrease faster than shown as MMICs replace many hybrid module designs.

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Table 1

Worldwide GaAs Semiconductor Merchant Consumption (Millions of Dollars)

	1989	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Total	3,222	3,397	3,869	4,365	4,674	5,589	5,995	12.1
Analog/Linear ICs	187	242	319	407	514	638	710	24.0
Devices	142	194	272	358	462	585	650	27.4
NRE	45	48	47	49	52	53	60	4.6
Digital ICs	117	163	224	359	475	592	660	32.3
Devices	88	117	176	311	425	542	610	39.1
NRE	29	46	48	48	50	50	50	1.7
Optoelectronics	2,627	2,687	3,008	3,254	3,560	3,949	4,178	9.2
Discretes and CCDs	2,560	2,615	2,925	3,157	3,445	3,801	4,008	8.9
OEICs	67	72	83	97	125	148	170	18.7
Microwave/Millimeter-wave Discretes	291	305	318	345	376	410	447	8.5

Note: Data include intracompany consumption for merchant suppliers and exclude intracompany consumption by full captives.
Optoelectronics include silicon IR emitters, silicon photodetectors, and laser drivers.
Source Dataquest (May 1991)

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Table 1

GaAs Market Share Estimates — U.S. Suppliers
(Millions of Dollars)

Company	1985	1986	1987	1988	1989	1990
Adams Russell[1]	10	13	15	18	NA	0
Alpha Industries	11	13	17	24	24	22
Avantek	17	19	22	26	21	27
Dexcel (Gould)	8	13	0	0	0	0
GE	20	32	16	20	0	0
GigaBit Logic[2]	7	8	10	12	17	12
GI Opto Division	38	34	28	0	0	0
Harris Microwave	4	6	7	8	26	24
Hewlett-Packard	166	166	186	223	224	235
Honeywell	31	35	30	30	31	25
Hughes	9	15	17	21	23	28
Litton	NA	NA	20	24	25	25
M/A-COM	29	38	35	35	44[3]	36[3]
Microwave Monolithics	3	5	6	6	7	8
MicroWave Technology Inc.	3	5	6	6	7	11
Motorola	17	18	24	24	25	30
Narda	15	16	18	19	18	17
Optek	NA	NA	NA	NA	77	66
Pacific Monolithics	7	8	10	12	13	14
Quality Technologies	0	0	0	40	38	34
Rockwell	8	15	21	28	25	25
Spectra Diode Labs	5	8	10	12	10	10
Teledyne	5	7	8	9	9	11
Texas Instruments	33	34	39	41	42	45
TriQuint	7	10	11	14	15	17
TRW	46	38	43	0	6	17
Vitesse	-	2	2	3	8	18
Others	55	110	60	62	105	123
Total	554	649	661	717	840	880

[1] [2]Acquired by M/A-COM in 1989
[3]Acquired by TriQuint in 1991
[1]Includes Adams Russell
NA = Not available
Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (May 1991)

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Table 2

GaAs Market Share Estimates—Western European Suppliers (Millions of Dollars)

Company	1985	1986	1987	1988	1989	1990
ASEA-Brown Boveri	5	6	8	9	9	10
Isocom	15	22	25	27	NA	NA
Litronix[1]	NA	NA	NA	NA	NA	NA
Microwave Semiconductor[2]	NA	NA	NA	NA	0	0
Philips	25	35	26	27	29	38
Plessey[2]	10	21	24	29	28	0
Siemens	75	77	85	105	120	138
Telefunken Electronic	41	58	77	82	86	87
Thomson-CSF	4	5	7	10	15	23
Others	2	4	15	18	10	41
Total	177	228	267	298	297	337

[1]Included in Siemens data (Microwave Semiconductor ceased operations in 1988.)
[2]Includes Plessey Three-Five through 1989 (GEC-Marconi acquired Plessey in 1989.)
NA = Not available (separately)
Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (May 1991)

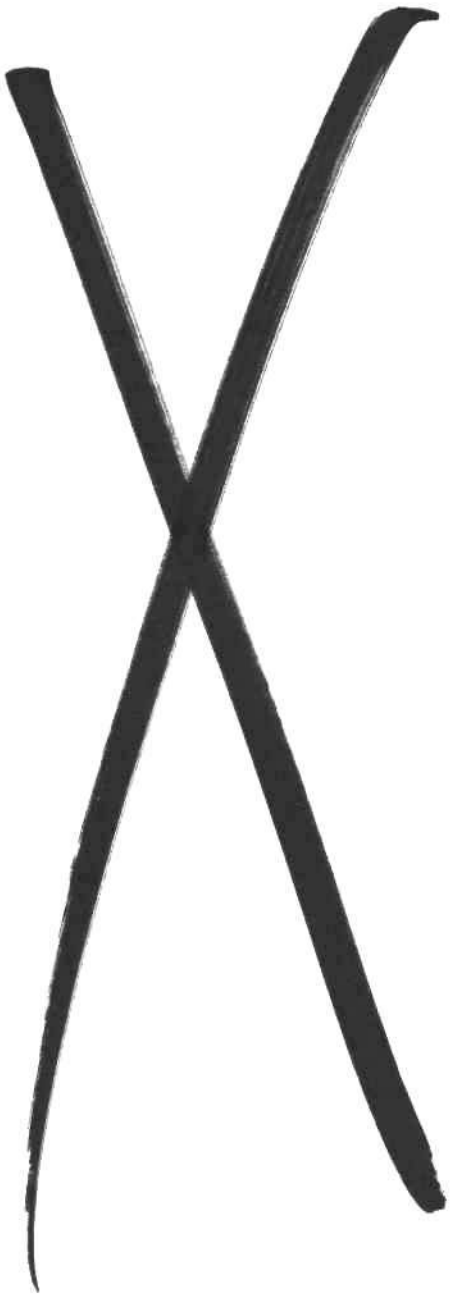
Table 3

GaAs Market Share Estimates—Japanese Suppliers (Millions of Dollars)

Company	1985	1986	1987	1988	1989	1990
Calif. Eastern Labs (NEC)	14	18	20	23	26	35
Fuji Electric	10	7	4	4	5	5
Fujitsu	55	76	88	131	136	144
Hitachi	55	65	71	80	78	85
Matsushita	104	133	160	197	326	335
Mitsubishi	32	56	55	57	61	62
NEC	50	65	75	108	140	145
Oki	14	24	32	44	43	43
Rohm	34	56	70	114	102	114
Sanken	6	10	13	19	18	19
Sanyo	40	49	85	62	160	170
Sharp	148	197	222	284	328	339
Sony	55	115	138	217	249	270
Toshiba	126	147	170	255	312	317
Others	75	30	52	82	97	69
Total	818	1,048	1,255	1,677	2,081	2,152

Source: Dataquest (May 1991)

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GaAs Semiconductor—Historical Shipment Data

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INTRODUCTION

This service section consists of a set of detailed tables showing estimated GaAs and related III-V compound semiconductor industry market share data for 1985 through 1990. This analysis provides insights into semiconductor markets and reinforces estimates of consumption, production, and company revenue that were made using other data. These tables detail the type of data, years covered, and units as follows:

Table Number	Type of Data	Calendar Years	Units
1	GaAs Market Share Estimates	1985-1990	Dollars
2	GaAs Market Share Estimates	1985-1990	Dollars
3	GaAs Market Share Estimates	1985-1990	Dollars
4	GaAs Market Share Estimates	1988-1990	Dollars

DEFINITIONS AND CONVENTIONS

Dataquest uses a common manufacturer base for all data tables. This base includes all suppliers to the merchant semiconductor market. It excludes captive suppliers that manufacture devices solely for the benefit of the parent company, such as Unisys and IBM. Included, however, are companies that actively market semiconductor devices to the merchant market as well as to other divisions of their own companies. A recent case in point is NCR, previously a captive supplier, which offered silicon IC products on the merchant market for the first time in 1984. For such companies, both external shipments and internal consumption are included. Devices that are used internally are valued at current market prices.

Factory Shipment Location

The fabrication and assembly of a semiconductor device can be performed in several different locations. Factory shipment is defined as occurring from the point where the device was tested and marked, irrespective of where the device was assembled or where the initial wafer fabrication was performed.

Regions

North America is defined as including both the United States and Canada. Latin America, including Mexico, is considered part of the Rest of World (ROW) category. The worldwide category is made up of data from ROW, Western Europe, Japan, and North America.

Power Devices

The difference between low-power and high-power transistors is set at the 1-watt power-handling capability.

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DATA SOURCES

The information presented in the consumption/factory shipment data is consolidated from a variety of sources, each of which focuses on a specific part of the market. These sources include U.S. Department of Commerce (DOC) trade statistics and Semiconductor Trade Statistics Program (STSP) marketing data, which are used in determining North American consumption and factory shipments.

Dataquest believes that the estimates presented here are the most accurate and meaningful that are generally available today. The sources of these data and guidelines for the forecasts presented in the tables are as follows:

- Unit sales or revenue (or both) published by major industry participants, both in the United States and abroad
- Estimates presented by knowledgeable and reliable industry spokespersons
- Government data or trade association data such as those from the Electronics Industry Association of Japan (EIAJ), the Ministry of International Trade and Industry (MITI), the Semiconductor Industry Association (SIA), and the DOC
- Published product literature and price lists
- Interviews with knowledgeable manufacturers, distributors, and users
- Relevant projected world economic data

CONSISTENCY

One of the key objectives in preparing these estimates is to achieve consistency among the various data elements that constitute the forecast and the historical database. To ensure the accuracy and consistency of the estimates, we have compared the value of directly obtained data elements with values obtained by indirect means, wherever possible.

ACCURACY

Tables 1 through 4 represent Dataquest estimates that we believe to be reasonably accurate. Where we have no reasonable estimate, none is given. The symbol NA in a table indicates that a reasonably accurate estimate is not available, and a zero in a table represents an estimate.

NEED FOR CAREFUL INTERPRETATION

Despite the care taken in gathering and analyzing the available data and in attempting to categorize those data in a meaningful way, careful attention must be paid to the definitions and assumptions used herein when interpreting the estimates presented in these tables. Various companies, government agencies, and trade associations may use slightly different definitions of product categories and regional groupings, or they may include different companies in their summaries. These differences should be kept in mind when making comparisons between these data and those provided by others.

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Table 4

GaAs Market Share Estimates—Asia/Pacific Suppliers
(Millions of Dollars)

Company	1988	1989	1990
AMPi	NA	NA	1
KEC	5	7	7
Kingbright	NA	NA	7
Ledtech	NA	NA	7
Liteon	NA	NA	6
Total	5	7	28

NA = Not available
Source: Dataquest (May 1991)

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Who's Who in Gallium Arsenide

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Gallium Arsenide Semiconductors *Worldwide*

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Who's Who in Gallium Arsenide

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Gallium Arsenide Semiconductors *Worldwide*

Published by Dataquest Incorporated

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Tel: (0758) 245 00
Fax: (0758) 167 15

ESTABLISHED: 1960 (Opto operations) **NO. OF EMPLOYEES: 400**

BACKGROUND

ABB HAFO AB was founded in 1960 as a subsidiary of ASEA in order to participate in the emerging optoelectronic industry. The Company was renamed ABB HAFO as a result of the merger of ASEA and Brown Boveri of Switzerland. HAFO invented the optocoupler in 1968. The Company offers a wide range of semiconductor components for commercial and military markets, including aerospace applications. The products are based on silicon, gallium arsenide (GaAs), and indium phosphide (InP) technologies.

COMPANY EXECUTIVES

Managing Director
Erik Bjorek

Technical Director
Bengt Andersson

Production Manager
Rolf Mollerberg

Marketing Manager
Bengt Lindequist

SERVICES

ABB HAFO AB offers design, production, test, and marketing of optoelectronic semiconductors.

PROCESS TECHNOLOGY

Plasma-etch compound-semiconductor processing (InP and GaAs)
Silicon CMOS VLSI processing
Thick-film hybrid processing and assembly

PRODUCTS

Optocouplers
GaAs lasers—800nm and 900nm wavelengths
InP lasers—1,300nm wavelength
Infrared emitters
AlGaAs and Si photodiodes
Others, including CMOS VLSI

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Alpha Industries Inc.

20 Sylvan Road
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617/935-5150

ESTABLISHED: 1962 NO. OF EMPLOYEES: 1,040

BACKGROUND

Alpha Industries, Inc., (Alpha) is a major manufacturer of microwave semiconductor devices, components, and subsystems for defense elec tronics, commercial communications, and other commercial markets. Alpha's GaAs activities originated in 1970. The Company reported sales of $64.6 million and $66.3 million for the fiscal years ending March 31, 1990, and March 31, 1991, respectively.

The Company has seven divisions, including the recently reorganized and expanded Advanced Technology Division. Alpha recently expended $20 million for clean room expansion, including the addition of sub-0.5u e-beam DW lithography. Aerojet-Alpha, a joint venture of Aerojet Electrosystems Co. (California) and Alpha, has developed MMICs for target-activated munitions.

Alpha was teamed with ITT/Martin Marietta on Phase I of the millimeter-wave monolithic IC (MIMIC) initiative, sponsored by the Defense Advance Research Project Agency (DARPA).

COMPANY EXECUTIVES

Chairman and CEO
George S. Kariotis

President and COO
Martin J. Reid

Senior Vice President and Chief Scientist
Dr. R.E. Goldwasser

Corporate Director of Marketing and Sales
David Barker

Senior Vice President and CFO
William Krein

STRATEGIC ALLIANCES

Alpha Industries has a joint venture with Aerojet Electrosystems—Aerojet-Alpha—and a joint venture with Martin Marietta—Gamma Monolithics.

PROCESS TECHNOLOGY

Alpha uses sub-0.5u GaAs technology.

PRODUCTS

GaAs discretes
MMICs and mm-wave ICs

FACILITIES

Alpha's Woburn, Massachusetts, facility has 15,000 square feet for GaAs production, including 12,000 square feet of clean rooms with Class 10 areas.

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ANADIGICS Inc.

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Fax: 908/668-5068

ESTABLISHED: January 1985 NO. OF EMPLOYEES: 115

BACKGROUND

ANADIGICS Inc., a privately owned company, designs, manufactures, and markets GaAs analog and digital ICs for the telecommunications, military, and instrumentation markets. The Company currently offers RF microwave and signal conditioning amplifiers, A/D converters, dividers, and multiplexers/demultiplexers. In addition, ANADIGICS offers GaAs services and designs both catalog and custom GaAs ICs, as well as custom hybrid assemblies, including fiber-optic data links.

The founders are Ronald Rosenzweig and George Gilbert, who cofounded Microwave Semiconductor Corporation, and Dr. Charles Huang, who was director of GaAs R&D and wafer fabrication services at Avantek.

The Company's strategy is to establish its own niche in producing GaAs ICs for high-frequency analog and digital applications in the defense and communications markets.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
*Ronald Rosenzweig
Microwave Semiconductor Corporation, President

Exec VP/COO
*George Gilbert
Microwave Semiconductor Corporation, Exec VP Opns

Exec VP/Mktg and Adv. Dev.
*Dr. Charles Huang
Avantek, Dir GaAs R&D

Dir Sales/Mktg
Javed Patel

Dir Finance
John Lyons
General Electric, Dir Finance

*Founder

RECENT HIGHLIGHTS

January 1988
ANADIGICS introduced the ALD30010, a 3-GHz laser driver.

February 1988
ANADIGICS was awarded a $500,000 contract from the navy to develop a chip set for X-band radars.

March 1988
ANADIGICS completed the first stage of a $4 million equity financing. Investors were ABS Ventures, Alan Patricof Associates Inc., Alex Brown Emerging Growth, Canaan Venture Limited Partnership, Century IV Partners, Fairfield Ventures, First Century Partnership III, Investments Orange Nassau, Memorial Drive Trust, Metropolitan Life, and Rothschild Inc.

April 1989
ANADIGICS introduced two new transimpedance amplifiers, the ATA03010 and the ATA30011.

September 1989
Received 1 million-piece MMIC order from Continental Microwave, Luton, Great Britain.

June 1990
Shipment rate exceeded 70,000 MMICs per month.

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ANADIGICS Inc.

STRATEGIC ALLIANCES

Bendix
June 1987
ANADIGICS was awarded a contract by Bendix Aerospace to develop CAD tools for the Department of Defense's (DOD's) MMIC program. Bendix will adapt the software tools for layout and simulation in the design of GaAs high-frequency broadband amplifiers and mixers.

British Satellite Broadcasting (BSB) and Continental Microwave Technology Ltd. (CMT)
1988-1991
ANADIGICS developed a Kμ-band down converter for British Satellite Broadcasting (BSB) under contract with CMT.

Thomson Composants Microondes (TCM)
March 1990
ANADIGICS and TCM have a technology agreement whereby TCM is the sole representative and only supplier of ANADIGICS products in Europe.

SERVICES

GaAs IC design
GaAs foundry
Assembly
Test

PROCESS TECHNOLOGY

1.0m and 0.5m GaAs MESFET
Low-power D-MESFET process technologies will be available in the future.

PRODUCTS

Device	Description
AOP1510	Op Amp, 150 MHz
AOP3510	Monolithic Op Amp, 350 MHz
AWA20601	10dB Gain Amplifier, 2 to 6 GHz
ACP10010	Comparator, 1.0ns Typical Delay
ADA25001/25002	25dB Gain Amplifier, 3 GHz
ADV3040	4-to-1 Divider
ALD30010	Laser Driver, 3 GHz
ATA30011	Transimpedance Amplifier, 3 GHz
APS30010	Phase Splitter, 3 GHz
ATA0310	Transimpedance 300-MHz Amplifier
ASW40010	DC—4-GHz Spdt switch
ASW80010	DC—8-GHz Spdt switch
AAR10000 Series	Analog Receiver Family—1GHz
ADR16000 Series	1.6-Gb per second (Gbps) Digital Receiver Family
ADR12030/35	1.2-Gbps Digital Rcvr/Clock Recovery Family
AKD12000 Series	Kμ-band MMICs

FACILITIES

Warren, NJ
55,000 sq. ft.
Design, test, manufacturing, administration

10,000 sq. ft.
Clean room

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American Telephone & Telegraph Company (AT&T)

550 Madison Avenue
New York, New York 10022
Tel: 212/605-5500
Fax: 212/605-6248

ESTABLISHED: 1885 NO. OF EMPLOYEES: Approx. 285,000

AT&T Microelectronics

2525 North 12th Street
Reading, Pennsylvania 19612-3396
Tel: (215)939-6457
Fax: (215)935-6775

ESTABLISHED: NA (GaAs activities) NO. OF EMPLOYEES: NA

BACKGROUND

American Telephone & Telegraph Company (AT&T) provides long distance communication hardware and services throughout approximately 200 countries and territories worldwide. Company sales exceed $35 billion annually. AT&T Bell Laboratories, a subsidiary of AT&T, has performed extensive basic and applied research in of III-V compound semiconductors and holds many patents in this technology.

AT&T is firmly committed to GaAs technology, as evidenced by its GaAs Center of Excellence in Reading, Pennsylvania. AT&T Microelectronics' Reading and other facilities produce silicon and compound semiconductor components and subsystems, including microwave and fiber-optic communications hardware, for internal use and for resale.

COMPANY EXECUTIVES

VP of R&D (Bell Labs)
Arnold Penzias

VP of GaAs ICs
Richard A. Pedersen

GaAs ICs Marketing Manager
David A. Harrison

STRATEGIC ALLIANCES

AT&T is a member of the Hughes team on Phase 2 of the DARPA MIMIC program. AT&T and Mitsubishi have established a technology agreement on GaAs ICs for communications applications. AT&T and M/A-COM have an agreement by which AT&T produces M/A-COM circuits using MBE processing.

SERVICES

Full-service GaAs IC foundry

PROCESS TECHNOLOGY

Bell Labs has extensive expertise in fabricating nanoscale (sub-0.1 micron) geometries, controlling layer formation at the atomic level. The Reading facility produces GaAs ICs to geometries below 1-micron gate lengths using MBE and other advanced equipment.

PRODUCTS

Fiber-optic transmitters, receivers, and transceivers
Fiber-optic regenerator chip sets
Multiplexers and demultiplexers
MMICs
DigICs

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American Telephone & Telegraph Company (AT&T)

FACILITIES

The 34,000-square-feet GaAs IC and laser production facility in Reading includes five modules of Class 10 clean rooms. Each one is 2,000 square feet and contains highly automated wafer fabrication and related equipment.

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California Eastern Laboratories

3260 Jay Street
Santa Clara, CA 95054
Tel: 408/988-3500
Fax: 408/988-0279

ESTABLISHED: 1959 NO. OF EMPLOYEES: 120

BACKGROUND

California Eastern Laboratories is a closely held corporation and is the exclusive North American sales agent for NEC's microwave semiconductors. (See "NEC Corporation" company information for additional data.)

COMPANY EXECUTIVES

President/CEO
Jerry Arden

Executive Vice President
Tom Fuller

Vice President, Marketing and Sales
Leonard Lea

Vice President, Engineering
Mark Burkett

SERVICES

Design center with fab support of NEC's Kasai facility
Applications engineering
Design engineering
Testing, including MIL STD 19500 screening

PRODUCTS

GaAs low-noise and power MESFETs and HEMTs
Diodes
MMICs and analog ICs
DigICs including 200-gate and 500-gate BFL arrays and standard logic
Hybrids

FACILITIES

Santa Clara, California
44,000 sq. ft.
Design and test only, no wafer fab facilities (NEC Corporation produces the chips.)

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Celeritek Inc.

617 River Oaks Parkway
San Jose, CA 95134
408/433-0335
Fax: 408/433-0991

ESTABLISHED: 1984 NO. OF EMPLOYEES: 180

BACKGROUND

Celeritek Inc., designs, manufactures, and markets GaAs FETs, MMICs, and custom subsystems such as up/down converters for military and commercial applications.

The Company has developed a thin-film microwave amplifier technology and manufactures many of its low-noise and medium-power GaAs FETs in-house. All microwave amplifier thin-film circuits use a high-energy sputtering process for reliable and repeatable metal adhesion. The Company can also manufacture silicon MOS capacitors. Celeritek uses a family of standard amplifier modules that can be combined and aligned to achieve customer-specific specifications.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
*Tamer Husseini
Granger Assoc., VP Operations

VP Semiconductor Operations
*Ross Anderson
Avantek, Mgr GaAs Dev

VP Finance
*John Beman
ROLM, Controller

VP Marketing/Sales
*Robert Jones
Avantek, Dir Marketing

VP Amplifier Operations
*Gary Policky
Avantek, Mgr Adv Dev M/W

*Founder

PROCESS TECHNOLOGY

Submicron GaAs MESFET

FACILITIES

San Jose, CA
23,860 sq. ft.
Research and development and manufacturing
1,000 sq. ft.
Class 100 clean room

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Celeritek Inc.

PRODUCTS

Family	Frequency	Power Output
Low-Noise Amplifiers		
CMA Series	0.5 to 18.0 GHz	+18 dBm
CMT Series	2 to 18 GHz	+18 dBm
CMT Series	18 to 40 GHz	+10 dBm
Medium-Power Amplifiers		
CPA Series	6 to 18 GHz	+27 dBm
CPT Series	6 to 18 GHz	+30 dBm
Microsize Connectorless Amplifiers		
240/400 Series	2 to 18 GHz	
520 Series	0.5 to 4.0 GHz	
MMIC Chips		
CMM-2 Amp	2 to 6 GHz	
CMM-4 Amp	2 to 18 GHz	
CMS-12 Switch	DC to 18 GHz	
GaAs FETs		
CF004-02	2 to 40 GHz	+13 dBm
CF003-01	2 to 20 GHz	+22 dBm
CF010-01	2 to 18 GHz	+28 dBm
Integrated Assemblies		
Frequency Converters		
Switched Amplifiers		
Log Amplifiers		

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COMSAT Laboratories

22300 Comsat Drive
Clarksburg, MD 20871-9475
301/428-4000

ESTABLISHED: 1963 NO. OF EMPLOYEES: 315

BACKGROUND

COMSAT Laboratories is the research and development center of the Communication Satellite Corporation. The Company is actively developing MMICs for small signal and power applications. Its products cover the frequency range of one to 94 GHz. COMSAT has provided foundry services to other companies, including Pacific Monolithics. COMSAT is a member of the TRW team on Phase 2 of the DARPA-sponsored MIMIC program.

COMPANY EXECUTIVES

President
Dr. John Evans

Director, GaAs Lab
Dr. Ho Huang

Director, Finance
Rendell Richards

Director of Business Development
Fred Gould

SERVICES

COMSAT Labs' capabilities and foundry services include custom MMIC design, analysis, prototype fabrication, and testing to government and military standards including Class S.

PROCESS TECHNOLOGY

GaAs 0.2-micron gate-length MESFETs using vapor phase epitaxy (VPE), metalorganic chemical vapor deposition (MOCVD), and molecular beam epitaxy (MBE) implanted layers, e-beam direct-write equipment, and Ti/Pt/Au metallization

PRODUCTS

GaAs power FETs
GaAs HEMTs
GaAs MMICs

FACILITIES

The Clarksburg, Maryland, facilities include 5,000 square feet of space of Class 100/10 clean rooms.

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EPITAXX Inc.

3490 U.S. Route One
Princeton, NJ 08540
609/452-1188
Fax: 609/452-0824

ESTABLISHED: 1984 NO. OF EMPLOYEES: 75

BACKGROUND

EPITAXX Inc. produces indium gallium arsenide phosphide (InGaAsP) light-emitting diodes, lasers, and photodetectors for fiber-optic and infrared instrumentation applications. The Company also supplies InGaAsP using a proprietary crystal growth technique, VPE, which allows the elements to be deposited from gases. Custom services include 2,000 and 2,500nm photodiodes, detector arrays, and pulsed laser diodes. EPITAXX sells its components to telecommunications vendors, such as GTE and ITT, and to fiber-optic companies, such as Fibercom and Plantronics Wilcom. The company supports compliance testing to Bellcore specifications.

In order to expand its products, EPITAXX conducts R&D sponsored by industry and the government. The following are some of the Company's development activities:

- Indium gallium arsenide (InGaAs) linear arrays for use in spectroscopy and imaging and airborne communication
- Extended-range sources and detectors for optical sensors and transoceanic communications applications
- InGaAs avalanche photodiodes for optical com munications and sensors, range finding, and instrumentation applications
- 5mm InGaAs visible response (500 to 1,700nm) detectors for optical test and calibration and temperature sensors

The Company was founded by Dr. Gregory Olsen and Dr. Vladimir Ban, former research scientists at the RCA David Sarnoff Research Laboratories in Princeton, New Jersey. The founders developed the VPE applications while employed there.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
Ken Fujawara

Exec VP Technology
*Dr. Vladimir Ban
RCA, Scientist

Marketing VP
Dr. Yves Dzialowski
General Optronic, Foreign Sales Manager

Finance VP
James Coleman
Lenox China, Account Executive

*Founder

RECENT HIGHLIGHTS

February 1988
EPITAXX announced that the Company was selected by the NASA Goddard Space Flight Center for a Phase-II Small Business Innovative Research (SBIR) contract to develop large-area InGaAs photodetectors for the 500 to 1,700nm spectral range.

March 1988
EPITAXX announced that the Company was awarded a $50,000, Phase-I SBIR contract by NASA's Goddard Space Flight Center to develop a linear array of InGaAs detectors. The array will have a minimum of 32 elements (30 x 30 microns each) and will be installed in a commercial multiplexer readout. EPITAXX plans to apply for a Phase-II program based on linear arrays of InGaAs detectors that are sensitive over the 0.8- through 2.2-micron spectral range.

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EPITAXX Inc.

April 1988
EPITAXX exhibited the following infrared components at CLEO '88:

- Edge-emitting light-emitting diodes (LEDs) (1,300 and 1,550nm) in a low-cost pigtailed package for local communication and optical instrumentation
- Large-area (0.5 to 3.0mm) InGaAs detectors for gyroscopes, gas sensors, space photography, SWIR detection, and fiber-optic test instrumentation
- High-speed, small-area, planar InGaAs PIN photodiodes for light-wave and range-finding receivers

PROCESS TECHNOLOGY

InGaAs on GaAs wafers
MIL STD 883C processing
Vapor phase epitaxy (VPE)

PRODUCTS

Device	Description
EPITAXX 1300	High-Power LEDs, 1,550 and 1,300nm
ETX60B	PIN InGaAs Photodetector, Low Capacitance and High Speed, 1,300 and 1,550nm
ETX75/100/300	InGaAs PIN Photodetectors, 900 to 1,700nm, with High Responsivity
ETX75F/100F	InGaAs Fibered Photodetectors with Low Dark Current and Capacitance, 1,300 and 1,550nm
ETX500/1000/2000	InGaAs Photodetectors, for Low Noise Measurements of Long Wavelengths (900 to 1,700nm)
ETX3000	Large-Area (3mm) InGaAs Photodetector for Low Noise Detection in the 0.8- to 1.7-Micron Spectral Range
ETX2550	InGaAs 2.5-micron
ETX-Array	256 element InGaAs Detector Array

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Fujitsu Ltd.

6-1, Marunouchi 1-chome,
Chiyoda-ku
Tokyo 100, Japan
(03)216-3211
Telex: J22833

ESTABLISHED: 1935 NO. OF EMPLOYEES: Approx. 94,825

BACKGROUND

Fujitsu Ltd. was founded in 1935 as a spinoff of the parent company, Fuji Electric Co. Ltd. Fujitsu began as a manufacturer of automatic telephone exchanges and related equipment, later adding carrier transmission and radio communications equipment to its line. The Company is considered a world leader in telecommunications; it is also involved in the manufacture and sale of computers and EDP systems, electronic components including semiconductors, and audio products. Fujitsu is one of the top four suppliers to NTT (Nippon Telegraph and Telephone Corp.), along with Hitachi, NEC, and Oki. The three largest shareholders in Fujitsu are Fuji Electric (14.3 percent), Asahi Mutual Life Insurance (6.8 percent), and Dai-Ichi Kangyo Bank (4.7 percent). In 1990, Fujitsu's company-wide R&D budget was $1.89 billion.

Fujitsu established its GaAs FET activity in 1979. The Company has focused its compound semiconductor R&D in several areas, including HEMTs, compact GaAs FET amplifiers, 1K, 4K, and 16K RAMs using E/D MESFET structures, and a 10ns, 16x16 multiplier. Fujitsu's VLSI GaAs work is paralleling that of NTT, which has also developed 1K and 4K SRAMs. In 1991, Fujitsu introduced 45,000-gate array and 64K SRAMs based on HEMT technology.

Fujitsu has developed self-aligned double heterostructure lasers operating at 0.9u to 1.7u wavelength (compatible with fiber-optic cables). In 1985, Fujitsu announced the development of an APD for 1.55u communication applications; the InGaAsP device uses an InP-implanted avalanche effect multiply area to improve the current multiplication ratio by 15 to 20 times that of conventional devices. The Company is equipping a plant in Dallas, Texas, for producing communications equipment.

COMPANY EXECUTIVES (GaAs ACTIVITIES)

President
Tadashi Sekizawa

Head of Marketing
Masatomi Yasufuku

Managing Director/General Manager, Components Group
Hiroyuki Ino

Executive Vice President/COO, Microelectronics
Taro Okabe

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Fujitsu is part of the DKB Group (Dai-Ichi Kangyo Bank), formed in 1971 through the merger of Dai-Ichi Bank and Nippon Kangyo Bank. DKB is the largest bank in Japan. The DKB Group consists of two subgroups—the Furukawa Group and the Kawasaki Group—that are successors to the former zaibatsu of the same name.

The top five shareholders of Fujitsu are Fuji Electric (15.8 percent), Asahi Mutual Life Insurance (7.3 percent), Dai-Ichi Kangyo Bank (5.7 percent), Industrial Bank of Japan (2.6 percent), and Sega Zurich (2.0 percent). Fujitsu's major financing is via DKB and Mitsubishi Group financial institutions.

From 1981 to January 1990, Fujitsu, Hitachi, Mitsubishi, NEC, Oki, and Toshiba jointly developed and demonstrated a GaAs-based prototype supercomputer system as part of the Japan National Supercomputer Project.

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Fujitsu Ltd.

In mid-1990, Fujitsu and Vitesse entered into a technology exchange agreement on the FURY Series of GaAs VLSI ASICs. Fujitsu is increasing its GaAs linear (including microwave) and digital IC capacity to support a 1993 run rate in excess of $200 million per year.

PROCESS TECHNOLOGY

Fujitsu uses submicron E/D MESFET technology.

PRODUCTS

GaAs low-noise and power FETs
HEMTs
APDs
PINs
Laser diodes
LEDs
MMICs
Detectors
DigICs.

FACILITIES

Aizu plant—includes some GaAs discrete production Kawasaki plant—67,000 square feet
Yamanashi plant—125,000 square feet; includes 3-inch and 4-inch GaAs wafer fab; produces FETs, other discretes, and optoelectronics

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General Electric (GaAs Operations)

Electronics Park
EP-3, Box 4840
Syracuse, NY 13221
315/456-0123

ESTABLISHED: 1981 NO. OF EMPLOYEES: NA

BACKGROUND

General Electric Company is an international, vertically integrated manufacturer of electrical and electronic systems and components. In 1986, the Company acquired RCA Corporation; in 1988, it sold part of its semiconductor operations, including Intersil, to Harris Corporation.

GE produces optoelectronic devices and GaAs MMICs. GE invested $3.5 million in advanced equipment for its GaAs R&D facility in 1985 and has made additional investments in the facility since that time.

GE and Hughes Aircraft are one of the three prime contractor teams on DARPA's MIMIC program, Phase 2. This team is developing 16 different GaAs IC chip types for radar and other military applications.

COMPANY EXECUTIVES

Manager, Electronics Laboratory
Dr. Walter Butler

Manager, Business Development and Technology Planning
Louis Lego

Manager, MMIC Materials and Devices
Dr. Alan Swanson

Manager, MMIC Prototype Facility
Dr. Anthony Immorlica

Manager, Finance
Ronald J. Ziomek

STRATEGIC ALLIANCES

GE has a joint venture with Hughes Aircraft on DARPA's MIMIC program.

PROCESS TECHNOLOGY

The Company uses submicron GaAs MESFET technology.

PRODUCTS

Optoelectronic devices
GaAs MMICs

FACILITIES

General Electric's laboratory in Syracuse, New York, has 120,000 square feet. This space is divided into 40 percent for R&D and 60 percent for GaAs products, including an 8,000-square-foot clean room for 3-inch wafer fab.

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GEC-Marconi Materials Technology Ltd.

GaAs Division
Caswell, Towcester, Northants, NN12 8EQ
United Kingdom
Tel: 011 440327 50581
Fax: 011 440327 54775

ESTABLISHED: 1965 NO. OF EMPLOYEES: 102

BACKGROUND

GEC-Marconi Materials Technology Ltd., established in April 1991, combines Plessey Research Caswell Ltd., Plessey Microwave Materials Ltd., and Hirst Research Centre activities.

Plessey Research Caswell, Ltd., acquired by GEC-Marconi, was formerly the Plessey Three-Five Group. Until mid-1990, the Plessey Three-Five Group was a group within Plessey Opto Microwave Ltd., a subsidiary of Plessey plc. The first GaAs FET production at Plessey plc occurred in 1965. In 1970 Plessey produced the first commercial GaAs FET.

In 1989, Plessey Opto Microwave Ltd. was restructured into three groups. Plessey Microwave Group focused on hybrids and modules. Plessey Opto Group was involved in lasers, PIN diodes, receivers, and other opto components. Plessey Three-Five Group had responsibility for chip manufacturing, MMICs, discrete FETs, ICs, and the Caswell R&D Center. A foundry service for GaAs ICs is available, offering D-MESFETs with 0.9u nominal gate lengths integrated with ionimplanted diodes and resistors, metal-insulatormetal (MIM) and interdigitated capacitors, and spiral dielectrically isolated (DI) bridge inductors.

GaAs Division shipments exceed $10 million annually. Its foundry has more than 20 active customers.

COMPANY EXECUTIVES

Managing Director
John Brian

Marketing Executive
Peter Bradshaw

Sales Executive
Pim Meaning

Director of R&D
Fred Myers

International Sales Manager
Ray Evans

STRATEGIC ALLIANCES

GEC-Marconi participates in various European Community (EC) ESPRIT projects.

SERVICES

The Company provides a full-service GaAs MMIC foundry.

PROCESS TECHNOLOGIES

F40 process—millimeter-wave GaAs
F14, 0.7 micron gate length MESFET
F20, 0.5 micron gate length MESFET

PRODUCTS

GaAs ICs including amps, switches, and attenuators
Fiber-optic devices
Low-noise and power MESFETs
HEMTs and HJBTs
LEDs and lasers

FACILITIES

The 40,000-square-foot facilities employ approximately 400 people in GaAs processes. Plessey invested £50 million between 1985 and 1989 to upgrade its facilities.

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Hamamatsu Corporation

360 Foothill Road
Bridgewater, NJ 08807
908/231-0960

ESTABLISHED: 1957 **NO. OF EMPLOYEES: Approx. 1,250**

BACKGROUND

Hamamatsu Corporation, a privately held United States-based company, markets semiconductors that are produced by Hamamatsu Photonics K.K. The parent company's Solid-State Division is the largest optoelectronic semiconductor facility in Japan. The Company specializes in photo electronic semiconductor components and subassemblies.

COMPANY EXECUTIVES

VP Engineering
Yuji Shinoda

Sales Manager
George Marshall

PROCESS TECHNOLOGY

GaAs and other compound wafer processing by VPE and MOCVD

PRODUCTS

Phototransistors
GaP, GaAsP, and other photodiodes
GaAs, GaAlAs, and other infrared LEDs
Photocouplers and photointerruptors
II-VI and III-V compound detectors
GaAs and other lasers

FACILITIES

The Hamamatsu City (Shizuoka Prefecture) facilities have a wafer start capacity of 15,000 3-inch GaAs and other III-V wafers per month.

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Harris Microwave Semiconductor Inc.

1530 McCarthy Blvd.
Milpitas, CA 95035
408/433-2222
Fax: 408/432-3268

ESTABLISHED: June 1980 NO. OF EMPLOYEES: 80

BACKGROUND

Harris Microwave Semiconductor (HMS) Inc. was formed to develop and manufacture GaAsbased FETs, MMICs, and digital ICs. In addition to offering standard products, the Company offers full and semicustom capabilities and provides foundry services. HMS is a vertically integrated operation of Harris Corporation's Semiconductor Sector. One hundred percent of the Company's funding has been provided by the Harris Corporation.

The Company has capabilities for manufacturing GaAs crystals and wafers as well as ICs, packaged products, and discrete devices. HMS is said to have the world's largest high-purity GaAs ingotgrowing capacity, which produces single-crystal GaAs ingots of up to 7 inches in diameter.

COMPANY EXECUTIVES

(Position and Name)

President/Chief Executive Officer
John T. Hartley

Vice President/General Manager
Dr. Joseph Barrera

Marketing and Sales Director
Vic Kovacevic

Engineering Director
Jaime Tenedorio

Marketing Communications Director
Shelley Hecker

RECENT HIGHLIGHTS

February 1988
HMS introduced the HMM-10620, a 2- to 6-GHz low-current, cascadable, broadband MMIC amplifier designed to meet the electronic warfare systems' low-current requirements.

May 1988
HMS introduced the HMM-11810, a 6- to 18-GHz low-current, cascadable broadband MMIC amplifier designed to meet the low current requirements of electronic warfare systems.

June 1989
HMS introduced the HMR-1100, a GaAs MMIC Pi Attenuator. The MMIC is a practical solution for slope and gain control in a variety of military components such as amplifiers.

1988-1991
HMS participated in Phase 0 and Phase 1 of the DARPA MIMIC initiative.

SERVICES

Foundry

PROCESS TECHNOLOGY

1.0- to 0.5-micron GaAs MESFET
0.25-micron in development
2-, 3-, and 4-inch wafers

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Harris Microwave Semiconductor Inc.

PRODUCTS

Device	Description
FETs (available in chip or packaged form)	
HMF-0300	2-18 GHz, 125mW Power
HMF-03100-100	2-20 GHz, Low Noise, Gain
HMF-03100-200	2-20 GHz, Gain/Drive
HMF-03100-300	2-20 GHz, Drive
HMF-0330	2-20 GHz, Low Noise, Low Current
HMF-0600	2-20 GHz, 250mW Power
HMF-0610	2-20 GHz, Gain
HMF-0620	2-14 GHz, High Transconductance
HMF-12000-100	2-16 GHz, 500mW Power
HMF-12000-200	2-16 GHz, 650mW Power
HMF-1210	2-20 GHz, Gain
HMF-24000-100	2-14 GHz, 800mW Power
HMF-24000-200	2-14 GHz, 1.2W Power
MMICs	
HMR-11000	Pi Attenuator, DC-18 GHz
HMR-10502	Analog Amplifier, 0.5-5.0 GHz
HMR-10503	Analog Amplifier, 1-5 GHz
HMM-11510	7.5-15 GHz MMIC Amplifier, Low Current
HMM-11520	7.5-15 GHz MMIC Amplifier, Low Current
HMM-10610	Broadband Amplifier, 2-6 GHz
HMM-10620	Broadband Amplifier, 2-6 GHz, Low Current
HMM-11810	Broadband Amplifier, 6-18 GHz
HMM-11820	Broadband Amplifier, 6-18 GHz, Low Current

FACILITIES

Milpitas, CA
37,000 sq. ft. total
15,000 sq. ft. manufacturing space, including
7,500 sq. ft. of clean room

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Hewlett-Packard Company

3000 Hanover Street
Palo Alto, CA 94304
415/857-1501

ESTABLISHED: 1939 (1965, HP Labs GaAs activities) NO. OF EMPLOYEES: 87,000

BACKGROUND

Hewlett-Packard (HP) is a vertically integrated electronics company that develops and manufactures products for the worldwide marketplace. HP's principal products include integrated instrument and computer systems, test/measurement instruments, computers, peripherals, medical electronics, chemical analysis instrumentation, handheld calculators, and solid-state components.

HP Labs conducts research to extend its technology base. The laboratories originated LED displays, the Schottky-gate GaAs FET X-band amplifier, and GaAs MMICs. HP's Microwave Division (MSD) makes transistors and other microwave components. The Optoelectronics Division (OED) produces LEDs, light bars, and linear arrays. Products of the Optocommunication Division (OCD) include fiber optics and couplers.

HP ships approximately $300 million in merchant and captive GaAs ICs and optoelectronic components per year. GaAs ICs are now used in many of HP's instrumentation products.

HP is a member of the Raytheon/TI team on Phase 2 of the DARPA-sponsored MIMIC program.

At press time, HP had announced its intent to acquire Avantek for a reported price of $82.8 million ($4.60 per share for 18 million shares). HP spokespersons indicated that the Avantek product line is expected to enhance the existing HP product line of compound semiconductor components, subassemblies, and subsystems.

COMPANY EXECUTIVES

Lab Director
Frank Carruba

Executive Vice President, Marketing and International
Dick Alberdin

VP and General Manager, Components Group
William F. Craven

General Manager, MSD
Paul Sedlewicz

General Manager, OED
Mike Cowley

General Manager, OCD
Rick Kniss

PROCESS TECHNOLOGY

GaAs, AlGaAs, and related III-V opto device processes
15 GHz and 24 GHz MMIC processes (production)
MODFET IC and HJBT IC (R&D)

PRODUCTS

LEDs
Optocouplers
Microwave diodes
Transistors
MMICs

FACILITIES

HP has manufacturing facilities at Santa Rosa and Rohnert Park, California.

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Hitachi Ltd.

6, Kanda-Surugadai
4-chome, Chiyoda-ku
Tokyo 101-10, Japan
(03) 258-1111

ESTABLISHED: 1910 NO. OF EMPLOYEES: 309,757

BACKGROUND

Hitachi Ltd. was founded in 1910 by Namihei Odaira, an engineer, to develop domestic manufacturing technology for electric power equipment. After World War II, the Company entered consumer electronics, and in 1950 it entered the field of electronics. Hitachi views electronics and the development of alternative energy sources as its two areas of strategic growth in this decade. Estimated total sales for the Company for its fiscal year ending March 1990 were ¥6.75 million.

Hitachi's compound semiconductor R&D effort has included development of InGaAsP lasers in the visible spectrum (specifically, 752nm to 756nm). Hitachi also has developed buried-layer GaAs FETs with threshold voltage deviations of only 5 percent.

Hitachi participated in the AIST/MITI Japanese national supercomputer project sponsored by NEDO, which resulted in a GaAs-based super computer prototype system demonstrated in 1990.

COMPANY EXECUTIVES

President
Katsushige Mita

Head of Marketing
Shuzo Hata

Group Executive, Electronic Devices
Kazuo Kimbara

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Hitachi originated from the pre-World War II Nissan Konzern. The Hitachi Group, formed under Hitachi Ltd., is not one of the six major Japanese industrial groups. The group companies have relations with former Nissan Kozern companies, including Nissan Chemical Industries, through cross-shareholdings and common directors; they also participate in deliberation councils with the DBK, Fuyo, and Sanwa Groups.

The top shareholders of Hitachi include Nippon Life Insurance (4.1 percent), Mitsubishi Trust (3.5 percent), Toyo Trust (3.1 percent), Yasuda Trust (2.8 percent), Dai-Ichi Mutual Life Insurance (2.7 percent), Mitsui Trust (2.5 percent), Sanwa Bank (2.3 percent), and Sumitomo Trust (2.2 percent). Approximately 14 percent of Hitachi's stock is foreign-owned; the ceiling for foreign ownership is set at 30 percent.

Hitachi has technology-sharing and/or licensing agreements with Asahi Chemical, Fairchild (bought by National Semiconductor), Fujitsu, General Motors (owner of Hughes Aircraft), Hewlett-Packard, Monsanto, Motorola, NTT, Signetics (a subsidiary of Philips), Sperry (now part of Unisys), Thomson-CSF, and others.

From 1981 to January 1990, Hitachi, Fujitsu, Mitsubishi, NEC, Oki, and Toshiba jointly developed and demonstrated a GaAs-based prototype supercomputer system.

PROCESS TECHNOLOGY

Hitachi produces for internal use and for the merchant market e-beam masking, wafer inspection, and test equipment for production processes requiring submicron resolution and 0.1-micron accuracy. This equipment is used in its GaAs and other compound semiconductor processes.

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Hitachi Ltd.

PRODUCTS

LEDs
Lasers
Detectors
Small-signal transistors
MMICs
DigICs

FACILITIES

Takasaki plant
Komoro factory—fab, assembly, and test of opto devices and hybrids

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Hittite Microwave Corporation

21 Cabot Road
Woburn, MA 01801
617/933-7267
Fax: 617/932-8903

ESTABLISHED: January 1985 NO. OF EMPLOYEES: 15

BACKGROUND

Hittite Microwave was formed to market custom and proprietary GaAs MMICs for military and commercial applications. The Hittite team has been involved in all aspects of design, development, and production of monolithic GaAs components, including participation in several Department of Defense GaAs technology development programs.

Hittite's expertise ranges from designing small, single-chip systems to 500-watt, continuous-wave, multichip components and subsystems. Hittite's facility is equipped to conduct design, layout, verification, packaging, and test of GaAs-based components. Wafer fabrication is conducted by foundries.

Hittite is part of the General Dynamics, Honeywell, TRW consortium that is addressing the critical technology, fabrication, and cost issues of inserting microwave/millimeter wave monolithic IC (MIMIC) technology into advanced tactical weapons systems. The team has targeted three main mission areas for MIMIC insertions—smart weapons, electronic warfare, and communications. The TRW team received a prime contract under Phase 2 of the MIMIC program.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/COO
Dr. Francis Paik
Raytheon, Business Dev Mgr

VP/CEO
*Dr. Yalcin Ayasli
Raytheon Research, Mgr R&D Monolithic ICs

VP Finance/CFO
Ronald Kaplan
Wang, Controller

Product Line Manager
Brian Bedard

*Founder

STRATEGIC ALLIANCES

Hittite is a member of the General Dynamics, Honeywell, TRW consortium, which has been awarded a Phase 2 contract under the Department of Defense MIMIC program.

PROCESS TECHNOLOGY

0.5- and 1.0-micron GaAs MESFET design capability (no fab)

PRODUCTS

MMICs
Signal Control Components
Microwave Radar Ranging Devices
Other proprietary products

FACILITIES

Woburn, MA
4,800 sq. ft. total
Offices, R&D, assembly, test
400 sq. ft.
Class 10 clean room (no fab)

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Hughes Microelectronic Circuits Division

P.O. Box 8
Newport Beach, CA 92662
Tel: 714/759-2411
Fax: 714/759-2280
Tel: 213/517-5590 (GaAs Circuits)

ESTABLISHED: 1977 NO. OF EMPLOYEES: 260

BACKGROUND

Hughes Aircraft Company, now owned by General Motors, began GaAs R&D in the late 1960s. The Microelectronic Circuits Division (MCD) in Torrance started operations in 1977. From 1977 to the early 1980s, the division invested about $1 million per year in capital equipment. In 1982, the prototype lab was completed. Another $10 million was invested in the pilot fab line constructed in 1985. As of mid-1985, Hughes was investing $40 million in GaAs ICs; $20 million had been invested prior to that time. In 1987, Hughes MPD tripled its GaAs clean rooms to a total of 44,300 square feet, permitting high-volume production in a facility separate from the prototype fab and diode fab areas.

In 1988, Hughes received a Phase I MIMIC award. Phase I was completed in mid-1991. Hughes Radar Systems Group received a $78.9 million Phase 2 MMIC award in mid-1991. Hughes is teamed with AT&T, GE, HMS, M/A-COM, and others on this DARPA-sponsored program. This team is developing a total of 16 chip types for military radar, communications, and smart weapons applications.

In mid-1991, Hughes moved its GaAs operations into the Microelectronics Circuits Division. Facilities remained essentially unchanged.

COMPANY EXECUTIVES

Microelectronic Circuits Division Manager
Don Schrock

GaAs Product Line Manager
C.A. Farris

GaAs Product Line Controller
Gil Gamboa

GaAs Product Manager
John Kuno

GaAs Product Marketing Manager
Ken Conklin

GaAs Applications Engineering
Eric Patell

GaAs Product Assurance Manager
P.J. Nobile

STRATEGIC ALLIANCES

MPD is a division of Hughes Aircraft, which is owned by General Motors. Hughes Aircraft is developing electronics for future automotive applications including collision avoidance and communications systems.

Hughes and McDonnell Douglas are teamed with AT&T Bell Laboratories on a DARPA program to develop SDHT (HEMT) SRAMs and logic circuits.

The Hughes MIMIC (DOD initiative) team includes AT&T, Cascade, GE, HMS (Harris Microwave Semiconductor), and M/A-COM.

SERVICES

The company provides a full-service foundry that includes circuit design, CAD support, wafer fab, packaging, and chip test and evaluation for internal and selected external use.

PROCESS TECHNOLOGY

GaAs MESFET to 0.25u gates; SDHT (HEMT)
Ion implantation, direct-write e-beam, and second-generation MBE equipment (Hughes patented the ion-implanted channel FET.)

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Hughes Microelectronic Circuits Division

PRODUCTS

LNAs
Power FETs including 1-Watt, 15-GHz devices
Matched drivers
MMICs

FACILITIES

MPD's facilities are located in Torrance, California. They include 44,300 square feet of clean rooms with 8,000 square feet for diode fabrication, 6,400 square feet for materials and prototype fabrication, and 29,900 square feet for GaAs 3-inch wafer process and IC production.

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Isocom Limited

Prospect Way
Park View Industrial Est.
Brenda Road
Hartlepool, Cleveland, England
Tel: (0429) 863609
Fax: (0429) 863581

Isocom, Inc.

274 E. Hamilton Avenue, Suite E
Campbell, CA 95008
Tel: 408/370-2212
Fax: 408/370-2309

ESTABLISHED: November 1982 **NO. OF EMPLOYEES:** 85

BACKGROUND

Isocom Limited was formed to design, manufacture, and market optocouplers with the goal of becoming a major participant in the $80 million military optocoupler market. Marketing efforts were concentrated in the European commercial and industrial markets for the first two years. In 1986, the Company began offering devices to the military market.

The Company's initial products included a range of optocouplers and interrupter switches in single-, dual-, and quad-package configurations. In 1984 and 1985, the product line expanded to include Hewlett-Packard-compatible, high-speed, high-gain optocouplers. Isocom's products, which currently include transistor-output, Darlingtonoutput, AC-input, photo SCRs, TRIACs, and Schmitt Trigger optocouplers, are used in power supplies, telecommunications, instrumentation, and modems. In the second quarter of 1985, the Company became one of the first to offer a range of surface-mount devices.

Isocom was founded by several former Litronix managers and is headquartered in Hartlepool, England, with a U.S. sales and marketing office in Campbell, California. Design, manufacturing, and test are done at the 25,000-square-foot Hartlepool facility. Some assembly is contracted to companies in the Far East.

COMPANY EXECUTIVES

(Position, Name)

Managing Director, Isocom Ltd.
E. Bostwick

President/CEO of Isocom Inc.
*Colin Rees

Vice President/General Manager Isocom, Inc.
Stephen Parry

*Founder

PROCESS TECHNOLOGY

Silicon
GaAs
GaAlAs

PRODUCTS

Minicouplers
High-Speed/High-Gain Couplers
High-Isolation Optocouplers
High-Speed Tristate Optocouplers
High-Voltage Photo Transistor Couplers
Switches
Hybrids
Visible Lamps
Visible Displays
Integrated Displays
Solid-State Relays

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Isocom Limited

FACILITIES

Hartlepool, England
25,000 sq. ft.
R&D, design, manufacturing, test

Campbell, CA
2,000 sq. ft.
Marketing and sales

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ITT GaAs Technology Center (GTC)

7670 Enon Drive
Roanoke, VA 24019
Tel: 703/563-8600
Fax: 703/563-8696

ESTABLISHED: 1983 NO. OF EMPLOYEES: Approx. 100

BACKGROUND

ITT GaAs Technology Center (GTC), a unit of ITT Corporation, was founded to support both internal and merchant market needs for MMICs and high-speed digICs implemented with GaAs technology. The activity was part of ITT's Electro-Optical Division until early 1983. ITT GTC was a key player in the DOD's MIMIC Phase I program and offers foundry services for both military and commercial applications.

By mid-1990, ITT GTC had designed and fabricated more than 200 types of MMICs for applications from DC to 18 GHz. The Company has significantly expanded its module test and assembly capabilities to accommodate volume production of c-band T/R modules.

COMPANY EXECUTIVES

Director
Dr. Dennis G. Fisher

Director, Engineering/Operations
Dr. Edward Griffin

Senior Manager, Technical Services
Ed Donoho

Manager, Business Development
Joseph A. Grzyb

SERVICES

ITT GTC operates a GaAs microwave and digIC foundry including design, fab, assembly, and test.

PROCESS TECHNOLOGY

The Company uses GaAs multifunctional self-faligned gate (MSAG) processing on 3-inch wafers. This process allows the manufacture of low-noise, power, and E/D MESFET digital circuits on a single chip.

PRODUCTS

MMICs:
- Low noise, 2 to 18 GHz
- Power, 2 to 12 GHz to 12W output to
- 70 percent efficiency

DigICs—DCFL standard cells, complexities to 5,000 gates

FACILITIES

ITT GTC has a 27,000-square-foot 3-inch wafer fab facility plus a 12,000-square-foot design/test/packaging area; the Company added a 2,000-square-foot packaging area in late 1987. Equipment includes ion implantation, SEM, and very high temperature burn-in capacity. The facilities have a throughput capacity that exceeds 100 wafer starts per week.

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Kyoto Semiconductor Corporation

418-3, Yodosaime-cho
Fushimi-ku Kyoto 613, Japan
075-631-8823
Fax: 075-631-8291

ESTABLISHED: April 1980 NO. OF EMPLOYEES: 20

BACKGROUND

Kyoto Semiconductor offers GaAs LEDs, phototransistors, photosensors, and LED displays. The diodes offer twice the efficiency of available units. The heterostructured diodes feature a 23.6 percent light-emitting efficiency at peak wavelengths of 190nm. Four selections of wavelengths are available: 660, 750, 830, and 890.

Kyoto Semiconductor's major customers are Mitsubishi Electric and General Instrument. The Company contracts assembly to companies in Taiwan.

COMPANY EXECUTIVES

(Position, Name, and Prior Company)

President
Jousuke Nakata
Mitsubishi

PRODUCTS

High Bright LEDs
Infrared LEDs
Photo TRs
Photosensors
LED Displays

FACILITIES

Kyoto, Japan
Production

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Laser Diode Incorporated

1130 Somerset Street
New Brunswick, NJ 08901
Tel: 908/549-9222
Fax: 908/549-9897

ESTABLISHED: 1971 NO. OF EMPLOYEES: Approx. 205

BACKGROUND

Laser Diode Incorporated originated as a division of M/A-COM. In 1986, the Company was sold by M/A-COM to The Morgan Crucible Company plc (Windsor, England). Laser Diode develops, produces, and markets optical components for commercial and military markets.

COMPANY EXECUTIVES

President and CEO
Robert B. Gill

Controller
Fanny Blumenthal

Laboratory Director
U. V. Choudary

Marketing Director
Michael Robertson

SERVICES

MIL Q 9858A processing
III-V epitaxy

PROCESS TECHNOLOGY

Submicron GaAs VPE and MOCVD processings; AlGaAs and other compound epitaxy

PRODUCTS

Continuous wave (CW) lasers (820, 1,300, and 1,550nm wavelengths)
Pulsed laser diodes and arrays (880 to 1,550nm wavelengths)
LEDs (820, 1,300, and 1,550nm wavelengths)
Fiber-optic data links and other subsystems
III-V epitaxial materials including 3-inch GaAs wafers

FACILITIES

The Company's four facilities include 1,200 square feet of manufacturing space.

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Lasertron Inc.

37 North Avenue
Burlington, MA 01803
617/272-6462

ESTABLISHED: 1980 NO. OF EMPLOYEES: NA

BACKGROUND

Lasertron Inc. a privately held company, was formed in Burlington, Massachusetts, in 1980 by Dr. Kenneth W. Nill and Dr. James J. Hsieh. The Company is believed to be the largest independent OEM supplier of 1,300nm and 1,550nm fiber-optic components. In 1980, Lasertron introduced the first commercial 1300nm lasers and LED sources, followed with transimpedance pinFET receivers in 1981, 565-Mbps laser sources in 1983, and several other leadership product introductions. In 1987, the company demonstrated 50 years MTTF for all of its products. In 1988, Lasertron introduced 10-GHz fiber-optic microwave transmitters and receivers and completed a USAF contract for 20-GHz diode laser prototypes. Lasertron has sales offices in Burlington, Massachusetts; Harpenden, Herts, United Kingdom; Munich, Germany; and Seoul, Korea.

COMPANY EXECUTIVES

President and CEO
Dr. James J. Hsieh

Executive Vice President
Dr. Kenneth W. Nill

Vice President of Manufacturing
Robert Barboza

Vice President of Sales
David Hardwick

Vice President, Product Assurance and Device Operations
Charles E. Hurwitz

Director of Engineering
Dr. Alex Rosiewicz

STRATEGIC ALLIANCES

Lasertron is licensed by AT&T to use the AT&T-designed Astrotec laser package.

SERVICES

Lasertron offers military contracting services.

PROCESS TECHNOLOGY

Buried heterostructure GaInAsP and GaAs MESFET processes

PRODUCTS

QLM series 1,300 and 1,550nm single-mode and multimode lasers
QLD series LEDs
QDF, QDFM, and QDFT series pinFETs
QDE and QDEP series PIN diode detectors

FACILITIES

Burlington, MA
70,000 sq. ft.
R&D, product design, test, final processing, marketing, and administrative facilities

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Litton Solid State Division

3251 Olcatt Street
Santa Clara, CA 95054-3095
Tel: 408/988-1331
Fax: 408/970-9950

ESTABLISHED: 1975 NO. OF EMPLOYEES: 240

BACKGROUND

Litton Solid State Division was the Dexcel Division of Gould until July 1987, at which time it was acquired by Litton Industries. Litton Industries is an integrated worldwide electronics com pany. It develops, manufactures, and markets electronics-based systems, products, and components for key high-growth worldwide markets: information systems, industrial automation, instrumentation, defense systems, and other electronic components and materials.

Litton Industries acquired the amplifier operations of Harris Microwave Semiconductor, Inc., of Milpitas, California in mid-1988.

Litton acquired the Varian Solid State Microwave Division, including its GaAs/InP foundry facilities located in Santa Clara, California, in early 1991.

COMPANY EXECUTIVES

President
Frank Olson

VP Marketing
Dean Merkley

VP Operations/Manufacturing
Robert Srigley

Controller
Susan Ruelas

STRATEGIC ALLIANCES

Litton Electron Devices is a division of Litton Industries, Inc.

SERVICES

Foundry including InP
Packaging
High-reliability screening

PROCESS TECHNOLOGY

Recessed-gate submicron GaAs MESFET; HEMT
VPE, ion implantation, air-bridge interconnections
Submicron InP MESFET and HEMT structures
MBE, proton isolation, 0.25-micron e-beam lithography

PRODUCTS

GaAs MESFETs—dual gate, low noise, power
HEMTs
Military amplifiers and other subassemblies
Gunn oscillators
InP diodes
GaAs MMICs
InP MMICs
Integrated assemblies

FACILITIES

Milpitas, CA
Approximately 37,000 sq. ft.
Administration, assembly, and manufacturing
Santa Clara, CA
Approximately 60,000 sq. ft.
R&D, design, fabrication, foundry, and support

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Lytel Incorporated

61 Chubb Way
P.O. Box 1300
Somerville, NJ 08876
Tel: 908/685-2000
Fax: 908/685-1282

ESTABLISHED: October 1984 NO. OF EMPLOYEES: 130

BACKGROUND

Lytel Incorporated (Lytel) was formed to design, develop, and manufacture InGaAsP technologybased electro-optic components for the telecommunications, data communications, and military markets. Products include semiconductor lasers, LEDs, and photodetectors using an indium phosphide materials technology.

Lytel's first products, introduced in January 1986, were InGaAsP high-power lasers for fiber-optic applications. The Company is focusing on quality, reliability, delivery, and performance.

Lytel's shipments first exceeded $1 million per month in 1989.

COMPANY EXECUTIVES
(Position and Name)

GM
Gerald Leehan

VP Engineering & Development
*Ron Nelson

Controller
Tim Bock

Director of Marketing
Dave Hubbard

*Founder

PROCESS TECHNOLOGY

InGaAsP, using LPE and MOCVD
1.3-micron opto components

PRODUCTS

InGaAsP High-Power Lasers
LEDs
Optical Data Links

FACILITIES

Somerville, NJ
57,000 sq. ft. total facilities
6,000 sq. ft.
Class 1,000 clean room
8,000 sq. ft.
Class 10,000 packaging and test

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M/A-COM Advanced Semiconductor Operations

100 Chelmsford Street
Lowell, MA 01851
Tel: 508/453-3100
Fax: 508/453-3535

ESTABLISHED: 1984 NO. OF EMPLOYEES: 195

BACKGROUND

M/A-COM Advanced Semiconductor Operations (ASO) was set up to supply GaAs wafers, FETs, standard MMICs, custom MMICs, and foundry services for both internal and external requirements. Except for GaAs wafers, the market segment targeted is essentially microwave and defense related. M/A-COM is heavily involved in the DARPA-funded MIMIC program, and is a member of the Hughes/GE team on Phase 2. About half of M/A-COM's 1991 sales were for weapons-related and defense-related applications.

M/A-COM ASO relies on M/A-COM Inc.'s worldwide network of field sales offices and representatives to market its products.

In mid-1989, M/A-COM acquired Adams Russell Inc., which includes the Adams-Russell Semiconductor Center. Consolidation of the two operations was completed early in 1990.

In 1990, M/A-COM acquired Light Control Systems Inc., a producer of fiber-optic cable assemblies. In 1991, M/A-COM sold its Active Assemblies Division.

COMPANY EXECUTIVES

Vice President and GM, Advanced Semiconductor Division
Douglas Maki

Vice President, Manufacturing
Peter Ledger (formerly VP of Semiconductor Products, M/A-COM)

Vice President, Marketing and Business Development
Larry Ward (formerly of M/A-COM OmniSpectra)

Manager, GaAs Products Marketing and Sales
Robert Tingley

SERVICES

Foundry-0.8u, 0.5u, and 0.25u D-MESFETs
Design
CAD
Assembly
Test
Packaging

PROCESS TECHNOLOGY

0.8u, 0.5u, and 0.25u GaAs D-MESFETs
0.8u GaAs E-MESFETs
0.5u optical lithography, 0.25u e-beam lithography

STRATEGIC ALLIANCES

In 1990, M/A-COM and AT&T began jointly offering foundry services and MMIC products. AT&T's Reading, Pennsylvania, facility performs MBE processing, in-process testing, and reliability validation services.

In 1991, M/A-COM signed a marketing and technology-sharing agreement with Axon, a leading supplier of cable products in France.

PRODUCTS

2-inch, 3-inch, and 4-inch semi-insulating GaAs wafers
0.8u FETs: 8W to S-band, 4W to C-band, 1W to Ku-band
0.25u FETs: Low noise up to K-band
MMICs: DC-18-GHz switches, DC-20-GHz attenuators, custom L- to X-band phase shifters
Broad- and narrow-band power and low-noise amplifiers

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M/A-COM Advanced Semiconductor Operations

FACILITIES

M/A-COM's GaAs product manufacturing and support facilities total more than 183,000 square feet. Included are 58,000 square feet of Class 10 clean room facilities. The ASD facilities are in Lowell and Burlington, Massachusetts. MBE processing and related support functions are provided by AT&T's Reading, Pennsylvania, GaAs facility.

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Matsushita Electric Industrial Co. Ltd.

1006 Kadoma, Kadoma City
Osaka 571, Japan
(06) 908-1121

ESTABLISHED: 1935 NO. OF EMPLOYEES: 198,300

Matsushita Electronics Corporation

1-1 Saiwai-cho, Takatsui City
Osaka 569, Japan
Tel: (0726) 82-5521
Fax: (0726) 82-3093

ESTABLISHED: 1952 NO. OF EMPLOYEES: 13,000

BACKGROUND

Matsushita was founded in 1918 by Konosuke Matsushita. The company established Matsushita Electric Industrial Co. Ltd. in 1935. It has become the largest consumer electronics company in Japan, the ninth largest worldwide semiconductor manufacturer, and one of the world's 50 largest industrial corporations. The Company's semiconductors are produced by a subsidiary, Matsushita Electronics Corporation (MEC), 65 percent owned by Matsushita and 35 percent owned by N.V. Philips (of the Netherlands).

The top five shareholders in Matsushita are Sumitomo Bank (4.4 percent), Sumitomo Life Insurance (4.2 percent), Nippon Life Insurance (3.9 percent), Matsushita Investment and Development (2.9 percent), and Mitsubishi Trust (2.3 percent). Konosuke Matsushita, founder, owns 2.6 percent of the company.

Matsushita started its GaAs activity in 1971. In 1982, Matsushita developed GaAlAs LEDs and announced a GaAs FET frequency divider (masterslave flip-flop) with a toggle rate of 2.5 GHz and P_d of 25mW. Matsushita also has developed a three-stage GaAs FET amplifier with a small-signal gain of 25dB and an operating range of 30 MHz to 1.7 GHz. The Company is a large-volume producer of lasers for CD players.

Matsushita and TRW are jointly developing 0.8-micron AlGaAs lasers for space communications.

COMPANY EXECUTIVES

Chairman
Masaharu Matsushita

President, Matsushita Electric Industrial Co. Ltd.
Akio Tanii

President, Matsushita Electronics Corporation
Kazuma Danjo

Head of Marketing
Kazuo Fujimoto

President, Matsushita Electronics Corporation
Fumio Kanazawa

STRATEGIC ALLIANCES

The company has major licensing and second-sourcing agreements with Hewlett-Packard, IBM, 3M Company, Mitsubishi, NTT, Philips, Sanyo, Sharp, Siemens, and TRW.

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Matsushita Electric Industrial Co. Ltd.

PROCESS TECHNOLOGY

GaAs MESFET
GaP

PRODUCTS

GaAs analog ICs
GaAs digICs
GaAs MMIC amps and other microwave ICs
Standard logic
Optoelectronic devices including CCDs
LEDs and LED panel displays
GaAs and A1GaAs lasers
Detectors
Small-signal and power GaAs transistors

FACILITIES

Kagoshima plant—includes opto production
Takatsuki plant
Okayama plant—includes transistor production
Nagaoka plant—includes opto and discrete production
Moriguchi City plant—GaAs discrete, GaAs IC, and opto R&D

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Microwave Monolithics

465 East Easy Street
Simi Valley, CA 93065
805/584-6642

ESTABLISHED: April 1982 **NO. OF EMPLOYEES: 25**

BACKGROUND

Microwave Monolithics specializes in GaAs MMICs for Department of Defense microwave specialty circuits as well as custom GaAs circuits.

The Company is privately held by five partners and completed first-round financing in 1983 through private sources.

Microwave Monolithics did custom GaAs circuit design research and development work for government agencies and OEMs until financing was secured. The Company began producing GaAs MMICs by year-end 1984.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
*Daniel Ch'en
Rockwell, Mgr M/W Rsch

*Founder

PROCESS TECHNOLOGY

0.5-micron GaAs fine-line capability

PRODUCTS

MMICs

FACILITIES

Simi Valley, CA
8,000 sq. ft.
Two Class 100 clean rooms

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MicroWave Technology Inc.

4268 Solar Way
Fremont, CA 94538
415/651-6700
Fax: 415/651-2208

ESTABLISHED: May 1982 NO. OF EMPLOYEES: 142

BACKGROUND

MicroWave Technology Inc. (MWT) is a vertically integrated manufacturer of GaAs-based microwave components and subassemblies. MwT designs, manufactures, and markets GaAs epitaxial materials, GaAs FET devices, MMICs, hybrid MICs, and microwave components and subassemblies. The Company's products are designed for defense-related applications.

MwT produces both ultralow-noise and mediumpower GaAs FETs and AlGaAs HEMT devices for applications ranging from 0.5 GHz to 40.0 GHz. The devices are produced with gate lengths from 0.1 to 0.25 micron. The Company is developing a family of high-performance MMIC products and has completed a series of 2- to 6-GHz MMIC amplifiers. Products in the 2- to 18-GHz and 6- to 16-GHz ranges are in development.

The Company also offers GaAs FET amplifiers from 0.5 to 26.5 GHz that use MMIC and hybrid MIC modules.

In 1987, MwT acquired Monolithic Microsystems, Inc., of Santa Cruz, California. Monolithic Microsystems makes detector log video amplifiers (DLVAs), log video amplifiers (LVAs), and threshold detectors based on proprietary monolithic LVA ICs. Products are used in various EW systems and other defense electronic applications. Monolithic Microsystems operates as a wholly owned subsidiary of MWT, with its manufacturing in the 8,200-square-foot Santa Cruz facility.

COMPANY EXECUTIVES

(Position, Name)

President/CEO
William Wilson

VP Finance and Administration/CFO
James M. Geyton

VP Materials Development
Arthur Herbig

VP Engineering/R&D
Dr. Masa Omori

Director, Sales
Aytch Roberts

VP Operations
Wen Ou

PROCESS TECHNOLOGY

GaAs MESFET
AlGaAs HEMT
0.25μ gate lengths
Thin-film hybrid VPE on GaAs wafers

PRODUCTS

GaAs Epitaxial Materials
GaAs FET Amplifiers, 0.5 to 26.5 GHz
GaAs MMIC Amplifiers, 2 to 6 GHz
GaAs MIC Microwave Products
Thin-Film Hybrids
Log Amplifiers
Detector Log Video Amplifiers

FACILITIES

Fremont, CA:
50,000 sq. ft.
Design, manufacturing

7,000 sq. ft.
Class 1,000 clean room

Santa Cruz, CA:
8,200 sq. ft.
Manufacturing

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Mitsubishi Electric Corporation

Mitsubishi Denki Bldg., 2-3, Marunouchi 2-chome
Chiyoda-ku, Tokyo 100, Japan
Tel: (03)218-2111
Telex: MELCO J24532

ESTABLISHED: 1898 NO. OF EMPLOYEES: 89,113

BACKGROUND

Mitsubishi Corporation was founded in 1898 as a heavy electrical equipment plant in Nagasaki. Its main areas of business are heavy machinery, electronic products and systems, industrial products, and consumer products. It was the first commercial Japanese electronics company to develop an integrated circuit, and in 1987 began R&D on 4Mb and larger DRAMs. Mitsubishi is Japan's third largest electronics company, and Japan's top defense electronics supplier. In 1986, the Company began marketing a sequential inference machine developed as part of MITI's Fifth-Generation Computer Project.

GaAs activity at Mitsubishi was initiated in 1963. Mitsubishi operated its first pulse-mode AlGaAs 780nm laser at room temperature in 1967. The company began marketing low-noise 12-GHz to 18-GHz GaAs FETs in mid-1980. In late 1982, Mitsubishi started constructing a prototype production line for GaAs LSI. Mitsubishi has a joint venture with Monsanto that produces and markets GaAs substrates.

In mid-1984, Mitsubishi announced that it had developed the technology required for mass production of GaAs solar cells for such applications as communications satellites. The cells have conversion efficiencies that range up to 19 percent. The cells are used in the CS-3 communication satellite launched in 1987. This development work was accomplished under the sponsorship of the National Space Development Agency of Japan.

A low-voltage 4Kx4 GaAs SRAM was developed by Mitsubishi's LSI R&D Laboratory, Itami, Hyogo, Japan, under the MITI Scientific Computing Systems Program (sponsored by Japan's NEDO). Test devices, using a 1.0u E/D DCFL SAG MESFET process and dual-layer metal, were operated at 1.0V power supply voltage, t_{aa} of 11ns max and P_d of 1.0W.

COMPANY EXECUTIVES

Chairman
Nihachiro Katayama

President
Moriya Shiki

Head of Marketing
Shinichi Yufu

Senior Executive Vice President/GM Semiconductor Div.
Yuichi Okutomo

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Mitsubishi is a member of the Mitsubishi group, a continuation of the Mitsubishi Zaibatsu. Although the zaibatsu were dissolved following World War II, the Mitsubishi Zaibatsu companies reorganized into one of the most powerful industrial groups in Japan.

The top five shareholders in Mitsubishi are Mitsubishi Trust and Banking Corporation (5.0 percent), Mitsui Trust and Banking Corpora tion (4.1 percent), Meiji Mutual Life Insurance Company (4.0 percent), Nippon Life Insurance Company (3.6 percent), and Mitsubishi Bank Ltd. (3.1 percent). The Mitsubishi Electric Group Employee Shareholders Union owns 2.1 percent; another 4.3 percent is foreign-owned.

Mitsubishi has technology-sharing and licensing agreements with Dai Nippon Printing Co., GE, Hoya Corporation, Intel, Materials Research Corp., Matsushita, Nihon MRC Co., Sanyo, Sharp, Texas Instruments (TI), Ulvac Coating Co., Westinghouse, and others. Recent agreements include photonic integration (NTT and Batelle) and silicon semiconductor alliances with National and TI.

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Mitsubishi Electric Corporation

From 1981 to January 1990, Mitsubishi, Fujitsu, Hitachi, NEC, Oki, and Toshiba jointly developed and demonstrated a GaAs-based prototype supercomputer system.

In October 1991, Mitsubishi signed a GaAs IC product agreement with AT&T.

PRODUCTS

MMICs and digICs
LEDs
Lasers
Detectors
Small-signal and power GaAs FETs
GaAs FET modules
2-, 3-, and 4-inch GaAs wafers and epi wafers

PROCESS TECHNOLOGY

1.0-micron E/D DCFL self-aligned gate GaAs MESFET
Submicron GaAs MESFET

FACILITIES

Kita-Itami Works
Optoelectronic Device Production

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Motorola Inc.

1303 E. Algonquin Road
Schaumberg, Il 60196
312/397-5000

ESTABLISHED: 1928 NO. OF EMPLOYEES: 100,000

Motorola Inc. Semiconductor Products Sector

5005 E. McDowell Road
Phoenix, AZ 85008
602/244-6900
602/897-5901 (GaAs Research and Development Labs)
602/244-6786 (Opto)

ESTABLISHED: 1954 NO. OF EMPLOYEES: 13,500 (GaAs R&D Lab: 65)

BACKGROUND

Motorola Inc. is one of the world's leading manufacturers of electronic equipment, systems, and components produced for both U.S. and international markets. Its products include two-way radio and other electronic communications systems, semiconductors, and defense and aero space electronics. The Opto division, established in 1966, supplies a broad range of IREDs, photodetectors, couplers, isolators, and other GaAs products.

Motorola SRDL is engaged in GaAs R&D and prototype production for captive consumption.

The company has announced an 18-19-GHz wireless interoffice network called ALTAIR wireless Ethernet. It also is developing IRIDIUM, a 23-GHz system using a total of 77 communications sattelites (7 in each of 11 polar orbits), which will provide global personal communication in the late 1990s.

By mid-1991, Motorola had designed and evaluated more than 250 different MMICs.

COMPANY EXECUTIVES

VP, R&D Laboratories Director
Bertrand Cambou

GaAs R&D Director
John Escher

Opto Marketing Director
Dean Walters

Opto Operations Manager
David Stevenson

PROCESS TECHNOLOGY

Motorola has two GaAs processes in R&D. The first is a 1.0-micron recessed gate process.

The Company also has a 0.35-micron GaAs MESFET process called MAFET and GaAs opto technology. Other processes include 0.8- and 0.5-micron MESFET and 0.6- and 0.25-micron MODFET.

PRODUCTS

Motorola offers infrared (IR) optoelectronics devices including IR emitters, photodetectors, optocouplers, optoisolators, and related products. The company is expected to enter the GaAs IC market by the mid-1990s.

FACILITIES

The corporate research center has approximately 65 people assigned to GaAs R&D. Size of the fab space is not available. The company has invested $100 million in a facility

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Motorola Inc.

that is expected to produce analog GaAs ICs by January 1992. Starting with 4-inch wafers, the plant will ultimately use 6-inch wafers as they become viable. Motorola also produces GaAs opto devices at its East Kilbride, Scotland, and Phoenix, Arizona, facilities.

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NEC Corporation

33-1, Shiba 5-chome
Minato-ku, Tokyo 108, Japan
Tel: (03)454-1111
Fax: (03)798-1510

ESTABLISHED: 1899 NO. OF EMPLOYEES: 114,599

BACKGROUND

NEC was founded in 1899 as a manufacturer of telephone sets and switchboards. Initial capitalization came from what later became Western Electric Company. NEC has nine operating groups that cover its four major areas of business, which are communications, computers and industrial electronic systems, electron devices, and home electronics.

NEC is one of the top five international suppliers of communications and computing equipment and services and is the number one manufacturer of semiconductors in the world. The Company is positioned to pursue the ECL-compatible GaAs digIC merchant market, ahead of most U.S. GaAs suppliers; sample digICs were first offered in February 1986 at a cost of approximately $250 each (about twice that of ECL 100K devices). The first GaAs digICs in large-volume production at NEC were prescalers.

California Eastern Labs (CEL) is the exclusive North American agent for NEC microwave semiconductors. The CEL product offerings include GaAs FETs and HEMTs, diodes, MMICs, digICs, and microwave hybrids.

NEC participated in the AIST/MITI Japanese national supercomputer project sponsored by NEDO, which resulted in a GaAs-based prototype supercomputer system demonstrated in January 1990.

COMPANY EXECUTIVES

Chairman
Atsuyoshi Ohuchi

President
Tadahiro Sekimoto

Head of Marketing
Kanji Sugihara

STRATEGIC ALLIANCES AND FINANCIAL BACKING

NEC is a member of the Sumitomo Group. This group began as a zaibatsu more than 100 years ago and was the third largest in Japan by 1941. NEC is the only electronics company of the 21 nucleus companies in the White Waters Club (Hakusui-Kai) of the Sumitomo Group.

The major shareholders of NEC are Sumitomo Life Insurance (6.9 percent), Sumitomo Trust and Banking (5.1 percent), Sumitomo Bank (4.6 percent), Nippon Life Insurance (3.6 percent), Dai-Ichi Mutual Life Insurance (3.2 percent), Sumitomo Marine and Fire Insurance (2.6 percent), and Toyo Trust (2.3 percent). Foreign ownership of NEC is 7.4 percent.

NEC has licensing or technology-sharing agreements with Corvus, Digital Research Corporation, Hewlett-Packard, Matra-Harris Semiconducteurs, Oki, Sharp, Sony, Sophia Systems, Standard Microsystems Corporation, Tektronix, Texas Instruments, and others.

From 1981 to January 1990, NEC, Fujitsu, Hitachi, Mitsubishi, Oki, and Toshiba jointly developed a GaAs-based prototype supercomputer system.

PROCESS TECHNOLOGY

Submicron GaAs MESFET and HEMT
InP
Other III-V compound semiconductor processes

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NEC Corporation

PRODUCTS

GaAs MMICs, digICs, and OEICs
Optocouplers
LEDs
Lasers
Detectors
Small-signal and power transistors—GaAs and silicon

FACILITIES

Tamagawa plant—R&D
Kagoshima plant—optoelectronics, discretes, others
Kyushu Denshi (Kumamoto)—LED fab, others

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N.V. Philips Gloeilampenfabrieken

Components Division
P.O. Box 218, 5600MD
Eindhoven, Netherlands
Tel: (040) 72 4173
Fax: (040) 72 2861

ESTABLISHED: 1891 (Parent Company) NO. OF EMPLOYEES: NA

Philips Microwave Limeil

GaAs Foundry and ASIC Design Center
22 avenue Descartes
94453 Limeil-Brevannes Cedex, France
Tel: (+33) 1.45.69.96.10
Fax: (+33) 1.45.69.44.77

ESTABLISHED: 1970 NO. OF EMPLOYEES: NA

BACKGROUND

N.V. Philips Gloeilampenfabrieken (Philips) was founded by Gerard Philips in 1891 to make carbon-filament lamps. The Company established its Physical Research Laboratory in 1914. Philips performs basic research in many areas including III-V compound semiconductors. The Company supplies internal needs and participates in the merchant market for LEDs, lasers, MICs, MMICs, discrete FETs, and digICs. It operates a GaAs foundry and ASIC design center in Limeil, France.

The Company has an agreement with Cray Research involving GaAs SRAMs for supercomputer applications. This activity is under way at LEP (France). The effort resulted in a 1K ECL-compatible design that operates at 2ns cycle time and dissipates 200mW.

Amperex, a wholly owned subsidiary of Philips that markets Philips semiconductors in the United States, changed its name to North American Philips Electronics Corporation in 1989.

COMPANY EXECUTIVES (N.V. Philips)

Managing Director
W. de Kleuver

Technical Director
J.C. Stuve

Marketing Manager
A. Baan

STRATEGIC ALLIANCES

Philips owns 35 percent of Matsushita Electronics Corporation; N.A. Philips Trust, which owns Signetics; LEP (France); and North American Philips Electronics Corporation.

SERVICES

Full-service foundery
ASIC design center

PROCESS TECHNOLOGY

GaAs, GaAlAs, and other III-V MESFET and HEMT processes
0.7u DCFL GaAs MESFET IC
0.7u ERO7AD GaAs analog low power and digIC

PRODUCTS

Small-signal and power GaAs FETs
LEDs, including IR emitters and detectors

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N.V. Philips Gloeilampenfabrieken

Laser diodes, CW and pulsed
Optocouplers
Opto discretes and OEICs
GaAs ICs including custom and ASICs
GaAs MMICs

FACILITIES

Philips produces GaAs opto devices at its plant in Stadskanaal, Netherlands.

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Oki Electric Industry Co. Ltd.

7-12, Toranomon 1-chome
Minato-ku, Tokyo 105, Japan
(03) 501-3111
Telex: 0222 6324 OKIDEN J

ESTABLISHED: 1881 NO. OF EMPLOYEES: 19,331

BACKGROUND

Oki Electric Industry Co., Ltd. (Oki), was founded in 1881 as a telephone manufacturing company by Kibataro Oki, a maker of traditional Japanese swords and armor. In 1916, the Company began quantity production of radio communications equipment. Oki first manufactured semiconductors in the early 1960s; it was the first Japanese company to produce green LEDs. Today, the Company is a leading supplier of telecommunications systems, EDP systems, and electronic devices, including semiconductors, in more than 100 countries.

Oki views GaAs and other new materials as instrumental in achieving major advances in semiconductor technology. One of its overall strategies is to advance ICs based on GaAs technology to mass production. Its R&D effort has included development of an 8x8 GaAs multiplier using W-Al gates for yield enhancement. Oki has done work on HEMTs for operation at liquid nitrogen temperatures with recorded propagation delays of 27ps per gate.

Oki participated in the AIST/MITI Japanese national supercomputer project sponsored by NEDO, which resulted in a GaAs-based prototype supercomputer system.

COMPANY EXECUTIVES

(GaAs ACTIVITIES)

Chairman
Namio Hashimoto

President
Nobumitsu Kosugi

Executive Vice President/General Manager, Electronic Devices Group
Masao Nogami

Director/General Manager, Marketing Division
Yoji Tanaka

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Oki is a member of the Fuyo Group, started after World War II and composed of companies having close financial relations with Fuji Bank. The group's policy-making council (Fuyo-Kai) is made up of the presidents of the 29 group companies. Marubeni is the Fuyo Group's central trading company.

Major shareholders of Oki are Yasuda Mutual Life Insurance (7.8 percent), Meiji Mutual Life Insurance (5.8 percent), Dai-Ichi Mutual Life Insurance (5.4 percent), Fuji Bank (4.1 percent), and Yasuda Trust and Banking (4.0 percent). Foreign ownership is 2.1 percent.

Oki has technology-sharing and licensing agreements with AT&T (GaAs ICs), Catalyst Semiconductor, Intel, Silicon Systems, Thomson-CSF, Voest Alpine AG (Austria), and others.

From 1981 to January 1990, Oki, Fujitsu, Hitachi, Mitsubishi, NEC, and Toshiba jointly developed a GaAs-based prototype supercomputer system.

PROCESS TECHNOLOGY

Oki uses III-V compound processing including GaAs, GaAlAs, GaAsP, and others.

PRODUCTS

Optoelectronic devices including LEDs
GaAs ICs including multiplexers and demultiplexers

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Oki Electric Industry Co. Ltd.

FACILITIES

Hachioji
  GaAs fab, assembly, and test capabilities
Chichibu (Tokyo)
  Optoelectronics, other

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Optek Technology Inc.

1215 West Crosby Road
Carrollton, TX 75006
Tel: 214/323-2200
Fax: 214/323-2392

ESTABLISHED: 1979 **NO. OF EMPLOYEES: 1,800**

BACKGROUND

Optek Technology Inc. was founded by James D. Crownover in 1979 as Crown Semiconductor Inc. to design, develop, and manufacture optoelectronic products for military and commercial markets. The Company was reincorporated in Delaware in August 1984, at which time it changed its name to Optek Technology Inc. Optek's sales in 1986 exceeded $11 million. The Company has more than 200 active customers and is now the largest manufacturer of IR optoelectronics products in the world.

Optek became a public company with an initial offering of 900,000 shares offered to the public at $6 per share in July 1987. There were 2.165 million shares of common stock outstanding and held of record by 94 stockholders as of May 1, 1987. The Company's authorized capital stock was 12 million shares of common stock and 1 million shares of preferred stock as of July 23, 1987.

In July 1988, Optek acquired TRW Optoelectronics, which added approximately 1,400 employees and 326,000 square feet of facilities. In 1989, corporate headquarters were relocated to the current address. In 1991, Optek consolidated its *Maquiladora* into a single facility in Zaragosa, Mexico.

COMPANY EXECUTIVES

Chairman
James D. Crownover (formerly Cofounder and Senior Vice President, Spectronics)

President and CEO
Tom Filesi (formerly of Motorola)

Executive Vice President, General Manager, and Secretary
Tom L. Barnes (formerly Manager of Inventory Control, TRW/Optron)

Vice President, Finance, and Treasurer
James M. Barry (formerly Vice President and CFO, OptoSwitch, Inc.)

Assistant Secretary
Mary Sanderford (formerly of Optek)

Director of Commercial Engineering
Richard G. Dahlberg (formerly Director of Engineering, C&F Tooling, Inc.)

Director of Commercial Sales
Jim Trautwein

Director of Distributor Sales
Wayne Davis

Director
Rodes Ennis

Director
Grant Dove

Director
Michael Cahr

Director of Military Sales
William Hoff

Director of International Sales
Cornelius Clark

SERVICES

The Company provides custom chip design and fabrication services.

PROCESS TECHNOLOGY

Optek uses GaAs, GaAlAs, and silicon processes.

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Optek Technology Inc.

PRODUCTS

LEDs
Emitters, including visible and IR emitters
Sensors, including photosensors, reflective sensors, and Photologic and Hallogic sensors (Photologic and Hallogic are trademarks of Optek Technology, Inc.)
Optocouplers and optoisolators
Interrupters (slotted switches)
Hybrids
Fiber-optic LAN systems

FACILITIES

Carrollton, Texas
Corporate headquarters and wafer fab, totaling 205,000 square feet

McKinney, Texas
A 20,000-square-foot building on 1.7 acres housing administration, engineering, and fab

Dallas, Texas
Plastics molding shop comprising 10,000 square feet

Mineral Wells, Texas
Military processing and environmental test facility consisting of 50,000 square feet

Zaragosa, Mexico
Assembly facility (Optek's subsidiary beneficially owns a building used for assembly, operated as a *Maquiladora,* an official Mexican government term for a foreign-owned company operating under Mexican law.)

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Opto Diode Corp.

750 Mitchell Road
Newbury Park, CA 91320
805/499-0335
Fax: 805/499-8108

ESTABLISHED: 1981 **NO. OF EMPLOYEES: 13**

BACKGROUND

Opto Diode Corp. (ODC) was formed in 1981 by James Kim, formerly with Rockwell's Collins division in Dallas, Texas. ODC offers semicustom high-reliability devices made to customer specifications. The Company is occupying a 15,000-square-foot facility in Newbury Park, California.

ODC had $1 million in sales in 1985 from GaAs infrared LEDs for solid-state relay and optoelectronics markets. Future plans are to penetrate the U.S. military market and European market.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
*James Kim
Rockwell, Sr Research Engr—Science Center

Sales Manager
Russell Dahl

*Founder

PROCESS TECHNOLOGY

AlGaAs on GaAs

PRODUCTS

Aluminum Gallium Arsenide Infrared LEDs

FACILITIES

Newbury Park, CA
15,000 sq. ft.
Design, manufacturing

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Opto Tech Corp.

32 Industrial East 4th Road
Science-Based Industrial Park
Hsinchu, Taiwan
ROC
(035) 777-481/3
Telex: 31592 OPTO TECH

ESTABLISHED: December 1983 **NO. OF EMPLOYEES: 120**

BACKGROUND

Opto Tech is offering GaAs-based products, silicon wafers, and photoresistor and photodiode semiconductors. The Company plans to offer small-signal and transmitting transistors, junction FETs, microwave transistors, and fast-recovery and Schottky-barrier diodes. Production began in July 1984.

The Company spun off from Fine Microelectronics and is owned by local investors and the Bank of Communications.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
James Chiu
Petrochemical Industry, President

Business Liaison
S. Shyu

PROCESS TECHNOLOGY

GaAs
Silicon

PRODUCTS

LED
Transistors
Photodiodes
Phototransistors
Infrared Devices

FACILITIES

Hsinchu, Taiwan
9,175 sq. ft.

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OPTOTEK Limited

62 Steacie Drive
Kanata, Ontario, Canada K2K 2A9
Tel: 613/591-0336
Fax: 613/591-0584

ESTABLISHED: 1977 NO. OF EMPLOYEES: Approx. 35

BACKGROUND

OPTOTEK Limited was founded in 1977 to specialize in LEDs and associated electronics for military and commercial applications in North America, Europe, and Japan. In 1981, the Company began developing GaAs MMICs.

COMPANY EXECUTIVES

President
David Kennedy

Vice President of Operations
Gunnar Wareberg

Vice President of Marketing
David Kennedy, Acting

Director of R&D
Randy North

SERVICES

MMIC foundry
Ion implantation and annealing
Thick-film and thin-film hybrid packaging

PROCESS TECHNOLOGY

GaAs MESFET, 0.5-micron, selective ion implantation
HgCdTe processing

PRODUCTS

Infrared LEDs, visible LEDs, and LED arrays
Photovoltaic detectors
Custom MMICs and hybrids
MMIC design software

FACILITIES

The OPTOTEK facilities total 37,000 square feet of space, including Class 1,000/100 clean rooms.

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Ortel Corporation

2015 West Chestnut Street
Alhambra, CA 91803
Tel: 818/281-3636
Fax: 818/281-8231

ESTABLISHED: 1980 NO. OF EMPLOYEES: 125

BACKGROUND

Ortel Corporation is a privately owned company founded in 1980 by Dr. Israel Ury, Dr. Amnon Yarviv, and Dr. Nadav Bar-Chaim. Prior to 1980, the founders were at the California Institute of Technology. The Company makes a complete line of semiconductor lasers, detectors, and fiber-optic transmitters and receivers.

Ortel also performs government-sponsored R&D in ultrahigh-speed and integrated optoelectronics, high-power lasers and laser arrays, and phase conjugate optics. The Company has conducted R&D under contracts from DARPA, NRL, RADC, MICOM, and others.

COMPANY EXECUTIVES

President/CEO
Wim Selders

Vice President, Manufacturing
Claude Mathews

Vice President/CFO
Stephen Workman

Director of Marketing
Larry Stark

Chief Technology Officer
Israel Ury

Vice President/Sales
Bill Moore

Vice President/QA
Bob Mielke

SERVICES

R&D
Design
Manufacturing
Test

PROCESS TECHNOLOGY

The Company uses GaAs buried heterostructure technology.

PRODUCTS

GaAs lasers
Detectors
Fiber-optic transmitters and receivers at 840nm and 1,300nm with bandwidths to 12 GHz
Fiber-optic delay lines

FACILITIES

Alhambra, California
Corporate headquarters, R&D, and manufacturing facilities totaling 24,000 square feet, of which approximately 8,000 square feet are clean rooms (Class 100)

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Pacific Monolithics Inc.

245 Santa Ana Court
Sunnyvale, CA 94086
Tel: 408/732-8000
Fax: 408/732-3413

ESTABLISHED: March 1984 **NO. OF EMPLOYEES: 85**

BACKGROUND

Pacific Monolithics Inc. designs and manufactures MMICs based on GaAs, as well as microwave subsystems based on its GaAs MMICs. The Company offers more than 200 microwave macrocells (PM Cells) for semicustom IC design for consumer, communications, and defense applications. Company strengths include yieldtolerant design techniques, advanced packaging technology, a proprietary CAD/CAE system, and foundry services.

The Company participated as a team member on several contracts for the Department of Defense, including Phase 0 and Phase 1 of the MIMIC program. The contracts were in the areas of communication, radar, electronic warfare, and smart weapons for the army, navy, and air force.

Pacific Monolithics has developed a set of monolithic GaAs subsystem building blocks for microwave signal processing. The Company's ASIC cell library includes amplifiers, mixers, oscillators, couplers, combiners, switches, attenuators, phase shifters, modulators, and demodulators. By mid-1990, the Company had developed more than 1,500 MMIC device types for its customers.

In March 1986, the Company relocated from a 10,000-square-foot facility to a 22,000-square-foot facility that can be expanded by an additional 13,000 square feet. Currently, Pacific Monolithics uses several foundry services, including TriQuint and COMSAT.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
Chris Weseloh

Senior VP of Technology, Chairman
Allen Podell
A.F. Podell Assoc., President of Technology

VP, Finance and Administration
Erl Fossum

VP Business Development
Frank Russell
Avantek, Sales Mgr

VP Marketing and Sales
Ron Ruebusch

VP Engineering
Rick Gold

Manager, Special Projects
*Doug Lockie
Strategic Technology, Consultant

*Founder

PROCESS TECHNOLOGY

GaAs D-MESFET, E/D-MESFET, and HBT processes
0.2-micron and smaller gate lengths

PRODUCTS

Channelized Up/Down Converters
Converters
Amplifiers
Oscillators
Attenuators
Active Isolators
Phase Shifters
Switches
Synthesizers
TR Modules
Single-Chip Radars
Microwave Sensors
Expendable Countermeasure Subassemblies

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Pacific Monolithics Inc.

FACILITIES

Sunnyvale, CA
35,000 sq. ft.
Lab, manufacturing, administration
6,000 sq. ft.
Class 100 clean room

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Photonic Integration Research Inc.

2727 Scioto Parkway
Columbus, OH 43221-4658
Tel: 614/876-5655
Fax: 614/876-5726

ESTABLISHED: July 1987 **NO. OF EMPLOYEES:** 20

BACKGROUND

Photonic Integration Research Inc. (PIRI) was formed to develop basic optical IC technology for commercial applications. The Company is the result of a joint venture between Nippon Telegraph and Telecommunicat ions (NTT), Mitsubishi Electric Corporation of Japan, and the Batelle Memorial Institute. NTT owns 49 percent of the Company; Mitsubishi owns 41 percent; and Batelle owns 10 percent.

PIRI president, Dr. Tadashi Miyashita, was formerly head of the Optoelectronic Materials Section of the Electronics Materials Department at NTT's Ibaraki Electrical Communications Laboratories. Shin Sumida also was previously at NTT's Ibaraki Telecom munications Laboratories, where the optical IC technology was invented.

In addition to developing commercial applications for optical waveguide technology, PIRI also develops applied components that are made available to equipment manufacturers for use in such end products as optical communications equipment, optical measuring equipment, automobiles, and airplanes. The Company expects advancement in the technology to lead to greater miniaturization and increased utilization of fiber optics.

PIRI is located in the Batelle Memorial Institute's Columbus, Ohio, facilities.

COMPANY EXECUTIVES

(Position, Name, and Prior Company)

President
Dr. Tadashi Miyashita
NTT

Manager, Manufacturing
Dr. Shin Sumida
NTT

Manager, Photolithography
Michael Myers

PRODUCTS

Optoelectronic Devices
Custom-Design Optical Devices

FACILITIES

5,000 square feet of administration and R&D
16,000 square feet of manufacturing including 3,000 square feet of clean rooms (to Class 100)

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Quality Technologies Corporation,

Optoelectronics Division
610 North Mary Avenue
Sunnyvale, CA 94086
Tel: 408/720-1440
Fax: 408/720-0848

ESTABLISHED: 1979 NO. OF EMPLOYEES: Approx. 1,900

BACKGROUND

Quality Technologies Corporation (QTC) was previously a division of General Instruments (GI). In September 1987, GI sold its Optoelectronics Division to Quality Technologies Corp., a Palo Alto, California-based holding company, reportedly for $25 million.

The optoelectronics division's semiconductor products consist of discrete and opto devices, ICs including VLSI devices, and hybrids. QTC ranks among the top 10 suppliers of opto components worldwide.

COMPANY EXECUTIVES

Chairman
Robert L. Parker

President and CEO
Ralph Simon

Vice President of Special Projects
Walter P. Steward

Vice Chairman and General Counsel
Donald L. Coomber

Vice President, Finance & Administration
Edward M. Miller

Vice President, Marketing/Sales
Charles Bates

Managing Director
G.T. Tuan (Kuala Lumpur)

RECENT HIGHLIGHTS

In July 1991, QTC acquired the Harris Corporation Singapore-based optoelectronics operation, acquired by Harris from GE in 1988. The operation's annual volume was $16 million before the QTC acquisition.

PROCESS TECHNOLOGY

The Company uses GaAs and related III-V optoelectronic device processes.

PRODUCTS

LEDs—discrete and arrays
Opto isolators
Optocouplers
Optoswitches
III-V materials
IR custom assemblies

FACILITIES

Quality Technologies Corporation's Sunnyvale, California, facility has 12,000 square feet. Additional assembly facilities are located in Singapore and Malaysia.

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Raytheon Company

141 Spring Street
Lexington, Massachusetts 02173
Tel: (617)862-6600
Fax: (617)860-2172

ESTABLISHED: 1901 **NO. OF EMPLOYEES: Approx. 78,000**

Raytheon Monolithic Microwave Center (MMC)

362 Lowell Street
Andover, Massachusetts 01810
Tel: (508)470-9715
Fax: (508)470-9744

ESTABLISHED: 1978 (GaAs activities) **NO. OF EMPLOYEES: 250**

BACKGROUND

Raytheon Company designs, manufactures, and services advanced electronic devices, equipment, and systems for government and commercial customers. The company performs geophysical exploration; it designs and constructs petrochemical facilities, electrical generating plants, and business aircraft; and it produces and markets consumer appliances and heating/cooling equipment.

Raytheon MMC is a part of Raytheon's $150 million Advanced Device Center initiative. The Company's firsts in monolithic microwave IC (MMIC) technology include the following:

- First completely monolithic microwave ICs
- First GaAs MMIC transmit/receive (T/R) switch
- First GaAs MMIC phase shifter
- First MMIC traveling-wave amplifier

By 1991, the Raytheon MMC facility contained more than $17 million of GaAs wafer processing equipment.

COMPANY EXECUTIVES

Director of Marketing
Scott Stevens

Programs Mgr., Microelectronics Center
John Maxfield

STRATEGIC ALLIANCES

Raytheon is engaged in a joint venture with Texas Instruments; the joint venture is a prime contractor on the DARPA MIMIC Program, Phase 2.

SERVICES

Full-service GaAs foundry

PROCESS TECHNOLOGY

Raytheon MMC currently runs five processes:

- MMC-01, 2-micron gate length, 7GHz f_t for power applications
- MMC-02, 0.9-micron gate length, 15 GHz f_t

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Raytheon Company

- MMC-03, 0.5-micron gate length, 18 GHz f_t, X-band applications
- MMC-04, 0.5-micron gate length, 27 GHz f_t
- MMC-05, 0.5-micron gate length, 18 GHz f_t, wideband power

PRODUCTS

SPDT Switches
Low Noise Amplifiers
Variable Gain Amplifiers
Power Amplifiers
T/R Switches
Attenuators
Phase Shifters
Others

FACILITIES

The MMC in Andover has 17,312 square feet of clean room exceeding Class 100, 8,374 square feet of assembly and test area, and 16,815 square feet of office space. The facility can produce 25,000 processed wafers per year.

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Rockwell Microelectronics Technology Center (MTC)

2427 West Hillcrest Drive
Newbury Park, CA 91320
Tel: 805/375-1295
Fax: 805/375-1268

ESTABLISHED: 1975 NO. OF EMPLOYEES: 150

BACKGROUND

Rockwell International is a multi-industry corporation engaged in R&D and the manufacture and sale of products for government and commercial markets. It was the prime contractor for the B1 bomber. Its principal space activity is the space shuttle program for NASA.

Rockwell developed the first DOD-sponsored GaAs foundry capability via DARPA and other funding. The cost of the facility was $16 million. Its production schedule was 100 3-inch wafers per shift per week in 1989 with a total planned capacity of 250 wafers per shift per week. The plant includes LEC crystal production, wafer prepara tion, device R&D, CAD systems, and complete fab capabilities.

In 1991, Rockwell added more than $1 million in CAD equipment. The Company will announce HBT products in early 1992.

COMPANY EXECUTIVES

MTC Business Director
Jai Haku

GaAs Product Marketing Director
Deepak Mehrotra

Operations Director
Mike McCoy

Director of Finance
David Price

Engineering Director
Gus Kinoshita

STRATEGIC ALLIANCES

IBM and Rockwell have a GaAs technology exchange agreement.

Rockwell MTC is a member of the Hughes team on DARPA's MIMIC program Phase 2.

SERVICES

The Company operates a full-service GaAs foundry.

PROCESS TECHNOLOGY

The Company uses 4-inch wafer, 0.5µ GaAs MESFET and 3-inch wafer, 1.4µ HBT technology.

PRODUCTS

MMICs
DigICs, including 16K SRAMs
6,000-gate arrays for operational use by DARPA
Optoelectronic devices

FACILITIES

Rockwell MTC's Newbury Park, California, facilities have more than 70,000 square feet, including 12,200 square feet of controlled environment, and 5,240 square feet of Class 10 clean rooms.

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Sharp Corporation

22-22 Nagaike-cho
Abeno-ku, Oaska 545, Japan
Tel: (06)621-1221
Fax: 6117-725300

ESTABLISHED: 1912 NO. OF EMPLOYEES: 24,079

BACKGROUND

Sharp Corporation was founded in 1912 by Tokuji Hayakawa. The Company is named after its first product, the Ever-Sharp pencil, invented by the founder. The Company's business operations cover development, production, and marketing of products including consumer appliances, office equipment, industrial equipment, and electronic components. Sharp is a leader in electronic calculators, including solar-powered models.

Sharp claims that it developed the first GaAs visible LED (in 1964). In 1985, Sharp developed a GaAs laser for continuous operation at 680nm at room temperature. The laser has a threshold current of 100mA and an optical power output of 5mW. Laser development is continuing at Sharp.

The Company entered the GaAs FET market in March 1986 with its LT300, a 1-GHz small-signal amplifier.

COMPANY EXECUTIVES

President/CEO
Haruo Tsuji

Head of Marketing
Kosaku Okano

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Sharp Corporation is a member of the Sanwa Group. Sharp's president is on the Sanwa Group's 42-company policy-making council called Sansui-Kai (Third Wednesday Conference).

The Company's eight major shareholders are Nippon Life Insurance Company (5.3 percent), Fuji Bank (4.4 percent), Daiwa Bank (4.2 percent), Sanwa Bank (4.0 percent), Yasuda Mutual Life Insurance Company (3.9 percent), Dai-Ichi Mutual Life Insurance Company (3.8 percent), Sumitomo Life Insurance Company (3.5 percent), and Taisho Marine and Fire Insurance (2.8 percent). Foreign stock ownership is 4.2 percent.

Sharp has technology-sharing or licensing agreements with NEC, RCA, Rockwell, Samsung (South Korea), WaferScale Integration, Zilog, and others.

PROCESS TECHNOLOGY

AlGaAs and other III-V VPE and MOCVD on GaAs wafers
GaAs MESFET: submicron

PRODUCTS

The Company produces GaAs FETs and optoelectronic devices including photocouplers, interruptors, photo relays, LEDs, LED arrays, and lasers.

FACILITIES

Nara factory (established 1964)
Discrete and opto fab, assembly, and test
Shinjo factory (established 1981)
Opto fab and test

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Siemens GmbH

Munich, Germany

ESTABLISHED: 1847 NO. OF EMPLOYEES: 363,000

Siemens Components Inc.

186 Wood Avenue South
Iselin, NJ 08830

ESTABLISHED: 1982 NO. OF EMPLOYEES: 20

Siemens Optoelectronics Division

19000 Homestead Road
Cupertino, CA 95014
Tel: 408/257-7910
Fax: 408/725-3439

ESTABLISHED: 1977 NO. OF EMPLOYEES: 190

BACKGROUND

Siemens is a leading international manufacturer of electric and electronic products and systems; its annual sales exceed $17 billion. More than 50 percent of its equipment and systems sales are derived from developments completed within the last five years. Siemens maintains facilities in 128 countries and employs more than 320,000 persons.

The Company's subsidiary, Siemens Components Inc. has four U.S. subsidiaries, including the Optoelectronics Division (formerly Litronix). Siemens Components has an advanced circuit research lab in Princeton, New Jersey. Siecor, Siemens' joint venture with Corning, is second only to AT&T in terms of kilometers of optical cable in service. Siemens owned and operated MSC (Microwave Semiconductor Corporation) until late 1988, at which time it discontinued MSC's GaAs operations and sold the silicon discrete operations.

The Optoelectronics Division was acquired by Siemens in 1978. The division designs, manufactures, and markets a wide range of opto components including LEDs, LED displays, more than 50 types of optocouplers, and more than 100 different IR devices. Its line of displays is self-contained, using LED and CMOS chip tech nology and requiring no external logic.

COMPANY EXECUTIVES (OPTOELECTRONICS DIVISION)

Senior Vice President/General Manager
Peter Albus

Vice President, Engineering
Ed Insel

Director of Marketing
Chuck Berghoff

PROCESS TECHNOLOGY

Siemens GmbH uses GaAs and other LED-related III-V processes.

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Siemens GmbH

PRODUCTS

GaAlAs LEDs including high-intensity GaAsP LEDs
LED displays
IR devices

FACILITIES

Munich, Germany
830,000 square feet
Primarily silicon wafer fab and test; includes R&D labs and some GaAs production

Regensburg, Germany
250,000 square feet
Opto device production

Cupertino, CA
55,000 square feet
Opto device production

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Solid State Optronics Inc.

1440 Koll Circle, Suite 107
San Jose, CA 95112-4609
408/436-1390
Fax: 408/436-1392

ESTABLISHED: June 1982 **NO. OF EMPLOYEES:** 11

BACKGROUND

Solid State Optronics Inc. designs and manufactures solid-state relays, photoresistors, and thyristors. The Company was founded by Zag Kadah in 1982. Prior to founding the Company, Mr. Kadah was employed at Electro-Trol Inc. as vice president in charge of the optoelectronics division. In 1979, Mr. Kadah founded Power Interface, a company that pioneered the development of an IC to drive back SCRs in solid-state relays.

The Company subcontracts manufacturing to a company in Asia; assembly is done in the Philippines.

COMPANY EXECUTIVES

(Position, Name, and Prior Company)

President
*Zag Kadah
Elec-Trol, Inc.

Marketing
Sid Kadah
UC Berkeley

Financial Officer
Fay Kadah
Magnex

*Founder

PROCESS TECHNOLOGY

Bipolar
Dielectric isolation
DMOS
GaAs and GaAlAs

PRODUCTS

Input/Output Modules
Interrupters
Photodiodes
Photo Arrays
Silicon Photo Detectors
Solid-State Relays
Hybrid Optoelectronic Modules

FACILITIES

San Jose, CA
1,200 sq. ft.
R&D, design, engineering, and assembly

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Sony Corporation

7-35 Kitashinagawa 6-chome
Shinagawa-ku, Tokyo 141, Japan
Tel: (03)448-2111
Telex: SONYCORP J22262

ESTABLISHED: 1946 **NO. OF EMPLOYEES: Approx. 100,000**

BACKGROUND

Sony was founded in 1946 by Masaru Ibuka and Akio Morita. The name Sony was adopted in 1958. Sony has many marketing firsts including: the first all-transistor radio in Japan (1955), the first transistor television (1960), the first VTR (1963), the first IC radio (1966), Walkman (1979), and Discman (1985). As a result of the negative impact of sluggish consumer sales, the Company plans to reduce its dependence on consumer electronics from 50 percent in 1986 to 20 percent by the end of 1990. Akio Morita remains chairman of Sony.

Sony entered the merchant semiconductor market in 1983. Also in 1983, the Company reported results of R&D and successful testing of a GaAs JFET chip containing 511 DCFL gates organized as a 4x4 multiplier, 10b accumulator, and 8b shift register.

Sony is constructing a 1.7-million-square-foot GaAs manufacturing facility in Miyagi Prefecture. The $51 million investment includes assembly and provision for adding a GaAs wafer fab by 1994.

COMPANY EXECUTIVES

President/CEO
Norio Oga

Managing Director/Senior General Manager, Semiconductor Group
Masahiro Takahashi

Head of Marketing
Fumio Kono

STRATEGIC ALLIANCES

In December 1984, Sony licensed MLEC crystal growth to Monsanto.

In February 1986, Sony and AMD announced a joint technology development program that includes development of common process technology and marketing of each other's products under their own company names.

Sony and TriQuint (Tektronix) entered into a technology agreement on GaAs ICs in 1988.

PROCESS TECHNOLOGY

GaAs JFET
MESFET
VPE and MOCVD epi processes

PRODUCTS

Optoelectronic devices including LEDs and lasers
Analog ICs
MMICs

FACILITIES

Atsugi factory
GaAs, R&D, laser fabrication, other
Kawasaki plant
Miyagi plant
1.7 million sq. ft.
GaAs assembly operations by 1992 and future GaAs wafer fab

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Spectra Diode Labs

80 Rose Orchard Way
San Jose, CA 95134
Tel: 408/943-9411
Fax: 408/943-1430

ESTABLISHED: 1983 NO. OF EMPLOYEES: NA

BACKGROUND

Spectra Diode Labs (SDL) originated as a joint venture of Spectra-Physics Inc. and Xerox Corporation. The Company has pioneered development of high-powered laser diodes. Research at Xerox PARC, begun in 1971, let to such developments as MOCVD, the first cw phased array laser diodes, and efficient MQW structures. In 1988, Ciba-Geigy purchased the Spectra-Physics share of SDL. Future product focus will be in highpower and high-brightness cw and pulsed GaAlAs lasers.

In October 1990, SDL retained Saloman Brothers to investigate the sale of the Ciba-Geigy share, the Xerox share, or both shares of the company.

COMPANY EXECUTIVES

President/CEO
Don Scifres

Director, Advanced Research
Dave Welch

Director, Marketing
David Evans

Business Manager
John Milton

STRATEGIC ALLIANCES

Spectra-Physics Inc.
Xerox Corporation

SERVICES

Custom design, development, and production—commercial and military
R&D contracts—government and commercial

PROCESS TECHNOLOGY

GaA1As MQW and SQW
MOCVD

PRODUCTS

SDL produces a family of more than 110 types of GaA1As high-power laser diodes up to 10 watts cw and 1.5KW pulsed.

FACILITIES

SDL has a 42,000-square-foot facility located in San Jose, California.

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Stanley Electric Co. Ltd.

9-13 Nakameguro, 2 chome
Meguro-ku, Tokyo, Japan
Tel: (03)710-2222
Fax: (03)792-0007

ESTABLISHED: 1933 NO. OF EMPLOYEES: 4,978

BACKGROUND

Stanley Electric Co. Ltd. is the leading supplier of electrical equipment for automobiles in Japan. The Company is considered the leader in the highbrightness segment of the LED market. The Company began marketing super-bright LEDs (300 to 1,200 millicandela) in 1982.

COMPANY EXECUTIVES

Chairman
Takaoki Kitano

President/CEO
Toru Tejima

Head of Marketing
Shuji Kobayashi

FINANCIAL BACKING

The major shareholders in Stanley Electric include Nippon Life Trust (5.6 percent), Mitsui Trust (4.7 percent), Honda (4.6 percent), Mitsui Bank (4.4 percent), and others.

PROCESS TECHNOLOGY

The Company uses GaAs and related III-V processes.

PRODUCTS

The Company produces LEDs and other opto devices.

FACILITIES

Stanley Electric's plant is in Hatano.

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Telcom Devices Corporation

914 Tourmaline Drive
Newbury Park, CA 91320
805/499-0611
Fax: 805/498-0242

ESTABLISHED: 1986 **NO. OF EMPLOYEES: 12**

BACKGROUND

Telcom Devices Corporation was formed in early 1986 to offer InGaAs photodiodes and indium gallium phosphide (InGaP) LEDs.

Founders James Kim, Ock-Ky Kim, and Larry Perillo are former Rockwell engineers. Telcom Devices is a subsidiary of Opto Diode Corp. (ODC) and is operating from ODC's facilities in Newbury Park, California. Both companies share clean room and manufacturing space.

Telcom Devices began volume production of its first products in May 1986. The products were InGaAs PIN photodiodes for fiber-optic applications and included the Planar 13PD100 and Planar 15PD100.

In mid-1991, Telcom Devices introduced the world's largest photodetector.

COMPANY EXECUTIVES

(Position, Name, and Prior Company)

Chairman/CEO
*James Kim
Rockwell

President
Doug Holmes
Rockwell

VP Engr
Hidehiko Kuwamoto

*Founder

PRODUCTS

InGaAs Photodiodes
Long-Wavelength LEDs
Photodetectors—5mm diameter

FACILITIES

Newbury Park, CA
10,000 sq. ft.
Administration, manufacturing

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Teledyne Monolithic Microwave

1274 Terra Bella Avenue
Mountain View, CA 94043
Tel: 415/493-1770
Tel: 415/962-6893 (Applications)
Fax: 415/968-6533

ESTABLISHED: 1984 NO. OF EMPLOYEES: 22

BACKGROUND

Teledyne Monolithic Microwave (TMMIC) was founded by Teledyne MEC, a subsidiary of Teledyne, Inc. Teledyne MEC manufactures microwave devices for use in electronic countermeasures. Teledyne, Inc., is a vertically integrated corporation involved in four major areas of work: aviation and electronics; machines and metals; engines, energy, and power; and commercial and consumer.

Teledyne MEC is supporting TMMIC in establishing a technical and business base, in preparation for TMMIC to spin off as an independent company. TMMIC introduced its first product, a 2- to 18-GHz MMIC amplifier, in 1986.

Teledyne is a member of the Raytheon/Texas Instruments team, which received Phase I and Phase 2 awards under the DARPA-sponsored MIMIC program.

COMPANY EXECUTIVES

President, Teledyne Microwave
Dr. James Ewan

VP, MMIC Operations
Dr. Steven Ludvik

Director, Applications
Dr. Robert Mandel

Contracts Manager
Carole Taylor

SERVICES

Design
Manufacturing

PROCESS TECHNOLOGY

The Company uses GaAs MESFET technology.

PRODUCTS

The Company produces MMIC subsystems utilizing GaAs MESFET technology that operate at microwave and/or millimeter-wave frequencies.

FACILITIES

The Teledyne Monolithic Microwave plant is approximately 15,000 square feet, including a 4,000-square-foot design center and a 6,000-square-foot clean room in Mountain View, California. No wafer fab is included at this facility.

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Telefunken Electronic GmbH

P.O.B. 1109
Theresienstrasse 2
7100 Heilbronn
Germany
Tel: (07131)67-0
Fax: (07131)67-2340

ESTABLISHED: 1982 NO. OF EMPLOYEES: 6,200

BACKGROUND

Telefunken Electronic GmbH began as an alliance of United Technologies Corporation (Hartford, Connecticut) and AEG-Telefunken (Heilbronn, Germany). AEG-Telefunken was founded in 1893; in 1979, it faced bankruptcy after it lost a nuclear power contract. Subsequently, it was rescued by a group of West German banks. In 1988, AEG-Telefunken repurchased its stake; that was sold to UTC in 1982 for an undisclosed sum.

Total worldwide sales of semiconductors by Telefunken Electronic GmbH exceed $275 million annually, of which approximately 40 percent are optoelectronic and other compound semiconductor sales.

COMPANY EXECUTIVES

Managing Director
Frank Dieter Maier

Technology Director
Klaus Bomhardt

Marketing Manager
F.G. Hohne

PROCESS TECHNOLOGY

GaAs and AlGaAs VPE on GaAs, GaP, and other compound wafers

PRODUCTS

Opto devices including lasers, detectors, optocouplers, and visible and IR LEDs
GaAs MESFETs
GaAs microwave ICs
Fiber-optic transmitters and receivers
Solar cells and solar panels

FACILITIES

Heilbronn, Germany
Braunau, Austria
Vocklabruch, Austria
Manila, Philippines

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Texas Instruments Inc.

13500 N. Central Expressway
Dallas, TX 75265
Tel: 214/995-2011 (Headquarters)
Tel: 214/997-3300 (Opto Marketing)
Tel: 214/995-6462 (Foundry)
Fax: 214/995-4288 (Foundry)

ESTABLISHED: 1960 (GaAs materials work)
1973 (GaAs FETs)
1986 (Foundry services)

NO. OF EMPLOYEES: 74,000

BACKGROUND

Texas Instruments Inc. (TI) is a vertically integrated producer of semiconductor materials, devices, and circuits; electronics; and other hardware including instrumentation, calculators, radar systems, ordnance, computers, and terminals. TI's Central Research Lab (CRL) has done work in GaAs technology for more than 25 years. By 1975, TI had demonstrated 8- to 10-GHz FETs. In 1982, the Company's Defense Systems and Electronics Group (DSEG) established a pilot production capability for MMICs and discrete power devices capable of operation to 18 GHz. CRL has pushed analog GaAs circuit operating frequency to more than 100 GHz and is developing a 4K ECL-compatible SRAM. CRL demonstrated a 1K SRAM with the smallest cell reported as of November 1985.

TI has invested more than $150 million in GaAs design and production facilities and continues investing several million dollars per year. One of its products, the TGA8014, is claimed to be the first true power amplifier available as a GaAs MMIC, delivering 400mW from 6 to 18 GHz. In 1987, TI reported performance and yield data on its single-chip X-band radar transceiver, which contains a fourbit phase shifter, three-stage LNA, and four-stage power amp.

The TI/Raytheon joint venture is developing 14 GaAs ICs under the MIMIC initiative; six are for EW applications, four are for use at 20 to 50 GHz, and four are for radar applications. The team received a Phase 2 award in August 1991.

COMPANY EXECUTIVES

Laboratory Director
Dr. Dean Collins (Central Research Laboratories)

Associate Laboratory Director
Dr. William R. Wisseman (Central Research Laboratories)

Optoelectronics Marketing Director
Milt Hogan

Foundry Operations Manager
Ray Toole

Manager Foundry Services
Steve Lazar

MMIC Marketing Manager
Paul Schurr

STRATEGIC ALLIANCES

TI and Raytheon have a joint venture in GaAs technology; the joint venture was awarded Phase 0, Phase I, and Phase II contracts under the U.S. DOD MIMIC initiative.

SERVICES

TI provides a full-service GaAs MMIC foundry.

PROCESS TECHNOLOGY

0.5μ and 0.25μ GaAs MESFET on ion-implanted 3-inch wafers (foundry)

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Texas Instruments Inc.

Four doping profiles: power, low-noise, low-current, intermediate, and low-noise high-current
E-beam lithography
4μ gold plated transmission lines and air bridges

PRODUCTS

Opto devices including LEDs, displays, and optocouplers
LNAs and power FETs:
- TGA monolithic amplifier series
- TGF GaAs FET series

Single-chip radar transceivers
Custom digICs including RISC microprocessors
MMICs

FACILITIES

In Dallas, Texas, TI has a 9,000-square-foot clean room at DSEG with capacity for more than 100 3-inch GaAs wafer starts per week. The single shift baseline is 10 lot starts per week.

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Thomson-CSF GaAs Department

Route Departmentale 128
BP48
91401 Orsay Cedex
France
(1)6019 7000

Thomson Composants Microondes

Grenoble, France

ESTABLISHED: 1968 NO. OF EMPLOYEES: 430

BACKGROUND

Thomson-CSF is a vertically integrated high-technology company dedicated to R&D of advanced manufacturing technology and to the manufacture of electronic equipment and systems. The Mitterand government has taken a significant interest in Thomson-CSF as part of the government's restructuring of French industry.

Thomson produces its own GaAs crystals, wafers, and discrete and IC semiconductors. It has about 250 employees involved in GaAs device development and production. Thomson has used 2-inch wafers since 1983 and 3-inch wafers since 1986. In 1988, the Company added a fab line with capacity for 50 2-inch wafers per week. Thomson's GaAs facilities supply 80 percent of the Company's internal needs for military and communications end-equipment usage of compound semiconductors. Sales in 1990 exceeded $60 million, including modules.

Thomson-CSF is a stakeholder in ANADIGICS (Warren, New Jersey) and in Vitesse Semiconductor Corporation (Camarillo, California). Both are U.S.-based GaAs IC companies.

COMPANY EXECUTIVES

Director
John Magarshack

VP Mktg & Sales
Herve Charlin

Manager, Hybrid Strategy
Francois Bizec

STRATEGIC ALLIANCES

Thomson-CSF Ventures invested $3 million in ANADIGICS in mid-1988 and another $3 million in 1989. It also invested an unspecified amount in Vitesse Semiconductor Corporation in October 1990.

SERVICES

GaAs MMIC and digIC foundry
Training in custom GaAs IC design
VPE and MOCVD epitaxial services
Wafer testing
JANTX-V equivalent military screening

PROCESS TECHNOLOGIES

0.8µ E/D-MESFET
0.7, 0.5µ D-MESFET
0.5µ, 20-GHz MESFET
0.25µ MESFET and HEMT
Ion implantation
Air-bridge interconnects

PRODUCTS

GaAs and InP diodes—power generation, receiving, and control
GUNN diodes to 100 GHz
GaAs FETs—power and low noise
Low-noise HEMTs to 40 GHz
MMICs
Linear GaAs ICs
BFL, SCFL, and DCFL logic devices
Second source of all Vitesse GaAs ICs
Hybrid microwave ICs

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Thomson-CSF GaAs Department

FACILITIES

Thomson-CSF has 13,000 square meters including 2,000 square meters of Class 100 clean rooms.

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Three-Five Systems Inc.

10230 S. 50th Place
Phoenix, AZ 85044
602/496-0035
Fax: 602/496-0168

ESTABLISHED: April 1985 **NO. OF EMPLOYEES: 110**

BACKGROUND

Historically, Three-Five Systems Inc. produced and marketed custom and semicustom products that combine silicon and GaAs technologies for the consumer, industrial, telecommunications, and computer markets. The Company's main product thrust now is custom user interface modules utilizing LED, LCD, and keyboard components.

The Company is headquartered in a 40,000-square-foot facility in Phoenix, Arizona. The facility houses all corporate functions as well as a quick-turn prototype manufacturing area. In 1987, Three-Five consolidated its domestic operations in Phoenix, Arizona, and eliminated a facility in Troy, New York.

The Company was formed via a leveraged buyout of National Semiconductor's Optoelectronics business unit and was named Three-Five Semicon ductor. The Company's founders are Frank Shroff, John Gragg, Dennis Riccio, Joe Riccio, and Brent Fox. Three-Five received acquisition funding, which was completed in December 1985, from Continental Illinois Venture Corporation (Chicago, Illinois) and OptoVen of Phoenix, an investment company formed specifically to invest in Three-Five.

In 1987, the Company changed its name from Three-Five Semiconductor Corporation to Three-Five Systems to reflect a shift from a front-end semiconductor emphasis to a broader systems approach. The Company has reorganized into two groups. The optoelectronics group supplies all existing and future standard products, and the display group is responsible for application-specific integrated displays (ASIDs) as well as other technologies that may be added. In September 1987, Three-Five raised $5.5 million in second-round financing, which was used to expand its technical staff and facilities to support the Company's thrust into new opto product areas. In March 1988, Three-Five initiated a further round of financing to support the Company's thrust into LCDs.

Currently, 400 products that were developed by the Company while it was a division of National are offered by Three-Five and include infrared and custom devices. New products include custom LCDs. In the long term, the Company will focus on PLCDs and GaAs-based products, optoelectronics (standard and custom), and integrated optoelectronic ICs. The Company will also focus on display systems, such as LED and LCD, with a higher degree of electronic control.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
David R. Buchanan
Talos Systems (now Calcomp Digitizer Division), Founder/Chairman/CEO

VP Finance/CFO
Kenneth M. Julien
CerProbe, VP/CFO

VP Quality
*Joseph Riccio
Motorola, Area Sales Mgr

VP Mktg/Sales
Jim Bowser

Mktg Dept Mgr.
Dave Lysne

Dir European Ops
Martin Woolfenden
National Semiconductor, Marketing Manager

Dir Manufacturing
Dr. Carl Derrington
Motorola, Prod Mgr, Sensors

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Three-Five Systems Inc.

Dir Materials and Process Technology
Dr. Joseph Morrissy
Alcatel Information Systems, Manufacturing Manager

Dir Engineering
Mike Petera
Alphasil, Elec Design Mgr

*Founder

PROCESS TECHNOLOGY

Liquid Crystal, including PLCD
GaAs

PRODUCTS

Application-Specific Integrated Displays(ASIDs)
Custom User Interface Modules (Displays and Keyboards)
LCD Modules—Standard and Custom
Integrated Displays
Integrated LED Bar Graphs
Infrared Emitters
LED Dot Matrix Displays
Visible Lamps and LED Digits
Multidigit LED Displays
Keyboards

FACILITIES

Phoenix, AZ
51,000 sq. ft.
Prototype laboratories, corporate headquarters
Manila, Philippines
Manufacturing, inventory
Swindon, United Kingdom
European headquarters

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Toshiba Corporation

1-1 Shibaura 1-chome
Minato-ku, Tokyo 105, Japan
Tel: (03)457-4511
Telex: J22587 TOSHIBA

ESTABLISHED: 1875 NO. OF EMPLOYEES: 142,000

BACKGROUND

Toshiba Corporation was founded in 1875 as Tanaka Seizo-sho. The Company merged with Tokyo Electric Company in 1939 and changed its English name to Toshiba Corporation in 1978. The Company is one of the two leaders of the Toshiba-IHI Group. Toshiba is focused in electronics and energy; it is targeting AI, next-generation computers, and software as highgrowth areas. It is the second-largest semiconductor supplier in the world.

Toshiba's GaAs activities began in 1974. GaAs developments by Toshiba include GaAs Schottky FETs for use in TV tuners, 4x4 parallel multi pliers with multiply time of 6ns and P_d of 39mW, GaAs MMIC operating at 12 GHz, Pt-gate GaAs FETs with transconductance of 1.8 milliSiemens, and a 1K gate array with 75ps gate delay.

In mid-1983, Toshiba reported developing a twin-mesa substrate laser and a methodology for forming a number of such lasers on the same substrate for use in multiplexing light sources. In late 1983, Toshiba began sampling a GaAlAs/ GaAs laser used in optical disks for audio systems at a sample price of $44.00. By 1984, the device was in mass production at an ASP of $13.00, and by 1989, the price had fallen to less than $2.50.

A 6,000-gate GaAs gate array was developed by Toshiba's VLSI Research Center at Saiwai-ku, Kawasaki, Japan, as a part of the MITI Scientific Computing Systems Program. The array used a conventional SCFL structure to implement 232 rows by 26 columns of cells. A test struc ture, with serial-parallel-serial registers occupying 80 percent of the die, consumed 952mW when operated at an 850-MHz rate. Die size is 8mm x 8mm^2.

Toshiba participated in the AIST/MITI Japanese national supercomputer project sponsored by NEDO, which resulted in a GaAs-based prototype supercomputer system.

COMPANY EXECUTIVES

President and CEO
Joichi Aoi

Senior Manager, Worldwide Business Planning
Takeshi Nakagawa

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Toshiba has electronics technology exchange agreements with Brooktree, GE, Hewlett-Packard, Intel, Korea Electronics Company, Laser Path, LSI Logic, Motorola, Olivetti, Pohang (South Korea), Robert Bosch GmbH, SGS, Siemens, Sun Microsystems, Tokuda Works, Zilog, Zoran, and others.

From 1981 to January 1990, Toshiba, Fujitsu, Hitachi, Mitsubishi and NEC jointly developed a GaAs-based prototype supercomputer system.

Major shareholders in Toshiba Corporation include Dai-Ichi Life Insurance (4.2 percent), Nippon Life Insurance (3.6 percent), Mitsubishi Trust (3.5 percent), Mitsui Trust (3.4 percent), and Mitsui Bank (2.9 percent). Foreign owners hold 3.4 percent.

PROCESS TECHNOLOGY

Toshiba uses GaAs and other III-V compound semiconductor processes, including submicron GaAs MESFET.

PRODUCTS

LEDs, lasers, and other opto devices
Analog ICs
MMICs
Discretes

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Toshiba Corporation

FACILITIES

Kitayushu plant
Tamagawa plant
Korea Electronics
Optoelectronics and discrete production

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TriQuint Semiconductor Inc.

Group 700
P.O. Box 4935
Beaverton, OR 97076
503/644-3535
Fax: 503/644-3198

ESTABLISHED: January 1984 **NO. OF EMPLOYEES:** 270

BACKGROUND

TriQuint designs, develops, manufactures, and markets microwave, linear, and GHz digital GaAs IC components. TriQuint also offers a broad range of foundry services. The Company's products are used in high-performa nce applications such as fiber-optic telephone communication, high-speed computer interfaces, instruments, and military systems.

The Company evolved from research on GaAs ICs that began in Tektronix Laboratories in 1978. Several of TriQuint's founders were leaders on the Tektronix research team. In 1984, TriQuint was formally established as a majority-owned subsidiary with the entrepreneurial freedom to establish a broad portfolio of long-term manufacturing contracts. In mid-1991, TriQuint had annual sales revenue of approximately $35 million and more than 1,200 customers worldwide.

COMPANY EXECUTIVES

(Position, Name)

President/CEO
Steve Sharpe

Executive VP/CFO
Spencer Brown

VP Sales
Robert Gunn

QA/Materials Director
Richard Allen

VP/GM Operations
Richard Wood

VP Digital Comm and DSP
Dennis C. Powers

VP/GM Microwave Products
Philip Snow

RECENT HIGHLIGHTS

February 1988
TriQuint announced a radio-frequency/large-scale integration (RF/LSI) GaAs IC foundry service named the QED/A process.

March 1988
TriQuint introduced the QLSI cell-based library, a GHz LSI cell-based library that supports LSI applications of up to 6,000 equivalent gates and toggle rates of up to 2 GHz.

May 1988
TriQuint was the first GaAs foundry to manufacture microwave and digital ICs on 4-inch wafers.

May 1988
TriQuint announced an optimized 0.5-micron microwave foundry process.

July 1989
TriQuint announced the shipment of wafers and die screened to U.S. DOD Class 5 requirements, the first commercial IC manufacturer to announce availability of this level of screening— permitting satellite systems applications.

January 1990
TriQuint announced joint development of a 14-bit, 1 giga-sample-per-second digital-to-analog converter, working with GE, Hughes, Motorola, and Sciteq.

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TriQuint Semiconductor Inc.

March 1990
TriQuint and McDonnell Douglas announced a joint effort to evaluate coproduction of GaAs VLSI including 64K SRAMs and 256K NVRAMs.

November 1990
TriQuint received a MIMIC Phase 3 award for $2.65 million.

January 1991
TriQuint announced the acquisition of GigaBit Logic Inc. (GBL) of Newbury Park, California, a merchant supplier of GaAs ICs.

July 1991
TriQuint announced management changes following the May 1991 addition of Gazelle Microcircuits of Santa Clara, California, a supplier of GaAs ICs, to the GBL acquisition. The changes included reorganization into three market-oriented business units: Computing/Networking, Digital Communications and DSP, and Microwave Communications.

August 1991
TriQuint announced a major production order for synthesized clock source chips from OnChip Systems Inc. of San Jose, California. First-year production is expected to exceed 100,000 units, which will be used in desktop PCs and workstations.

STRATEGIC ALLIANCES

Tektronix
January 1984
Tektronix spun off TriQuint, remaining the parent company and completing a sales agreement with the new subsidiary.

EEsof
May 1986
EEsof and TriQuint teamed up to incorporate TriQuint's GaAs custom MMIC foundry models into Touchstone, EEsof's minicomputer- and workstation-based MMIC CAD program. Jointly, they developed a GaAs MMIC element library that allows users to simulate microwave ICs, using MMIC components that model components available from TriQuint's custom MMIC foundry facility.

TRW
June 1987
TRW Components and TriQuint agreed jointly to develop and supply class-S level GaAs devices for space applications. TriQuint will provide microwave and digital GaAs technology in addition to foundry services.

MSC
March 1988
Microwave Semiconductor Corporation and TriQuint agreed to provide customers with GDS-II tape interchangeability and equivalent performance for GaAs analog and digital ICs and MMICs.

Hewlett-Packard
May 1988
TriQuint's MMIC Library of foundry design models are incorporated into Hewlett-Packard Company's microwave CAE design system.

Gazelle Microcircuits
May 1988
Gazelle Microcircuits signed a foundry contract with TriQuint for 4-inch digital wafer production.

Pacific Semiconductor Pty (Sydney, Australia)
May 1990
TriQuint and Pacific jointly acquired all patents formerly held by Gain Electronics Company.

PROCESS TECHNOLOGY

1.0- and 0.5-micron gate length depletion mode MESFET processes capable of fabricating D-MESFETs VIAs
1.0- and 0.5-micron gate length enhancement/ depletion mode MESFET processes capable of fabricating E- and D-MESFETs
3-inch wafers
4-inch wafers

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TriQuint Semiconductor Inc.

PRODUCTS

Foundry Process	Description
1A/1D Process	1.0-Micron Gate Length Depletion Mode MESFET for D-MESFET, Schottky Diodes, Implanted Resistors, MIM Capacitors, and Airbridge Inductors
HA Process	0.5-Micron Gate Length Depletion Mode MESFET Process for Both 0.5- and 1.0-Micron D-MESFETs, Schottky Diodes, Implanted Resistors, Precision Nichrome Resistors, MIM Capacitors, and Airbridge Inductors
QED Process	1.0-Micron Gate Length Enhancement/Depletion Mode MESFET for E- and D-MESFETs, Schottky Diodes, Implanted Resistors, and Airbridge Inductors
QED/A Process	An Enhanced Version of the QED Process that Allows the Mixing of Low-Power Digital LSI Circuits and Precision Analog Circuits on a Single Die
3A Process	Optimized 0.5-micron Microwave Process

Gate Arrays

Family	Linewidth	Delay	Gates
QLSI	1.0	0.15	2,000; 3,000; 4,000

Cell-Based Library

Family	Cells
Q-Logic	1,000 Gates, Data Encoders/Decoders, MUX/DEMUX, Counters, Dividers, Prescalers
QLSI	8,000 Gates, ZFL Cells, SCFL Cell Family

MMICs (Die and Components)

TQ9111	1- to 8-GHz Amplifier
TQ9141	1- to 10-GHz Power Divider
TQ9152	1- to 10-GHz SPDT Switch
TQ9161	1- to 10-GHz Variable Attenuator
TQ9121	0.5- to 20.0-GHz 10w Noise Amplifier
TQ9131	0.5- to 20.0-GHz Active Combiner

Digital Products

TQ1131	Pgm 8:1, 16:1 MUX
TQ1132	Pgm 1:8, 1:16 DEMUX
TQ1133	4:1 MUX
TQ1134	1:4 DEMUX
TQ1135	12:1 MUX
TQ1136	12:1 DEMUX

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TriQuint Semiconductor Inc.

Family	Cells
Linear ICs	
TQ6330	Pin Driver
TQ6331	Line Receiver
TQ6111-D	8-Bit DAC, 600 Ms/S, Die Form
TQ6111-M	8-Bit DAC, 600 Ms/S, Ceramic Package
TQ6111-BI	8-Bit DAC, 600 Ms/S, Board Module, Instrumentation Version
TQ6111-BV	8-Bit DAC, 600 Ms/S, Board Module, Video Version
TQ6112-D	8-Bit DAC, 1,000 Ms/S, Die Form
TQ6112-M	8-Bit DAC, 1,000 Ms/S, Ceramic Package
TQ6112-BI	8-Bit DAC, 1,000 Ms/S, Board Module, Instrumentation Version
TQ6112-BV	8-Bit DAC, 600 Ms/S, Board Module, Video Version
EK-TQ6101	GIGADAC Evaluation Kit

Additionally, TriQuint will produce certain GaAs products acquired in the aquisitions of GigaBit Logic and Gazelle.

FACILITIES

Beaverton, OR
35,000 sq. ft.
Administration, engineering, manufacturing

15,000 sq. ft.
Class 100 clean room

Santa Clara, CA
NA

Newbury Park, CA
NA

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TRW Inc.

1900 Richmond Road
Cleveland, Ohio 44124
Tel: (216)291-7000
Fax: (216)291-7629

ESTABLISHED: 1901 **NO. OF EMPLOYEES: Approx. 75,000**

TRW Electronics and Technology Division

Electronic Systems Group
One Space Park
Redondo Beach, California 90278
Tel: (310)814-1986 (GaAs MMIC Products)
(310)814-1735 (GaAs Foundry)
Fax: (310)812-7011 (GaAs Foundry)

ESTABLISHED: 1975 (GaAs activities) **NO. OF EMPLOYEES: Approx. 240**

BACKGROUND

TRW Inc. is a vertically integrated supplier of electronic and other products, systems, and services in the areas of space and defense, automotive, consumer and commercial credit reporting, and real estate information. TRW also provides products and services used in oil and gas drilling, waste management, and coal combustion systems. Sales exceed $7 billion annually.

TRW invested more than $25 million in its GaAs pilot line. TRW Electronic Systems Group's Electronics & Technology Division has operated the GaAs pilot line and foundry since 1988. The pilot line was operating two shifts per day by early 1991. The Company is a prime contractor for Phase 2 of the DARPA MIMIC Program.

COMPANY EXECUTIVES

GaAs Operations Director
Aaron Oki

Marketing Director
Scott Andrews

Manager, MMIC Engineering
Robert M. Parrish

STRATEGIC ALLIANCES

The TRW team for Phase 2 of DARPA's MIMIC Program includes Alliant, Avantek (acquired by Hewlett-Packard in late 1991), COMSAT, EEsof, General Dynamics, Hercules, Mentor Graphics, Texas Instruments, and Westinghouse.

SERVICES

Full-service MESFET/HBT foundry including design, fab, assembly, and test.

PROCESS TECHNOLOGIES

0.2-micron HEMT to 60 GHz
0.5-micron MESFET to 40 GHz
2-micron HBT to 23 GHz
E-beam lithography, MBE epitaxy

PRODUCTS

GaAs microwave and millimeter-wave ICs, including:
- Low-noise amplifiers
- Power amplifiers
- Phase-locked loops
- D/A and A/D converters
- Frequency synthesizers
- Transceivers
- Others

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TRW Inc.

GaAs Discrete FET, HEMT and HBT Transistors
Impatt diodes

FACILITIES

TRW's 8,000-square-feet pilot line clean room includes 2,850 square feet of Class 10 area. The highly automated line requires less than 20 operators and has single-shift capacity of at least 100 3-inch wafers per week. TRW's Microelectronic Fabrication Center features over 13,000 square feet for MMIC production, including 6000 square feet of Class 10 clean rooms.

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Vitesse Semiconductor Corporation

741 Calle Plano
Camarillo, CA 93010
805/388-3700
Fax: 408/433-0331

ESTABLISHED: July 1984 **NO. OF EMPLOYEES: 188**

BACKGROUND

Vitesse Semiconductor Corporation designs, manufactures, and markets cost-effective digital GaAs large-scale ICs for the high-performance marketplace and offers foundry services on a contract basis. Products are manufactured using enhancement/depletion mode transistors and self-aligned gate technology according to silicon manufacturing techniques. The Company's first products were commercial versions of a family of GaAs ICs, including gate arrays, RAMs, and logic products.

Initially, the Company was funded by Norton Company and organized into two divisions—the Integrated Circuits Division, which was responsible for GaAs IC designs, and the Digital Products Division, which was developing a minisupercomputer product. Early in 1987, the Integrated Circuits Division raised $10 million, establishing an independent company, and was renamed Vitesse Semiconductor Corporation. Dr. Louis Tomasetta, formerly president of the IC Division, is president and CEO of the new company. Dr. Tomasetta was director and program manager of the $40 million DARPA GaAs pilot program at Rockwell International.

Vitesse remains in the existing 45,000-square-foot facility and will use the additional funding raised in 1987 to develop additional products and expand into higher-volume production. The building is designed specifically for the production of LSI-level digital ICs in GaAs. Approximately 12,000 square feet have been designated as clean room area, and half of that area is a Class 10 clean room.

In March 1987, Pierre R. Lamond was elected chairman of the board. Mr. Lamond organized the $10 million financing of Vitesse Semicon ductor and also serves on the boards of Convex Computer, Cypress Semiconductor, and several other private companies. In October 1987, Dr. T.J. Rodgers, president and CEO of Cypress Semiconductor Corporation, joined the board of Vitesse Semiconductor.

Vitesse has established a nationwide network of manufacturers' representatives to sell its foundry services and products. In June 1987, Vitesse signed Zeus as its first distributor to sell its 29G00 family of products.

Vitesse announced $250,000 in profit on $3.5 million in sales in first quarter 1990 and $500,000 in profit on $4.5 million in sales in second quarter 1990. Calendar year 1990 sales were $17.8 million with $1.7 million in profit.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
*Dr. Louis R. Tomasetta
Rockwell, Dir R&D Center

Executive VP
*Patrick L. Hoffpauir
VLSI Technology, GM ASIC Ops

Director of Marketing
Robert Nunn
AMD, Mktg Mgr

VP Sales
Neil Rappaport
AMCC, Ntl Sales Mgr

VP Product Development
*Ira Deyhimy
Rockwell, Mgr IC Engr

VP Technology Development
James Mikkelson
Hewlett-Packard, Mgr Process Dev

Senior VP Finance/CFO
Ray Thomas
Everest & Jennings, Sr. VP Finance/CFO

*Founder

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Vitesse Semiconductor Corporation

RECENT HIGHLIGHTS

March 1988
Vitesse announced that it has developed the VS8010, a MUX/DEMUX with control logic that meets the SONET standard at the 1.2-Gbps communications rate.

November 1988
Vitesse announced the world's first GaAs VLSI product, a 10,000-gate array, the VSC 10000.

January 1989
Vitesse announced a GaAs 22,000-gate array using standard cells.

August 1989
Vitesse announced shipment of its VSC10K GaAs gate array to E-Systems for that company's high-performance digital signal processor series.

October 1990
Convex Computer announced use of Vitesse GaAs ICs in its C2 series computer.

Vitesse announced the VSC864, 64x64 crosspoint switch.

January 1991
Vitesse announced $1.7 million profits on $17.8 million sales in calendar 1990.

STRATEGIC ALLIANCES

Norton
July 1984
The initial investment of $30 million in Vitesse was provided by the Norton Company, a $1.3 billion company located in Worcester, Massachusetts.

Advanced Micro Devices
November 1985
Vitesse and AMD agreed to develop and manufacture AMD's AM2900 family of MPUs in gallium arsenide.

TRW
December 1986
Vitesse signed a sales and marketing agreement with TRW Components International Inc. (TRWCI) covering logic, memory, and ASIC products. Vitesse will supply high-performance wafers, die, and packaged devices to TRWCI, which will assemble, test, qualify, and sell to the space-quality, Class-S-level market. The companies also will cooperate to solve the radiation problems found in logic and memory products.

E-Systems
August 1987
Vitesse signed an agreement allowing E-Systems to use Vitesse's proprietary GaAs technology in its current and future programs. E-Systems also has an option to purchase design, packaging, and test technologies. The agreement allows Vitesse to participate in the EW systems market through E-Systems' military programs.

VLSI Technology
September 1987
Vitesse will develop a GaAs cell library for VLSI's design tools. VLSI will provide technical information and assist in the porting effort. When the library is completed, both companies will market the tools, which Vitesse will use internally. VLSI will extend the tools to its silicon compiler library; Vitesse will own the library and provide fabrication.

Ford Microelectronics
October 1987
Vitesse and Ford Microelectronics agreed to second-source each others' IC foundry services. The companies will develop common design rules.

Fujitsu
November 1989
Vitesse and Fujitsu Ltd. announced an alternate-source agreement with regard to Vitesse's FURY GaAs VLSI gate array family.
October 1990
Thomson CSF's subsidiary, Thomson Composants Microondes (TCM), will second-source the FURY Series.

Convex
1990-1991
A series of announcements revealed the long-standing, close-working relationship of Convex and Vitesse in the use of GaAs ICs in Convex Supercomputers.
May 1991
Convex Computer announced its 3800 Series GaAs supercomputer, which uses 180 to 550 Vitesse GaAs ICs per system.

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Vitesse Semiconductor Corporation

PROCESS TECHNOLOGY

GaAs E/D MESFET
0.6-1.25 microns gate lengths
4-inch wafers
4 layer metal
Up to 344 pins per chip

FACILITIES

Camarillo, CA
45,000 sq. ft.
Total space
10,000 sq. ft.
Class 10 clean room

PRODUCTS

Foundry

LSI Enhancement/Depletion Mode Process, 0.8-Micron Feature Size, Sub-100ps Gate Delays, 3-layer metal

	Device	Description
Gate Arrays	VSC1500	Structured Cell Array
	VSC4500	Gate Array
	VSC10K	Gate Array
	VSC15K	Gate Array
	VSC30K	Gate Array
	VSC100K	Gate Array
	VCB50K	Standard Cell Array
	VGFX200K	195,000-Gate Array
	VGFX350K	350,000-Gate Array
SRAMs	VS12G422E	256x4 SRAM, 3, 4, 5ns
	VS12G422T	256x4 SRAM, 4, 6, 8ns, TTL I/O
	VS126476	4Kx1 SRAM 2.5ns Self-Timed
Microcomponents	VS29G01	4-Bit Slice Processor
	VS29G02	Look-Ahead Carry Generator
	VS29G10	Microcontroller
Standard Products	VS8001	12:1 MUX at 1.2 GHz
	VS8002	1:12 DEMUX at 1.2 GHz
	VS8010, 11, 12, 21, 22	SONET MUX/DEMUX
	VS8004	4:1 MUX at 2.5 Gbps
	VS8005	1:4 DEMUX at 2.5 Gbps
	VSC864	64x64 Crosspoint Switch

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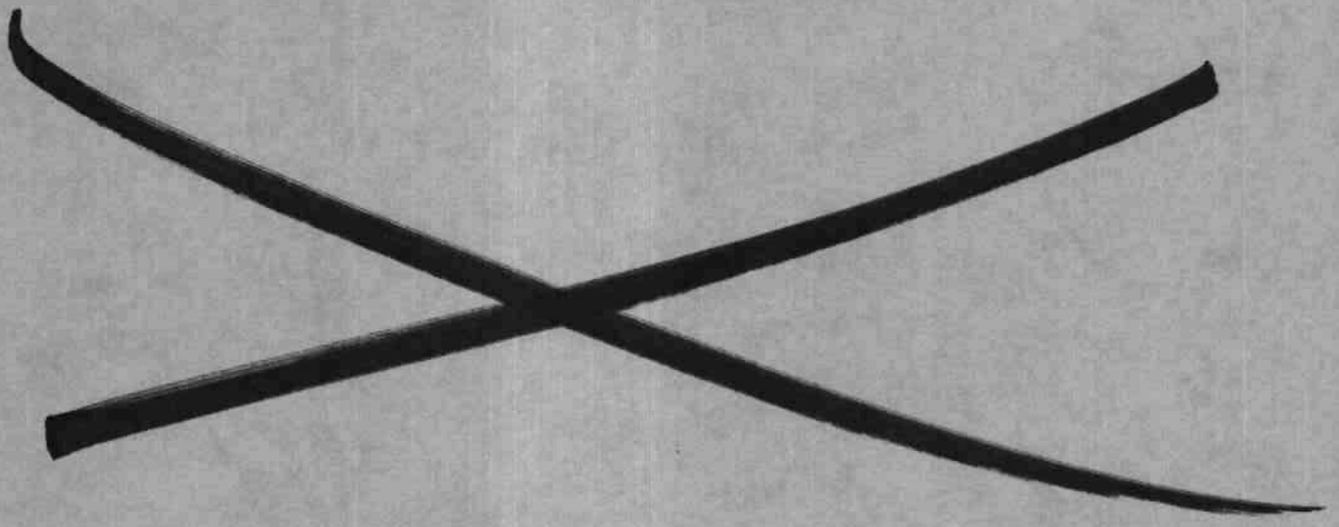
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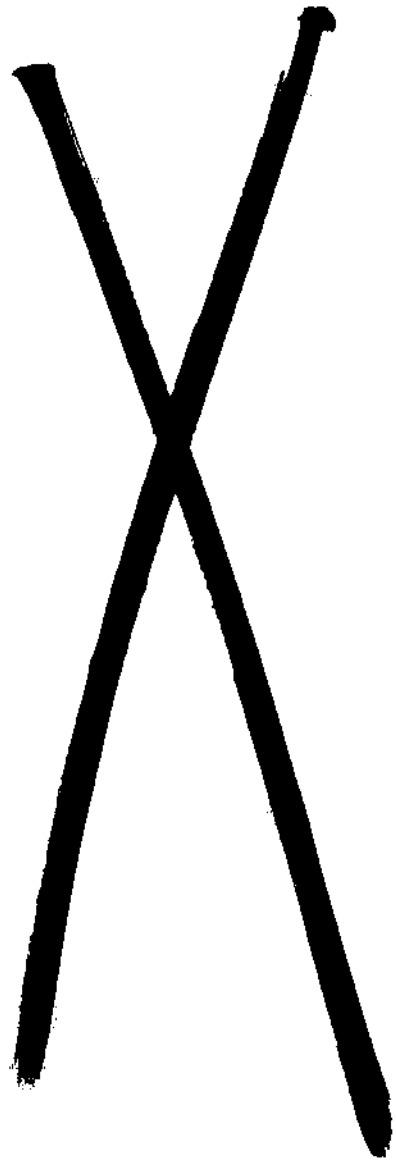
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0011633





Analog/Linear GaAs ICs—Executive Summary

INFORMATION RESOURCE CENTER
DATAQUEST INCORPORATED
1290 Ridder Park Drive
San Jose, CA 95131-2398
(408) 437-8600

INTRODUCTION

Analog GaAs integrated circuits (ICs), including microwave monolithic ICs (MMICs), are causing a major evolution in systems, pushing performance to record heights. The concept embodied in the first single-chip K-band radar module has revolutionized the design and functionality of radar systems. The TVRO downconverter MMIC, pioneered by Pacific Monolithics, proved that GaAs MMICs can be worst-case designed for production costs of less than $10 for certain applications; pricing in 1990 was below $8 for high-volume quantities of DBS receiver chips.

This section focuses on analog and linear GaAs, including microwave and millimeter wave, integrated circuits. It includes discussions of products, competitors, markets, and applications, and summarizes some of the major issues involved in this exciting, rapidly growing field.

TECHNOLOGY

Analog GaAs ICs offer the same types of advantages over hybrid devices as is the case in silicon technology, namely:

- Lower manufacturing costs via batch processing
- Improved quality and reliability through fewer wire bonds and discrete components
- Reduced size, weight, and power
- Circuit design flexibility, with potential for new functions not achievable in hybid form

The first MMIC patent was filed in 1966. Since that time, MMIC functions have evolved toward ever-increasing levels of integration. A good example of the advantages of GaAs MMICs over hybrid MICs is found in electronic warfare (EW) applications. MMICs allow designers to place high-density threat detection and jamming capability into heretofore inaccessible places in aircraft structures, such as in wingtips, nosecones, and leading edges of flying surfaces.

The primary disadvantage of GaAs MMICs compared with hybrid MICs is that performance and peak power are limited to levels dictated by the use of a single manufacturing process. However, advanced HEMTs and HBTs enable IC designs that overcome this limitation in applications up to 30 GHz.

PRODUCTS

GaAs analog and linear ICs may be categorized as including the following types of products:

- Amplifiers—Transimpedance, AGC, operational, LNAs, power
- Converters—A/D, D/A, sample and holds, phase-locked loops
- Analog signal conditioners—Mixers, tuners, switches, doublers
- Oscillators
- Comparators

As in the case of silicon technology, these GaAs IC products are available in standard, ASIC, and custom forms. The particular approach used typically depends on the design constraints of function, performance, cost, and availability. At the end of 1990, more than 40 companies were serving the merchant market for GaAs analog/linear ICs. Eleven foundries are available to serve the growing customer base for GaAs analog/linear ASICs and custom products.

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MARKETS

The analog/linear GaAs IC market is growing at an approximate 20 percent compound annual growth rate (CAGR) through 1995.

The market areas and their typical applications are as follows:

- Military/government—Radar, lidar, satellite communications, ECM and EW equipment, fiber-optic links
- Communications—TVRO, commercial satellite, cellular phones, wireless interoffice networks
- Instrumentation—Spectrum analyzers, microwave testers, signal generators
- Consumer—CDs, videodiscs, VCRs
- Automotive—Collision-avoidance radar, radar detectors

COMPETITORS

The companies listed in Table 1 were serving the GaAs analog/linear merchant market at the end of 1990. There are also many captive suppliers, some of which are teamed in support of the DOD MIMIC initiative. These are tabulated later in this section.

GaAs Analog/Linear Partnerships, Joint Ventures, and Alternate Sources

The following are typical examples of the many supplier companies' interrelationships in this industry segment:

- Pacific Monolithics/TriQuint
- Pacific Monolithics/COMSAT Labs
- Rockwell/IBM
- MicroWave Technology/Monolithic Microsystems
- TRW/FEI Microwave, Inc.
- TRW/TriQuint
- Ciba-Geigy/Spectra-Physics
- Amoco/Spectra Diode/Kodak/Litton Airtron
- Thorn-EMI/Varian
- Ford ASMMIC Team:
  - Ford Aerospace/Communications Corp.
  - Ford Microelectronics, Inc.
  - Singer Dalmo Victor Division
  - IBM Federal Systems Division
  - COMSAT
  - Pacific Monolithics
  - TriQuint
- M/A-COM/AT&T

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Table 1

Analog/Linear GaAs IC Suppliers by Region

Western Europe	Japan	United States
Alcatel	Fujitsu	Alpha Industries
LME	Hitachi	ANADIGICS
Italtel	Mitsubishi	AT&T
Philips	NEC (CA Eastern Labs)	Avantek
Plessey 3-5	NTT	COMSAT Labs
Siemens	Oki	Celeritek
Telefunken	Sharp	Harris
Thomson-CSF	Sony	Hewlett-Packard
	Toshiba (Matcom)	Hittite Microwave
		Hughes
		ITT GTC
		M/A-COM
		Microwave Monolithics
		MicroWave Technology
		Narda
		Pacific Monolithics
		PCO, Inc.
		Raytheon
		Rockwell
		Sanders Associates (Lockheed)
		Teledyne
		TI MMCD
		TriQuint (including GBL)
		TRW
		Varian
		Westinghouse

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ISSUES

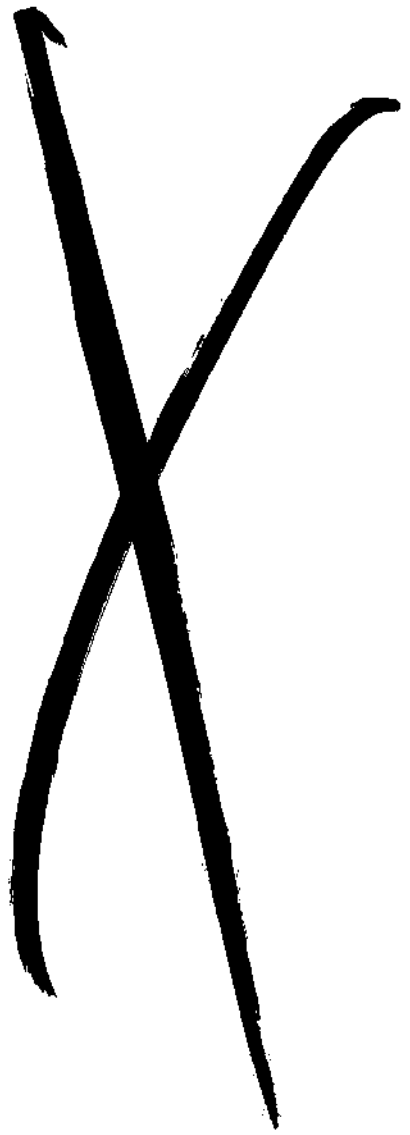
The user issues involved in the use of GaAs analog/linear ICs include the following:

- Design considerations:
  - Monolithic versus hybrid tradeoffs
  - Choice of MESFET, HEMT, or HBT technology
  - Decreasing the risk of system obsolescence
  - Transmission line and/or guided-wave environment considerations
  - Design tolerance of parametric variations
  - Test problems due to lack of high-performance equipment

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- Export controls
- Frequency spectrum crowding
- Product availability and cost:
  - Impact of international competition
  - Impact of industry structural changes
- Safety issues, including potential radiation hazards

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Analog/Linear GaAs ICs—Forecast

Table 1 presents Dataquest's forecast of the merchant market for GaAs analog and linear ICs. In the table, the estimated nonrecurring engineering (NRE) charges are separated from device sales. Our forecast includes the following assumptions:

- Continuation of MIMIC program, funded in excess of $500 million over five years
- No major changes in GPS satellite program
- Continuing participation of Japanese suppliers in U.S. defense market
- Continuing growth of personal radiotelephone markets

Table 1

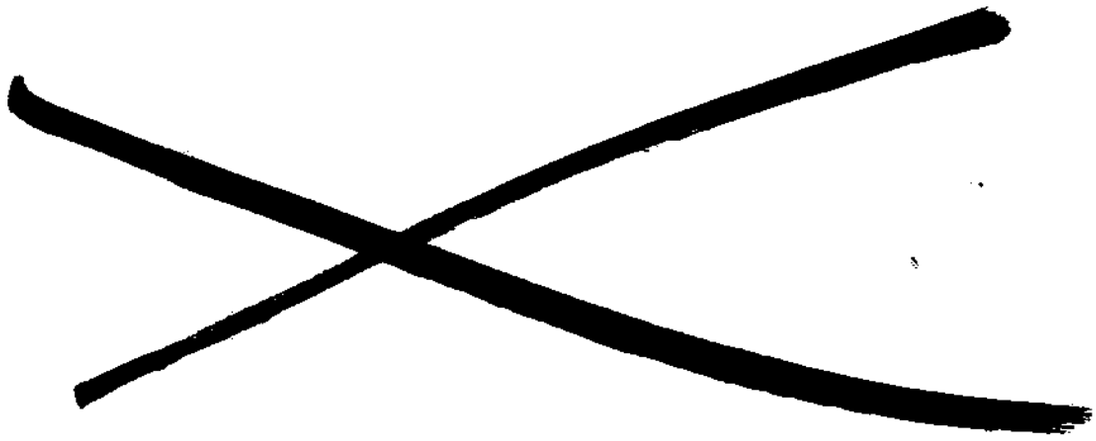
Worldwide GaAs Analog/Linear IC Merchant Consumption Forecast
(Millions of Dollars)

Category	1989	1990	1991	1992	1993	1994	1995	CAGR (%) 1989-1995
Analog GaAs ICs	187	242	319	407	514	638	710	24.9
Devices	142	194	272	358	462	585	650	28.9
NRE	45	48	47	49	52	53	60	2.8

Note: Some columns do not add to totals shown because of rounding.
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Analog/Linear GaAs ICs—Product Analysis

INTRODUCTION

GaAs analog ICs include two overlapping subsets, linear products and monolithic microwave integrated circuits (MMICs). Linear products have outputs that are linearly proportional to their inputs and function at a varying range of frequencies across the spectrum, depending on the particular device design. MMICs operate in the microwave frequency spectrum (above 3 GHz). The term MMIC has recently been extended to include millimeter-wave ICs, which operate at 30 to 300 GHz.

LINEAR PRODUCTS

GaAs linear ICs may function below microwave frequencies. In this case, they are referred to as "analog GaAs ICs" by most suppliers. Such functions are usually implemented in GaAs instead of silicon to gain a specific advantage such as reduced power or improved radiation hardness.

MMICs

The first MMIC patent was filed for in 1966. Since that time, MMICs have led the evolution of analog and linear GaAs and other III-V compound semiconductor technology toward ever-increasing levels of integration. One of the primary reasons for their early success is that impedances can be more carefully controlled on a chip than in discrete circuit form. Also, the FCC and others dictate careful parametric control to minimize frequency variations from specifications, making it highly desirable to integrate as much of the transmitter and receiver functions as possible. Figure 1 shows a diagram of an MMIC amplifier.

Amplifiers

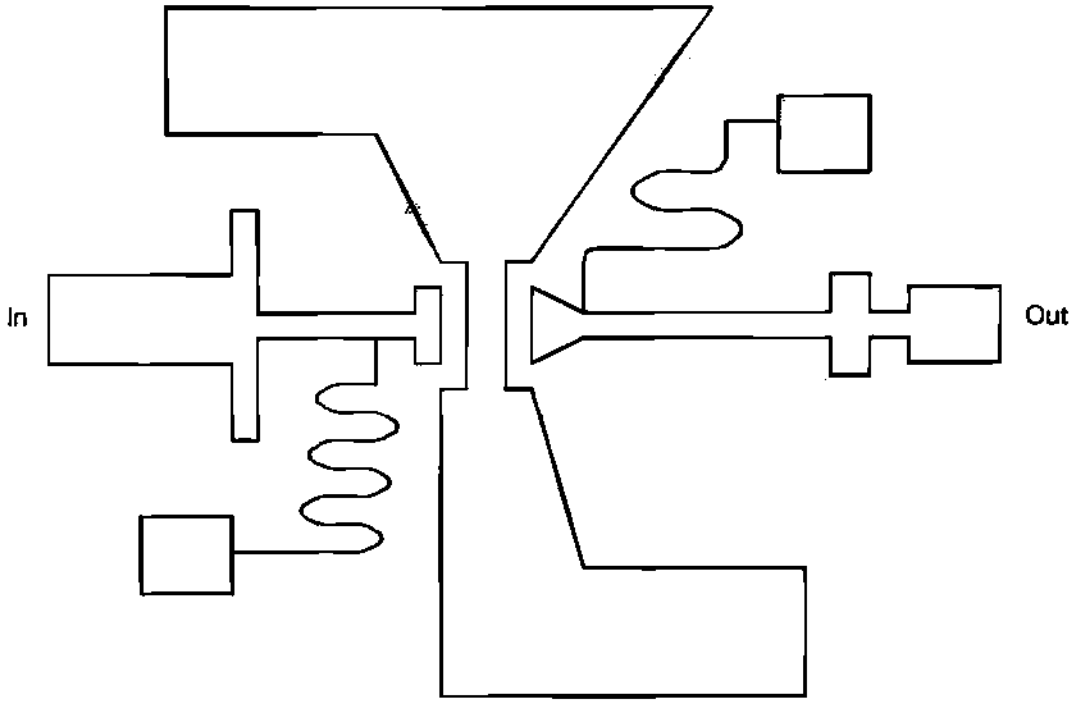
Microwave amplifiers are more easily integrated than such functions as A/D and D/A converters because of the relatively low components count of an amplifier. For this reason, MMIC amplifiers experienced early success. Today, GaAs amplifiers are available for commercial applications at prices of less than $8 in large volumes.

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Figure 1

Diagram of MMIC Amplifier



Source: Dataquest (April 1991)

A/D and D/A Converters

Several suppliers are producing GaAs A/D converters, and plans are under way to produce D/A converters as well. The recent availablity of HBT technology has led to flash A/D 8-bit converters that operate above 1 GHz.

Mixers and Tuners

GaAs mixers have been developed for consumer applications such as TV receivers. On a 1u process, Matsushita Electric produces a dual GaAs FET mixer that features 8dB conversion gain without external matching components. Mixers are now included as standard cells in ASIC MMIC cell libraries.

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GaAs tuners have a wide range of applications in military and commercial (including consumer) hardware. For example, China's Research Institute of Electronic Technology (Nanjing) has developed a two-stage DBS tuner using GaAs components. Until recently, these were hybrid assemblies; the emergence of MMIC technology has resulted in an increasing number of monolithic tuner functions.

Oscillators

Microwave frequency oscillators represent another function that required hybrid assembly until recently. GaAs processing to 0.5u geometries allows monolithic design of high-performance oscillators, and several companies now offer MMIC oscillators as standard products.

ASICs AND CUSTOM CIRCUITS

Microwave functions traditionally have represented an opportunity for semicustom and custom product suppliers because unique specifications are usually imposed by each customer and each application. The nature of MMIC applications requires custom or semicustom implementation to maximize available performance at reasonable cost. Avantek, M/A-COM, and others have supported this business primarily with discrete and SSI chips in hybrid subassemblies, using "off-the-shelf" dice matched to the customer's requirements. Many suppliers are evolving ASIC capabilities in response to market needs.

The availability of 3-inch wafers with improved defect density characteristics coupled with enhanced modeling of GaAs functions on relatively inexpensive workstations has led to a rapid migration toward monolithic ASIC solutions to multifunction microwave design problems. As is the case in silicon technology, GaAs ASICs are often the most cost-effective solution for both customer and supplier.

STANDARD CELL APPROACH TO CUSTOM MMICs

In mid-1986, Pacific Monolithics Incorporated pioneered in MMIC technology with its introduction of the world's first commercially available GaAs MMIC standard cell library. Pacific's family of macrocells ranges from attenuators through frequency synthesizers and downconverters. Examples of cells contained in the library are shown in Table 1. The company is adding cells to this family as needed to support future applications. Other suppliers have followed Pacific's lead in the standard cell approach.

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Table 1

Pacific Monolithics' Cell Library

Existing		In Development	
Function	Frequency (GHz)	Function	Frequency (GHz)
Amplifier Gain Blocks		Amplifiers	
10dB	2 to 6	SS amp, 10 dB	6 to 18
15dB	0.1 to 2	SS amp, 10 dB	6 to 12
15dB	1 to 3	LNA, 12dB	11 to 14
AGC amp, 10dB	2 to 6	Power amp, 10dB	6 to 18
		Power amp, 10dB	6 to 12
Oscillators (VCOs, DROs)		AGC amp, 10dB	6 to 18
Neg. resistance	1 to 3		
Neg. resistance	3 to 6	Mixers	
		Balanced-diode	6 to 10
Double-Balanced Mixers		Balanced-diode	10 to 18
Diode mixer	1 to 3	Dual-gate	2 to 6
Diode mixer	3 to 6	High-dynamic range	6 to 10
Diode mixer	6 to 8		
		Oscillators	
Attenuator	DC-12	Neg. resistance	6 to 12
		Neg. resistance	12 to 18
FET SPDT Switch	DC-12		
		Subsystems	
Low-Noise Amplifiers		Freq. downconverters	10 to 14
FET LNA, 16dB	3.7 to 4.2	Freq. downconverters	6 to 17
FET LNA, 13dB	4.4 to 5.0	Freq. synthesizers	DC-5
FET LNA, 16dB	1.2 to 1.6		
		Digital ICs	
Power Amplifier, 12dB	3 to 7	Dividers	6
		Flip-flops/latches	1.5
Biphase Modulator	5 to 10		
		Other Building Blocks	
QPSK Modulator	5 to 10	Balun	6 to 12
		Balun	6 to 18
Power Splitter/Combiner	5 to 10	Attenuator	6 to 18
90° Hybrid	3.5 to 4.5		
Active Isolator	0.1 to 10	Limiting Amplifiers	2 to 6
Balun	1 to 3		
		Vector Modulator	5 to 10
Balun	2 to 6		
		Subsystems	
Balun	5 to 8	Freq. downconverters	1 to 3
		Freq. downconverters	3 to 6
		Freq. downconverters	5 to 8
		Image-rej. dnconv.	3.7 to 4.2

Source: Pacific Monolithics

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FOUNDRY SUPPORT FOR GaAs ASICs AND CUSTOM ICs

Several companies offer GaAs ASIC support via foundry services, and the list is growing. The major analog/linear foundries, locations, and contacts are summarized in Table 2. The company profiles (located behind the "Profiles" tab) give the details of each company's available services as of late 1989.

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Table 2

Analog/Linear GaAs Foundry Contacts

Company/Location	Phone	Foundry Contact
ANADIGICS Warren, NJ	(201) 668-5000	Javed Patel Director, marketing and sales
Avantek Santa Clara, CA	(408) 727-0700	Peter Manno Vice president, marketing and sales
COMSAT Labs Clarksburg, MD	(301) 428-4000	Dr. Ho Chung Huang Executive director, Micro Division
Harris Milpitas, CA	(408) 433-2222	Jim Klug Program director
ITT GTC Roanoke, VA	(703) 563-3912	Joe Grzyb Project manager
M/A-COM Lowell, MA	(508) 453-3100	Robert Tingley Director, marketing and sales
Plessey 3-5 Towcester, United Kingdom	(0327) 51871	Jim Arnold Applications executive
Sanders Nashua, NH	(603) 885-1054	Dr. Paul Hoff Technical director, advanced devices
TI MMCD Dallas, TX	(214) 995-6462	Steve Lazar Foundry services manager
TriQuint Beaverton, OR	(503) 644-3535	Dennis Powers Vice president, marketing and sales
Varian Associates Santa Clara, CA	(408) 562-2834	Michael Kopec III-V sales manager

Source: Aziek Associates

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COST MODEL

Table 3 shows a cost model of a GaAs MMIC amplifier produced in a facility assumed to be capable of 500 wafer starts per week. Other assumptions are shown in the model. As with any relatively new semiconductor device, production costs of GaAs MMICs are changing rapidly; this model is for reference only and may not represent present costs for an efficient supplier.

Table 3

GaAs MMIC Amplifier Cost Model

Wafer Sort	Cost ($)
3-inch wafer cost = $190, fab cost = $910, fab yield = 75% good wafers; therefore, the fab cost per gross die (fab wafer cost/1,200 die locations) is:	1.22
Wafer sort cost per gross die:	0.20
Cost per gross die through wafer sort:	0.42
Therefore, cost per net die at wafer sort yield of 75% is:	1.90
Assembly	**Cost ($)**
Cost of die through wafer sort:	1.90
Assembly cost per wafer sort die (including packaging cost):	0.85
Therefore, cost per assembled die at 95% assembly yield is:	2.75
Final Test	**Cost ($)**
Assembled die cost:	2.75
Test time/device = 0.3 minutes	
Test cost/unit (cost/hour/devices tested/hour):	0.60
Final test yield = 90%	
Therefore, cost per final tested unit is:	3.72
Mark, Pack, Ship	**Cost ($)**
Operation cost at 99.9% yield:	0.40
Therefore, total variables cost per net unit:	4.12
Assume overhead* = 125%	
Therefore, break-even cost per unit:	9.27

*The term "overhead" as used here includes all other costs of growing a viable business, e.g., R&D, marketing, selling, accounting, management, and other costs and expenses.
Source: Dataquest (April 1991)

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TYPICAL PRODUCTS

Table 4 gives examples of GaAs analog ICs that have accumulated at least five years of production experience. There is a much greater variety of devices on the market, and the list is growing very rapidly.

Table 4

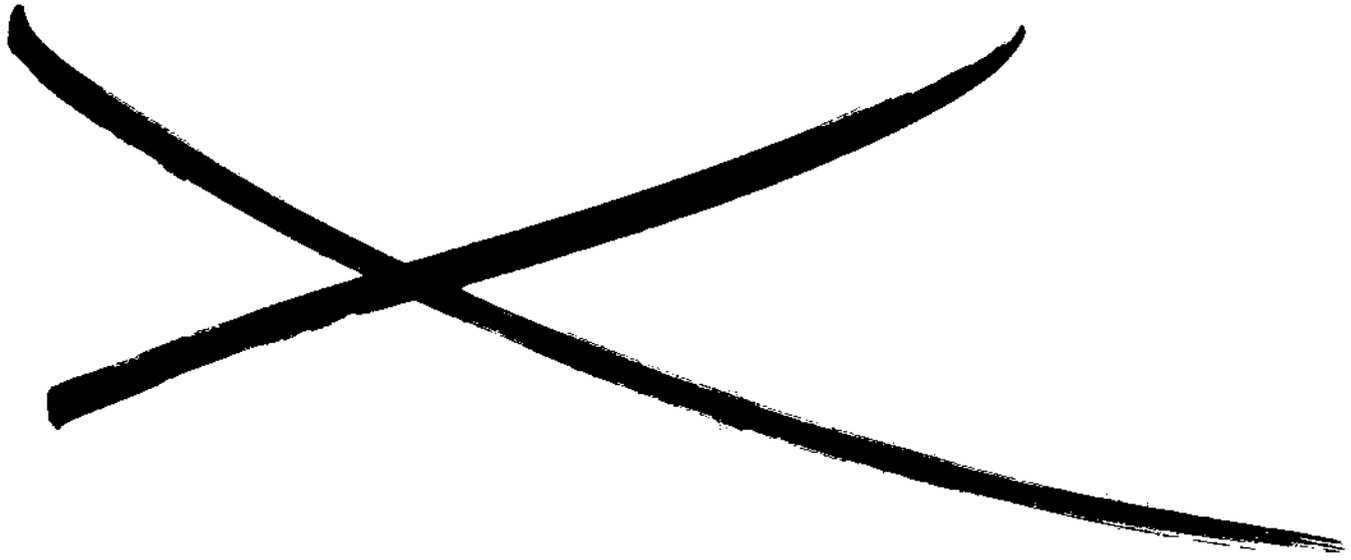
Examples of GaAs Analog Products

Company	Part No.	Description	Comments
ANADIGICS	AOP3510	Op amp; 350 MHz gain	
Harris	HMR10502	Monolithic rf amp; 10dB gain from 500 MHz to 5 GHz	Needs external bypass capacitors
	MHR 10503	Same as 10502 but has on-chip source-bypass capacitors	
	HMM-11810-0	Amplifier	5dB gain from 6 to 18 GHz
Pacific Monolithics	PM-AM0607	Amplifier	10dB gain from 2 to 6 GHz
TriQuint	TQ9111	Amplifier	7dB gain from 1 to 18 GHz
	TQ9141	Two-way power splitter	1 to 10 GHz
	TQ9151	SPDT switch	1 to 10 GHz
	TQ9161	Variable attenuator	1 to 10 GHz

Source: Dataquest (April 1991)

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Analog/Linear GaAs ICs—Competitive Analysis

SUMMARY

The analog/linear segment of the GaAs IC market has a unique set of competitors, including many start-ups and at least one supplier that is fully dependent on foundries for wafer fab. These companies are concentrated primarily in the United States and Japan; Western Europe has three or less companies per country.

Table 1 shows the major merchant suppliers of GaAs analog and linear ICs by region; some of these supply only on a limited-contract basis. Table 2 lists many of the other companies having MMIC design and production capabilities.

Table 1

Analog/Linear III-V IC Suppliers by Region

United States	Japan	Western Europe
Alpha Industries	Fujitsu	Alcatel
ANADIGICS	Hitachi	Italtel
AT&T	Mitsubishi	LME
Avantek	NEC (CA Eastern Labs)	Philips
Celeritek	NTT	Plessey 3-5
COMSAT Labs	Oki	Siemens
Harris	Sharp	Telefunken
Hewlett-Packard	Sony	Thomson-CSF
Hittite Microwave	Toshiba (Matcom)	
Hughes		
ITT GTC		
M/A-COM		
Microwave Monolithics		
MicroWave Technologies		
Narda		
Pacific Monolithics		
PCO Inc.		
Raytheon		
Rockwell		
Sanders Associates (Lockheed)		
Tachonics		
Teledyne		
TI MMCD		
TriQuint (including GBL)		
TRW		
Varian		
Westinghouse		

Source: Dataquest (April 1991)

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Table 2

Other Companies with Analog/Linear III-V IC Capabilities

United States	Japan	Western Europe
Aerojet	Fuji Electric	GEC
Ball Aerospace	Honda	STC
Eaton	Matsushita	TEV
E-Systems	Sanyo	Thorn-EMI
GE (includes RCA)		
Honeywell		
HP		
IBM		
Kodak		
Litton		
Lockheed		
Loral		
Magnavox		
Martin-Marietta		
Monsanto		
Singer		
Watkins-Johnson		

Source: Dataquest (April 1991)

MIMIC COMPETITORS

The U.S. Department of Defense MIMIC Program Phase 0 awards were made to 12 teams of companies in early 1987. In mid-1988, Phase I awards were made to four teams. Table 3 shows the prime contractors and other details of the Phase I awards. The Phase I contracts are scheduled for completion in 1991.

Phase I teams include:

- AT&T, E-Systems, Hercules (Sperry Clearwater division), M/A-COM, Cascade Microtech, and Harris Microwave supporting Hughes/GE
- Three divisions of ITT, Harris GSD, Pacific Monolithics, Alpha Industries, SRI, and Watkins-Johnson supporting ITT/Martin Marietta
- Aerojet General, Consilium, Compact, General Dynamics, Litton Airtron, Magnavox, Norden, and Teledyne supporting Raytheon/TI
- General Dynamics, Honeywell, and Kodak supporting TRW

The DOD expects to make additional funding available for technology projects such as direct-write e-beam and MOMBE systems developments. Eliot D. Cohen, of the Office of the Secretary of Defense, stated to an audience at the 1989 MTT that the present demand estimate is 700 to 1,000 4-inch wafers per week by the mid-1990s to satisfy the currently projected MIMIC uses. This figure could increase substantially as new defense needs emerge.

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Table 3

MIMIC Phase I Summary

Prime Contractors	Award ($M)	Service Branch	Freq. Range Upper Limit	Technologies	Applications
Hughes/GE	50	Air Force	To 30 GHz	MESFET, HEMT	Radar
ITT/Martin Marietta	49	Army	Above 30 GHz	SAGFET	Communications, smart munitions
Raytheon/TI	68	Navy	To 30 GHz	MESFET	Electronic warfare
TRW	58	Army	Above 30 GHz	MESFET, HBT, HEMT	Electronic warfare, smart munitions

Source: Dataquest (April 1991)

PARTNERSHIPS

A natural consequence of GaAs technology development is increased activity in the areas of partnerships, agreements, joint ventures, and teaming efforts. This section summarizes many of the major such actions in the GaAs analog/linear industry segment. MIMIC teams were discussed in the "Competitive Analysis" section.

Pacific Monolithics/TriQuint

TriQuint performed well as Pacific Monolithics' primary foundry, supplying processed wafers to mutually acceptable specifications. Dataquest believes that this relationship led to some of their specific teaming on the DOD MIMIC program.

Pacific Monolithics/COMSAT Labs

In July 1987, Pacific Monolithics announced signing an agreement with COMSAT Laboratories of Clarksburg, Maryland, to exclusively develop and pursue products and markets for power and millimeter-wave MMICs, and to seek Phase I-III contracts under the DOD MIMIC program. Pacific will provide design and marketing skills; COMSAT will contribute 30-GHz MESFET foundry capability. The agreement is also intended as a vehicle for exploring additional business opportunities in monolithic and millimeter-wave devices.

Rockwell/IBM

Early in 1987, Rockwell International and IBM entered into an agreement for the cooperative development of high-speed digital and optoelectronic GaAs devices for future computers and telecommunications equipment. The program involves Rockwell's GaAs pilot line at Newbury Park, California, Rockwell development teams at Newbury Park and Thousand Oaks, California, and IBM development teams at East Fishkill and Yorktown Heights, New York.

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MicroWave Technology/Monolithic Microsystems

In June 1987, MicroWave Technology, Inc., of Fremont, California, completed its acquisition of Monolithic Microsystems, Inc., of Santa Cruz, California. Under the agreement, Monolithic Microsystems will become a wholly owned subsidiary of MicroWave Technology and will continue manufacturing at its present 8,200-square-foot facility.

TRW/FEI Microwave, Inc.

In mid-1990, FEI Microwave Inc. became the exclusive distributors of GaAs MMICs produced by TRW. Initial products included a power amplifier, a logarithmic amplifier, and SP4T switches.

TRW/TriQuint

TRW Components International (a subsidiary of TRW, Inc.) and TriQuint have agreed to jointly supply GaAs devices for space applications. The companies are working together on procedures for producing Class-S-level GaAs components. TriQuint provides foundry support.

Ciba-Geigy/Spectra-Physics

In June 1987, it was reported that Ciba-Geigy had signed a definitive agreement to acquire Spectra-Physics for $266 million. A prior lawsuit seeking to enjoin Ciba-Geigy's initial (reportedly hostile) takeover offer was reported as being dismissed without prejudice by the Delaware Federal Court. Dataquest believes that this acquisition will strengthen Ciba-Geigy's ability to participate in the GaAs industry infrastructure.

Amoco/Spectra Diode/Kodak/Litton Airtron

Amoco Laser Company, a wholly owned subsidiary of Amoco Corporation, has formed a strategic alliance with Spectra Diode Labs, Eastman Kodak, and the Airtron Division of Litton Industries to support its laser systems product line. Spectra Diode makes the semiconductor lasers, Kodak provides production support, and Litton Airtron supplies wafers. Amoco intends to use this alliance to pursue communications, projection TV, reprography, and other commercial and military applications. Dataquest believes that the relationship could lead to additional IC capability.

Thorn-EMI/Varian

The company, TEV, is a U.K.-based joint venture of Thorn-EMI Electronics of the United Kingdom, and Varian Associates of the United States. The company supplies tubes for broadband EW and expendables for military applications. TEV also is developing 70 to 80mW, 90-GHz oscillators for missile-seeking mortars (smart munitions). The company is focusing on applications in earth resources satellites and synthetic aperture radars (SARs).

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The Ford ASMMIC Team

Ford Aerospace and Communications Corporation established a team effort to enable insertion of microwave/millimeter wave ICs into widespread system applications. The team consists of Ford Aero, Singer Dalmo Victor Division, IBM Federal Systems Division, COMSAT, Pacific Monolithics, and TriQuint. The approach is called ASMMIC for "application-specific MMIC."

GaAs IC designs based on the ASMMIC approach have been produced and tested to 28 GHz, and new designs to 100 GHz are in process. A reduction in system integration time by a factor of three is claimed for the approach. Typical applications include communications receivers, antennas, radar, and electronic support systems.

M/A-COM/AT&T

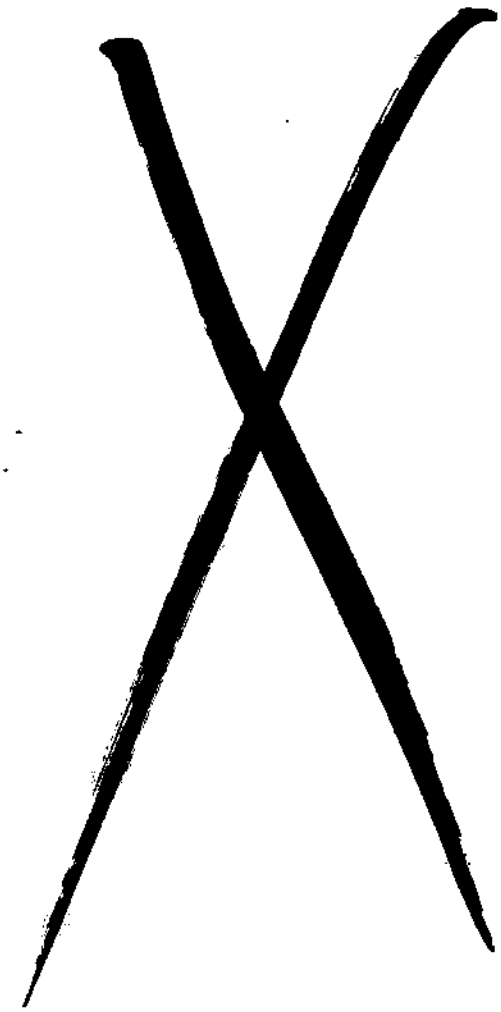
In 1990, M/A-COM and AT&T announced a combined effort to produce MMICs at foundry facilities in Lowell, Massachusetts, and Reading, Pennsylvania. The Lowell facility, owned by M/A-COM, provides customer interface, custom design, ion implantation, test, assembly, military screening, and life tests. The AT&T-owned Reading facility performs MBE on wafers, process monitoring tests, and reliability validation. Worldwide marketing and sales are performed by M/A-COM.

JAPANESE COMPETITION

NEC remains the largest Japanese supplier of GaAs MMICs. The most likely future competitors in analog/linear GaAs ICs include Hitachi and Mitsubishi, both of which have developed MMICs for television and VCR applications. The volume experience gained on these products will allow these two companies to become more aggressive in other types of MMICs.

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Analog/Linear GaAs ICs—Emerging Technology and Trends

EMERGING TECHNOLOGY

The emerging technologies influencing analog/linear GaAs ICs include scaling through refined photolithography and related processing, adoption of standard cell design methodology, increased complexity of functions on a single chip, and integration of electronic and photonic functions on the same die. The DOD MIMIC (millimeter-microwave IC) initiative is expected to intensify many of these activities.

Scaling and Performance

The relatively low volume of wafers processed by a MMIC fab line allows working to tighter specifications than is usual for silicon fab. A "loose" GaAs MMIC process as of late 1990 has 0.5u minimum geometries. However, this would be considered difficult to control in most silicon fab areas. Next-generation GaAs processes will use 0.15u or tighter minimum gate lengths. As a result, transistor cutoff frequencies are being pushed beyond 100 GHz in new GaAs processes, and performance continues to climb dramatically.

Standard-Cell Designs

Shortly after Pacific Monolithics announced the industry's first extensive GaAs MMIC standard-cell family in 1986 (comprising more than 50 cells), others joined the bandwagon. Now several suppliers are claiming standard-cell MMIC capability, and more announcements are expected soon. This approach is very cost-effective for many designs.

MIMIC Program

The DOD MIMIC initiative, which is also discussed in the "Competitive Analysis" section, represents a major effort to incorporate the advantages of compound semiconductors into a variety of military applications. These applications include the following:

- Ultrareliable radar for the Air Force ATF
- Shared-aperture radar for the Navy ATA
- MILSTAR network communications terminals
- Smart munitions
- Wideband jammers
- Antiradiation missiles
- Other "brilliant" weapons

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TRENDS

The product and process improvements in analog/linear GaAs ICs are accelerating. Table 1 represents a cross section of activities in this field. Papers were presented at recent major conferences and seminars by the companies listed.

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Table 1

Product Concepts in Analog/Linear GaAs ICs

Company	Product Concept
Alpha/Aerojet/ GAMMA Monolithics	Monolithic Ka-band VCO (voltage-controlled oscillator)
Alpha Industries	2- to 18-GHz SPDT switches
ANADIGICs	7-Gbps decision circuit IC
ATR (Osaka)	Broadband active inductor
COMSAT Labs	60-GHz MMIC LNAs
Ford/COMSAT Labs/ Pacific Monolithics	ASMMIC (application-specific MMIC) cell library
Fujitsu	17ps HEMT pseudorandom number generator
GAMMA Monolithics	35-GHz MMIC LNA
General Electric	Wideband MMIC variable gain amplifiers
Hitachi	1.8-GHz GaAs tuner for DBS reception
Hughes Aircraft	V-band MMIC transmit-receive switch
ITT	MMIC IF upconverter
LEP/TRT (France)	MMIC for FM continuous wave radars
Matsushita	15-GHz single-stage divider
Mitsubishi	HEMT fabricated with focused ion beam lithography
NEC Corporation	9.5-GHz prescaler
NTT	10-Gbps HBT decision circuit
Pacific Monolithics	6- to 18-GHz MMIC amplifiers
Raytheon	14- to 37-GHz power amplifier MM-wave monolithic IMPATT VCO 3-bit K/Ka-band MMIC phase shifter
Texas Instruments	0.5- to 4-GHz true logarithmic amplifier 60-GHz CW IMPATT oscillator X-band monolithic LNA 3-watt X-band variable gain amplifier Ka-band monolithic power amplifier modules X- and Ka-band MMIC variable attenuation limiters
TRW Inc.	GaAs HBT log IF amplifier Q-band monolithic 3-stage amplifier
Varian	MMIC Ka-band HEMT LNA
Vitesse	2.5-Gbps telecommunications chip
Westinghouse	6- to 18-GHz analog phase shifter

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Analog/Linear GaAs ICs—Applications and User Issues

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APPLICATIONS

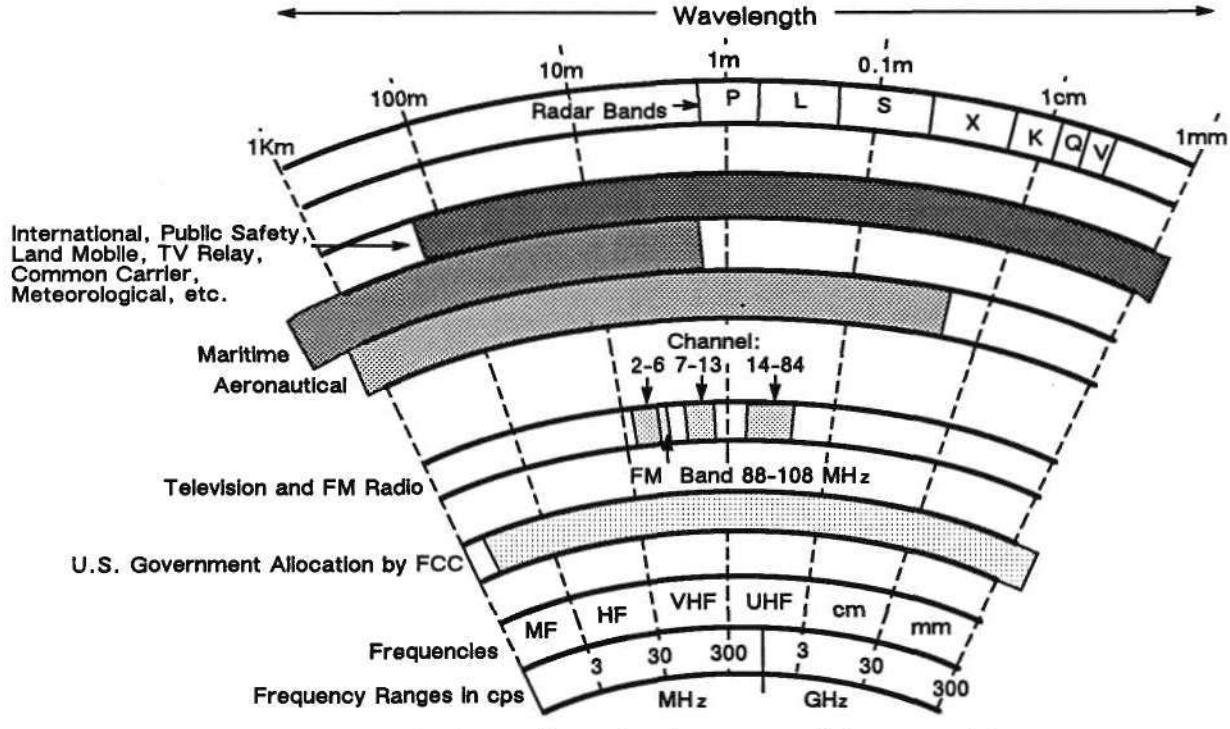
The unique properties of GaAs and other III-V compounds allow solutions to technical problems that were heretofore not economically solvable. Primary examples are found in the fields of fiber-optic and satellite communications, high-speed test/measurement, and military and government electronics.

Military and government applications including aerospace provided the initial impetus for compound semiconductor technology development. Among these are radar, satellite communications, electronic warfare, electronic countermeasures, smart munitions, surveillance, and high-speed signal processing.

This section gives examples of the growing number of diverse applications for GaAs and other III-V compound semiconductors, some of which are shown in Figure 1. The problem of interference among applications is increasingly acute as the frequency spectrum becomes crowded; precise control of operating frequencies and radiation patterns are major system design considerations. As further cost improvements are realized, end uses increasingly are extending into the full spectrum of markets—telecommunications, computer, instrumentation, CAD/CAE/CAM, artificial intelligence, robotics, military/aerospace, automotive, and consumer.

Figure 1

Applications by Operating Frequency



Note: Only portions of the indicated bands are allocated as shown, to avoid frequency clutter.

Source: Aztek Associates

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COMMUNICATIONS

The communications applications of III-V compound devices include the broad categories of fiber-optic links and microwave radio links. Each imposes different demands on the technology, and new companies have emerged to seek market advantages in each area.

In all communications systems, parallel-to-serial and serial-to-parallel conversions are used to minimize the number (and therefore cost) of links. This creates a large demand for high-speed multiplexing and demultiplexing circuits, which is a driving force in GaAs chip development. Additional demand is created by the need for very fast coders and decoders for serial bit streams. Such functions readily lend themselves to GaAs analog IC implementation.

For example, in fiber-optic transmission systems, a line code is often used to achieve an equal distribution of 1s and 0s to optimize performance over long distances. Because this line code adds redundancy to the signal, it can be used to monitor the link for bit errors. The low I/O count and high bit rates involved, coupled with the real-time nature of these functions, dictate the use of a highly exotic version of silicon technology or a straightforward, loose-tolerance approach with GaAs technology.

The many organizations presently involved in this field include the Center for Digital Systems Research (Research Triangle Park, North Carolina), General Electric (GE), and International Telephone and Telegraph (ITT). A device developed by ITT features a 144-gate error detection circuit that has been tested at 2.5 GHz and has experienced less than 12 percent speed degradation when operated at 125°C. The chip was designed, fabricated, and tested by a team of engineers from ITT Standard Telefon OG Kabelfabrik A/S (Oslo, Norway) and ITT GaAs Technology Center (Roanoke, Virginia).

An IC chip developed by GE incorporates an encoder, laser driver, optical detector, and decode logic; the die size is 45 mils by 90 mils. TriQuint fabricated the GE circuit using the 1u E/D process, as part of a multichip project. The first lot of wafers exhibited combined transceiver yields of 65, 70, and 82 percent for the three best wafers.

Fiber Optics—Long Lines and LANs

Since 1984, there has been explosive growth in the fiber-optics field. The number of suppliers of lasers, LED drivers, detectors, and sensors to this market approximately doubled in less than two years (1984 to 1986). The advantages of fiber-optic communications include:

- Freedom from disturbance by external electromagnetic sources
- Immunity to crosstalk
- Unidirectional signal flow; minimum reflection problems
- Ground loops and offset voltages eliminated

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- Data transmission rates in excess of 10 GHz
- Simplified signal multiplexing
- Lower losses and less power consumption
- Enhanced security against "tapping"
- Reduced electrical hazards—no arcing or sparking
- Resistance to harsh environments
- Less cross-sectional area and weight, and more ruggedness than electrical cable
- Reduced cable costs

Figure 2 shows a typical fiber-optic transmission link and illustrates the uses of III-V devices in such a system. The driver and amplifier circuits are typically GaAs analog ICs, particularly for transmission frequencies above 1 GHz.

A comparison of various LAN interconnect media is presented in Table 1. The range of unrepeated fiber-optic transmissions is extending rapidly as companies race to gain market advantage; this range has doubled in less than two years to 90km. Coupled with the major cost and security differentials with respect to IR and microwave radiation, this makes fiber the medium of choice for the foreseeable future.

Increasingly, fiber-optic system suppliers are positioning themselves for growth in the data communications market, an area expected to expand by 10x during the next five years. In 1984, AT&T began marketing a LAN system aimed at facilities with networks up to 1km in length; it now offers a product line that can handle 2 to 3km networks.

In the United States, Bell Labs has developed a 44.7 Mbps fiber-optic communication system, which is manufactured by Western Electric (now AT&T Technologies). Known as the FT3 Lightwave Digital Transmission System, it is used primarily for trunk applications in metropolitan areas. The first installations were made in Atlanta, Georgia, in 1976 and in Chicago, Illinois, in 1977. A GaAlAs laser source is used, generating a binary coded signal of 0.5mW at 0.825u. The detector is a silicon APD. Repeater spacings are 6.6 to 10km. LED sources have been used on shorter links.

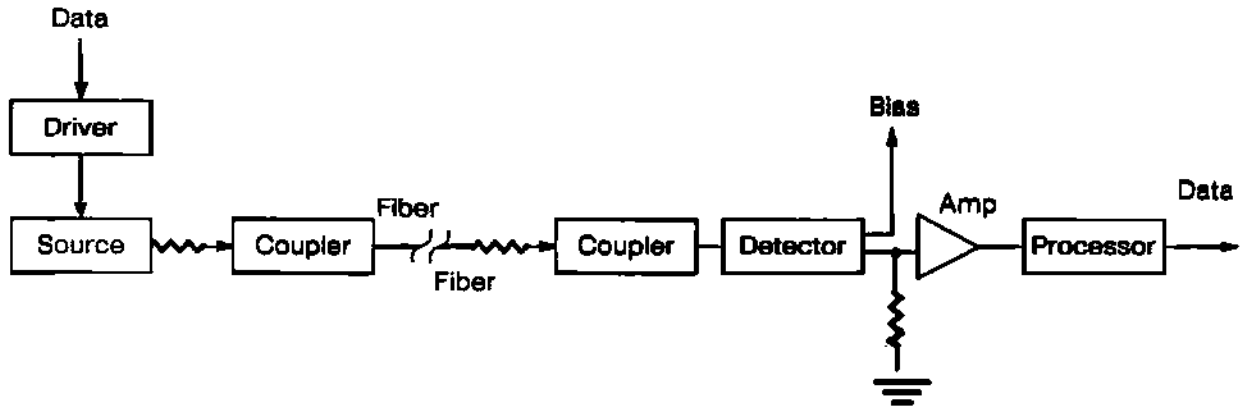
In the United Kingdom, two trial systems were set up in 1977: STL/STC, Hitchin to Stevenage, 9km; and BPO (now British Telecom), Martlesham to Kesgrave, 5.75km. The STL/STC link used silicon junction technology; the BPO link used a GaAs MESFET transmitter. The BPO link later was extended 7.25km to Ipswich using LED and laser sources. Based on system success, British Telecom ordered 10,000km of a combination of 1.3u multimode fiber and monomode fiber cables for its second-generation system.

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Figure 2

Typical Fiber-Optic Transmission Link



Source: Dataquest (April 1991)

Table 1

Comparison of Communications Media

Medium	Bandwidth	Range	Security	Noise Immunity	Cost	Notes
Twisted Pair (Shielded)	100 KHz	1.2km	Fair	Very good	Low	Limited range
Twinax	200 MHz	1.0km	Fair	Very good	High	Controlled Z; can be 802-compatible
Ribbon Cable	10 MHz	0.1km	Fair	Poor	High	Shielding available
Coaxial Cable	400 MHz	2.0km	Fair	Fair	Very high	Can be 802-compatible
Fiber Optics	10 GH3	150+km	Very good	Excellent	Low	Costs continuing to decline
Telephone Line (PABX, PBX)	60 KHz		Poor	Poor	Low	Low cost, installed base
Infrared (Radiation)	20 MHz	0.3km	Fair	Good	Low	Line of sight, reduced range in fog
Microwave (Radiation)	100 MHz	60km	Fair	Poor	High	Line of sight, subject to scatter; link loss depends on antenna size

Source: Dataquest (April 1991)

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In 1985, Philips installed a fiber-optic LAN system, called Philan, in its Geldrop, the Netherlands, project center. The system allows simultaneous TDM transmission of voice and data, and incorporates error control and flow control. Philan uses a meandering-ring structure to link several hundred user stations over a span of 6km. It functions both as a circuit switching net for continuous speech, video, and machine dialogues, and as a packet-switching net for intermittent traffic among various equipment.

Recently, AT&T began service with a long-haul link called the FT Series G, designed to operate at a 1.7-GHz bit rate. It has been tested between Philadelphia and Wayne, Pennsylvania, and can handle 24,000 simultaneous calls on a single pair of glass fibers. The GaAs regenerator circuits are spaced at 24-mile intervals. In another test, AT&T transmitted signals at a 1-GHz bit rate through a 150km long single-mode fiber.

Fiber-optic links are planned for future aircraft applications. Boeing Commercial Airplane Company delivered an aircraft utilizing a FBL (fly-by-light) system in 1989.

Microwave Links

Microwave applications of III-V compound semiconductors include earthbound systems, airborne links, and space systems such as geosynchronous satellite systems. For example, Japan is actively converting its ground-based microwave relay system to a digital system for improved performance.

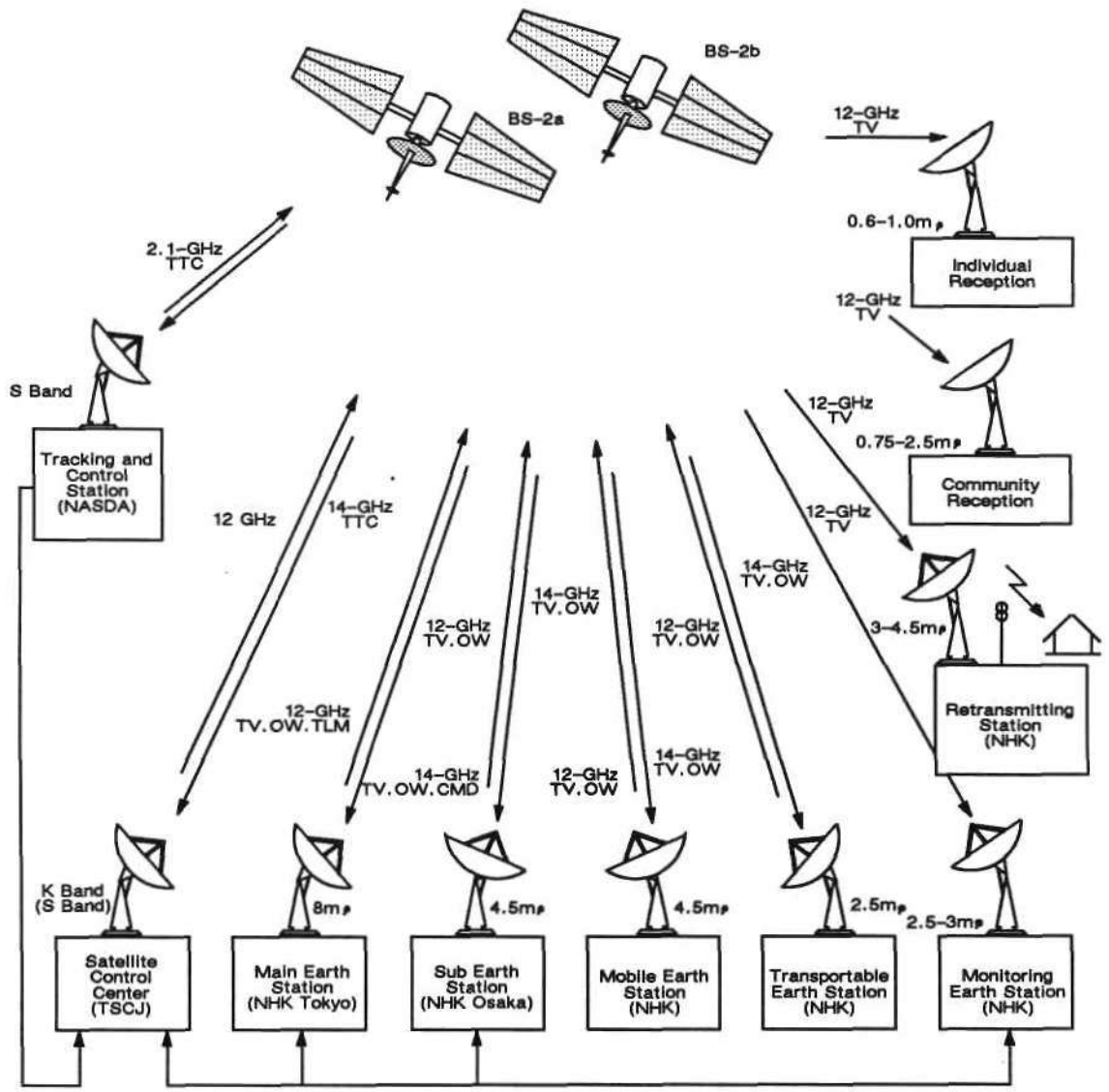
An example of a geosynchronous satellite system is ARABSAT, which comprises a series of satellites to accommodate 8,000 simultaneous telephone circuits, several TV channels, telex, and data transmission services. Twenty-two Arab League countries use the system. NEC is supplying 10 of the earth stations and the satellite control network for the ARABSAT system.

Another example is Japan's BS-2 satellite system. Uplinks are 14 GHz for television traffic and 2.1 GHz for control; downlinks are 12 GHz and 2.1 GHz. Two satellites are used: BS-2a, which was launched in January 1984, and BS-2b, launched in February 1986. Japan expects to upgrade the system with BS-3 satellites in 1991. Figure 3 depicts the system concept.

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Figure 3

Japan's BS-2 Satellite TV System



Source: NHK

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Cellular Radio

The volume potential offered by cellular radio applications is attractive to a growing number of industry participants, which include Fujitsu, Motorola, and NEC. A relatively small example of the potential market is found in Kuwait. Kuwait installed a NEC-supplied integrated cellular telephone system in 1986, which included radio equipment and digital switching for 21 base stations and 15,000 mobile telephones. The system incorporates microwave radio and fiber-optic links, and a medium-scale computer for traffic control and accounting.

Motorola has announced plans to launch 77 satellites for operation at 18 GHz. This system will make possible a worldwide cellular network and will put Motorola into the common-carrier business.

TVRO

Commercial television reception from satellites has attracted much recent attention to GaAs technology, because silicon devices cannot operate at the frequencies of the systems being installed. Pacific Monolithics is believed to be the first company to offer an economical solution to the receiver problem in this application, having introduced a MMIC amplifier for TVRO applications in the $20 range in 1985. Japanese suppliers expect direct broadcast satellite (DBS TV) applications to account for a domestic market of as much as $4 billion in GaAs MMICs.

Peripherals

High-performance optical storage using laser readout is a potentially rapid-growth application for III-V compound devices including GaAs. Reliable eraseability and alterability at lower system per-bit cost are key to the displacement of present high-density magnetic media.

At the 1985 NCC, Verbatim Corporation demonstrated a 3.5-inch erasable optical disk of 40-Mbytes capacity. This and other activities such as work under way at Kodak, Sony, and 3M may soon lead to a quantum jump in cost-effective storage capacity for machines ranging all the way down to personal computers.

High-speed color graphics displays for workstations and other real-time applications are now using GaAs circuits to resolve speed problems. GigaBit and other companies have supplied GaAs circuits used in the front-end video section of such graphics systems.

Optical Computing

The ability of GaAs and other III-V compounds to function near the visible spectrum has spurred serious research into optical computing. Many of the circuits required will be analog in nature. Since the mid-1970s, interest in this field has fluctuated and recently has attracted the attention of the U.S. DOD for potential SDI applications. AT&T is investing R&D effort in a prototype optical computer based on multiple quantum well (MQW) device technology. The prototype unit operating tests started in early 1990.

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Venture capital firms such as Venrock Associates have invested in this technology, and start-up teams are presently seeking capital to fund new enterprises in this field. Although many technical problems in optical computing are unsolved, Dataquest believes that this area holds much promise for growth in the 1990s and will generate demand for both analog/linear and digital GaAs ICs.

INSTRUMENTATION

Instrumentation applications for GaAs and other III-V devices now include:

- High-speed oscilloscopes
- Logic analyzers
- Signal generators
- Spectrum analyzers

The same dilemma in testing exists today that existed when ECL was initially developed in silicon technology: What does one use to test the highest-speed components? At present, 60-GHz testing can be accomplished at the wafer level but is limited to one or two signal probes; Cascade Microtech is considered a leader in this area.

Demands for high-speed wafer-probe stations with more than three probes and for multi-GHz final test equipment for packaged devices have risen acutely with the introduction of LSI GaAs chips. Both suppliers and users are driving these requirements.

The Hewlett-Packard 8780A Vector Signal Generator uses a GaAs current switch IC as a part of its circuitry. GaAs was chosen for its high performance and low energy. The devices are produced at HP's Microwave Technology Center. More than one dozen other HP instruments use GaAs ICs to achieve performance requirements.

Several recent announcements have been made regarding nonintrusive test techniques and methodology. Stanford University and others are making substantial progress in this area. The basic concept involved is the sensing of radiation from the chip at close proximity to determine on-chip signal characteristics.

Dataquest believes that the instrumentation segment of the electronic industry will increasingly adapt GaAs analog/linear ICs to instrumentation circuitry, which will lead to a corresponding displacement of some silicon components in this application. We also expect growth in the use of InP and other compound chips to solve some of the highest-speed test problems.

CONSUMER

Consumer demand for increasingly sophisticated electronic products is driving the market for IR LED and laser transmitter and receiver chips, display chips, optical circuitry, and other III-V compound semiconductors. Broad categories of consumer applications include a wide range of remote controls, displays, toys, and optical storage devices such as audio CD players.

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Toys

In 1986, a new toy laser-gun reportedly experienced first-year volume sales of 1 million units. The rapid decrease in GaAs laser pricing to less than $4 is expected to inspire new toy and game products. Although this market has not yet been tapped by GaAs analog ICs, primarily due to chip cost, experience indicates that this market has future potential for GaAs ICs.

Optical Disks

The rapid growth in demand for compact audio and videodisc players exemplifies the type of growth that can occur in the consumer market as low-cost GaAs devices become available. The recent surge of CDROM activity has driven costs low enough to make optical storage a home-computer peripheral. This increased activity is adding life to a product that had apparently matured in the 1980s. Some CD players now use GaAs lasers that cost less than $0.80 each in large volume.

AUTOMOTIVE

One application of GaAs technology to automotive equipment is the GaAs Hall-effect sensor developed by Siemens. Using this sensor, GaAs devices can be designed to function at temperatures well above the physical limits of silicon, allowing use in the engine compartment for tasks such as measuring crankshaft rotation. Honda is constructing a captive GaAs facility scheduled for volume operation by 1992.

The present automotive aftermarket consumes hundreds of thousands of GaAs chips annually for radar ("speed trap") detectors. Future automotive applications may include GaAs processors for global positioning satellite (GPS) location sensing and collision avoidance.

Collision Avoidance Devices

In 1990, several organizations were investigating the potential market for collision avoidance radar for automotive applications. Low-cost collision avoidance radar, a new application for GaAs ICs, can significantly improve motor-vehicle safety. Hughes has developed a unit that will be used in General Motors automobiles starting in 1994. One company, Vehicle Radar Safety Systems Inc., is already producing a $900 unit, and development activity among automakers is intense. Dataquest expects widespread use of this equipment on passenger vehicles by the late 1990s; this will create a market for high-frequency GaAs circuits that will exceed today's military market.

The advent of production-worthy GaAs chips has made possible low-cost Doppler radar units. By adding a nominal amount of DSP hardware, the Doppler units can provide collision-danger warning signals to the driver of an automobile or other vehicle. A Gunn diode oscillator, power amplifier, mixer, receiver LNA (low-noise amplifier), filters, and, if required, an A/D converter are easily implemented with GaAs. The remaining functions in the unit, including DSP, can be built with silicon devices, as can the filters and A/D converter (depending on operating frequency).

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The following automotive IC development projects were under way by 1989.

Battelle

Battelle recently developed a millimeter-wave radar concept for vehicle collision-avoidance. The proposed system operates at a frequency between 35 and 95 GHz, has a beam-steerable antenna, uses FM/CW (frequency modulated, continuous wave) Doppler radar circuitry, and requires a 10Mbps computer for DSP. Battelle estimates the prototype funding requirement at approximately $750,000.

Daimler-Benz

The European Prometheus project, launched in 1986 by Daimler-Benz, includes development of a collision-avoidance system. A spokesperson for Daimler-Benz estimates that the Prometheus system could reduce European traffic casualties by a factor of two within 15 years. The project involves more than 15 European auto producers and at least 50 research organizations throughout Europe.

Nissan

Nissan Motor Corp. is developing a system using two pulse-Doppler transceivers and an on-board computer to detect danger conditions ahead. Progressive audible alarms will alert the driver as conditions change.

Ford

In the United States, Ford Motor Company and GM/Hughes are working on collision avoidance systems for vehicles. The GM/Hughes unit demonstrated on the Buick Riviera is a forerunner of future systems of this type.

MILITARY/GOVERNMENT

Military, defense, and other government applications for GaAs IC technology include equipment such as radar receivers, phase array transmitters, guidance and control, navigation, electronic warfare including electronic countermeasures, and communications. Germany, Japan, the United Kingdom, France, Canada, and the United States have government-sponsored programs in one or more of these areas that have provided much of the R&D funding for development and application of GaAs technology.

Pulsed Radar

Radar applications were among the first major uses of GaAs devices. Table 2 lists radar carrier-frequency ranges, wavelengths, and corresponding band designations. Figure 4 is a block diagram for a pulse radar system. GaAs is useful in all RF blocks in this type of radar.

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Table 2

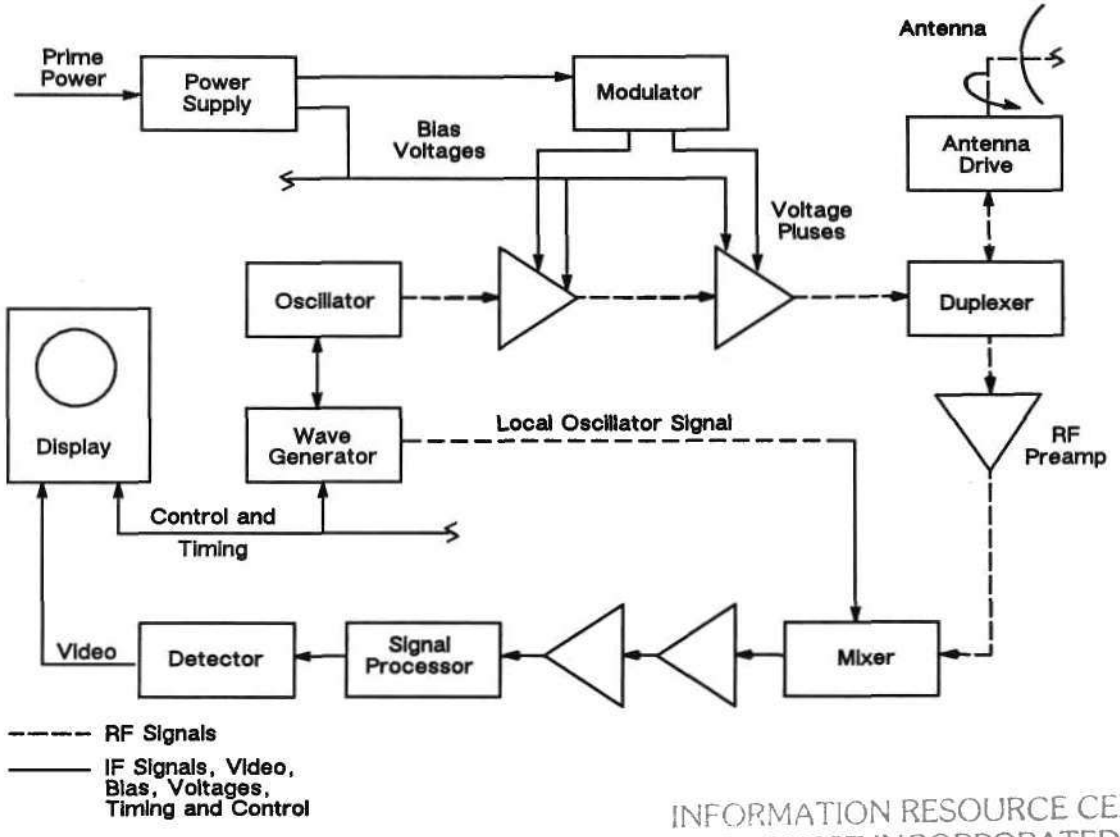
Radar Carrier-Frequency Bands

Band Designator	Nominal Frequency Range	Typical Wavelength
VHF	30-300 MHz	3.0m at 100 MHz
UHF	300-1,000 MHz (1 GHz)	1.0m at 300 MHz
L	1-2 GHz	30.0cm at 1 GHz
S	2-4 GHz	10.0cm at 3 GHz
C	4-8 GHz	5.0cm at 6 GHz
X	8-12 GHz	3.0cm at 10 GHz
K_u	12-18 GHz	2.0cm at 15 GHz
K	18-27 GHz	1.5cm at 20 GHz
K_a	27-40 GHz	1.0cm at 30 GHz
mm	30-300 GHz	0.3cm at 100 GHz

Source: Dataquest (April 1991)

Figure 4

Block Diagram of a Pulse Radar System



Source: Dataquest (April 1991)

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Phased Array Radar

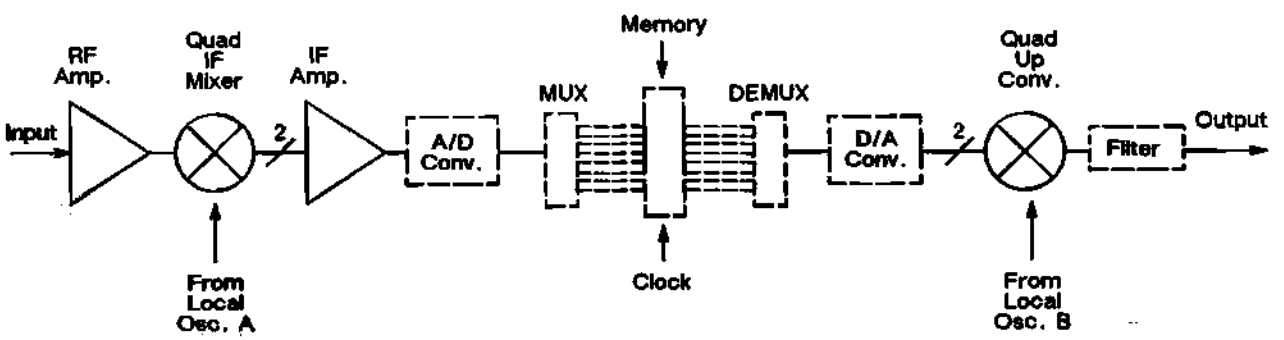
A significant breakthrough in cost-effective radar design was made possible with the advent of MMIC technology. In 1986, Hughes Aircraft achieved 15 percent yields on early pilot production of a two-stage X-band power amplifier for use in a solid-state phased array radar, and Westinghouse reported 30 percent yields on a similar chip. Several companies, including Raytheon and TI, developed transceiver modules containing a maximum of three chips for use in this type of application. The major advantages of phased array radar are the elimination of mechanical rotating or oscillating hardware, which greatly enhances radar performance, and reduced size and weight of associated electronics. In 1989 and 1990, several companies reported developments leading to single-chip radar transceiver chips.

Signal Processing

A digital RF memory is useful for electronic warfare. This function requires GaAs MMICs for preprocessing and postprocessing of signals to be most effective. Figure 5 shows an example of a digital RF memory function. The amplifiers, mixer, A/D and D/A converters, MUX and DEMUX blocks, up-converter, and filter are all candidates for GaAs analog/linear MMICs.

Figure 5

DRFM Functional Block Diagram



Source: Dataquest (April 1991)

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Hardware Redundancy Techniques

Redundancy in hardware design can enhance system reliability. Triple modular redundancy (TMR) is a fault-tolerant technique used extensively in electronic hardware, including military systems, for increased reliability. Because TMR can lengthen system cycle time, GaAs is a more attractive medium than silicon for implementation.

A TMR chip designed by the Research Triangle Institute has been built and demonstrated. The design was based on TriQuint's 1u D-MESFET process; TriQuint fabricated the prototypes. Initial tests indicated that the circuit adds less than 3ns overhead to a TMR processor configuration.

MIMIC Program

The DOD MIMIC (millimeter-microwave IC) initiative represents a major effort to incorporate the advantages of compound semiconductors into a variety of military applications. These include:

- Ultrareliable radar for the U.S. Air Force ATF
- Shared-aperture radar for the U.S. Navy ATA
- MILSTAR network communications terminals
- Smart munitions
- Wideband jammers
- Antiradiation missiles
- Other "brilliant" weapons

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The MIMIC program entered Phase 0 early in 1987 with the award of 12 major and 4 smaller contracts to prime contractors. Phase I began in mid-1988, with awards to four teams. The Phase I awards are detailed in the section entitled Competitive Analysis. At press time, Phase II proposals were submitted but awards had not yet been made.

The primary issue faced by MIMIC program participants is the usual dilemma of how to recover costs in the face of tighter U.S. defense budgets. Government demands for competitiveness among suppliers have not been accompanied by a minimum level of business required for survival, and, to date, the suppliers have not made the necessary marketing investment to develop additional business base for cost recovery.

USER ISSUES

The user issues involved in the application of GaAs IC technology to analog/linear functions are similar to those encountered in digital and optoelectronic applications.

Material defects and process variations presently cause wafer probe yields below 50 percent for many high-density, high-performance GaAs devices. Combined with relatively high substrate cost, custom test equipment requirements, and high package costs, the results are functional density and pricing that presently limit GaAs ICs to only the highest performance applications where no alternative technology is available.

To Integrate, or Not to Integrate?

The issue of deciding whether to use a monolithic approach or a hybrid approach is very complicated. At microwave frequencies, all passive and active components exhibit some time-variant combination of resistance, inductance, and capacitance. This aggravates the usual chip layout and packaging problems, and eliminates many of the options available at lower frequencies.

The degree of integration achievable above 10 GHz is not obvious to most designers, so a key design concept is to proceed with caution and test the assumptions. Often, a hybrid approach is the only achievable solution to a system problem with time constraints. Companies such as Pacific Monolithics are focusing on this specific area with novel monolithic solutions to very difficult integration problems.

Decreasing the Risk of System Obsolescence

The advent of cost-effective GaAs analog/linear and digital functions has expanded the users' options to include any desired combination of silicon and GaAs analog/linear, ECL, TTL, NMOS, and CMOS. Thus the systems house and its competitors have a wider variety of design approaches than ever before.

The user must carefully make elaborate tradeoff studies before risking a hardware design to overnight obsolescence (by new silicon devices from any one of dozens of suppliers). Astute users will take advantage of the unique properties of GaAs ICs in systems approaches that can be made very resistant to obsolescence by silicon evolution.

Transmission Line Environment

The user must determine whether expertise exists in-house or is to be developed, if GaAs is to be used for maximum performance advantage. GaAs ICs allow operation at frequencies requiring terminated-line interconnections. This problem can be postponed by maximizing the use of TTL interface levels in the near term, but sooner or later it must be confronted by those pursuing the performance market.

All of the major computer houses have developed the necessary expertise within their respective ECL design groups, as have the RF houses within the microwave design function. Others, which grew up on low-frequency silicon analog/linear NMOS or bipolar and gravitated toward CMOS, will face a design cost barrier at some point in the future. This barrier height increases with time.

Parametric Control

Threshold voltage control is receiving increased attention from both designers and producers of GaAs digICs. The parametric variations in GaAs linear circuits are indeed numerous. The development of a good, low-cost gate-insulation method will reduce reliance on Schottky structures and their related threshold voltage variations. Better CAD tools and device models will also help the designer accumulate the expertise and knowledge necessary to take advantage of GaAs analog/linear device technology.

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Testing

Testing remains a problem area in GaAs IC production and suppliers have been forced to develop in-house test capability. This area represents a market opportunity for the first company to successfully build a 50+ GHz test system that can be priced within reach of the more than 600 GaAs IC users.

International Competition

A major concern among U.S. suppliers of GaAs ICs and discrete components is the relative timing of the Japanese competitors' market entries. Predatory practices such as those experienced in the small-signal FET market would have a disastrous effect on U.S. GaAs IC development. All of the major Japanese suppliers to the communications market have GaAs analog/linear development under way, and the consumer analog/linear device suppliers are not far behind. We believe that they are waiting for the U.S. suppliers to develop the market further before attacking.

Export Controls

Because of the extensive use of GaAs and other III-V semiconductors in some types of military equipment, export of devices can be a major issue. This is a problem or a potential problem for suppliers in any country, not just the U.S. suppliers.

Some Japan-based potential suppliers are believed to be withholding GaAs analog/linear merchant market entry until they have met their internal needs for parts for communications equipment and other critical applications. This would strengthen Japan's position in the world GaAs IC marketplace.

Spectrum Crowding

As more and more equipment operates at microwave frequencies, crowding of the frequency band is becoming a major issue. Fortunately, some emissions are easily shielded; otherwise, spectrum crowding would have already reached an intolerable state. Although the U.S. FCC and similar agencies from other governments regulate emissions, the semiconductor user must not ignore the basic problems that arise from a lack of attention to the end-use environment.

Cost Factors

Compound semiconductor yields are improving and costs are decreasing dramatically. As recent industry experience shows, users should seek price projections when planning new designs and should consider having the projections updated quarterly throughout the development and prototyping cycle.

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Product Availability

The rapid change in GaAs analog/linear IC technology has caused rapid obsolescence of many existing device designs. This is causing some suppliers to reevaluate their product portfolios and others to reassess their positions in the microwave device marketplace. As a result, the user may face loss of one or more sources of supply, and may need to qualify new suppliers as the industry completes its readjustment to the realities of the 1990s.

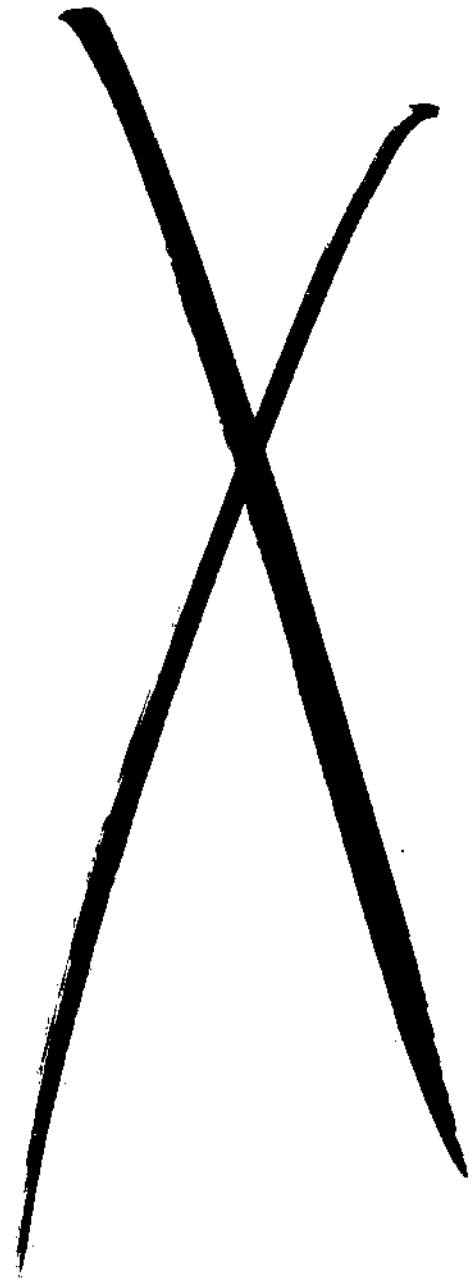
Safety Issues

Microwave amplifiers may represent sources of dangerous radiation, depending on the frequency of operation. Whereas the cancer-causing and other hazardous effects of X-rays have long been known, the real and potential adverse effects of microwave and near-visible radiation are not so well understood. However, there is evidence that long-term exposure to UV radiation is carcinogenic. Organizations such as the University of Washington School of Medicine are studying the effects of pulsed microwaves on human tissue such as heart muscle.

The problems are complex; for example, in a 1988 test at 2.5 GHz, the most radiation-resistant microwave-protective suits proved to be less flame-retardant than other suits having high resistance to radiation at this frequency. All of the suits tested appeared to provide reasonably good protection above 700 MHz, but were not satisfactory at VHF frequencies, which are used for commercial and civil television and for communications bands.

In another example, lidar (laser radar) operating at 780nm and 10mW power in RM-CW (random modulation continuous wave) mode has been determined to be eye-safe within ANSI standards, according to the National Institute for Environmental studies, Tsukuba, Japan. However, the ANSI standards may not be sufficiently stringent to prevent long-term damage to the eye or other tissues. Thus, manufacturers and users alike need to carefully determine whether safety hazards exist or will be created in their particular environments as changes are made and as new chips and applications evolve.

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Analog/Linear GaAs ICs—Historical Shipment Data

Tables 1 through 5 summarize shipment revenue estimates for analog/linear GaAs ICs. Estimates for NRE charges are separated from device shipment figures.

Table 1

Estimated Worldwide Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	80	107	138	157	187	242
NRE	40	51	53	50	45	48
MMIC amps	12	17	21	28	31	42
ASICs	19	24	42	51	78	114
Other	9	15	22	28	33	38

Source: Dataquest (April 1991)

Table 2

Estimated U.S. Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	78	101	124	137	159	180
NRE	40	50	51	48	43	38
MMIC amps	11	14	17	22	24	27
ASICs	18	22	37	43	66	88
Other	9	15	19	24	26	27

Source: Dataquest (April 1991)

Table 3

Estimated Western European Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	2	5	11	15	17	30
NRE	0	1	2	2	2	6
MMIC amps	1	2	3	4	4	5
ASICs	1	2	4	6	8	14
Other	0	0	2	3	3	5

Source: Dataquest (April 1991)

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Table 4

Estimated Japanese Analog/Linear GaAs Merchant Shipments (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	0	1	3	5	11	32
NRE	0	0	0	0	0	4
MMIC amps	0	1	1	2	3	10
ASICs	0	0	1	2	4	12
Other	0	0	1	1	4	6

Source: Dataquest (April 1991)

Table 5

Estimated Japanese Analog/Linear GaAs Merchant Shipments (Billions of Yen)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	0	0.1	0.4	0.65	1.52	4.32
NRE	0	0	0	0	0	0.54
MMIC amps	0	0.1	0.1	0.23	0.41	1.35
ASICs	0	0	0.1	0.23	0.55	1.62
Other	0	0	0.1	0.19	0.55	0.81

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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GaAs ASICs—Historical Shipment Data

Tables 1 through 4 summarize historical shipment estimates for GaAs digital and analog/linear ASICs. In the tables, estimated NRE charges are shown separate from device shipment figures.

Table 1

Estimated Worldwide GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total GaAs ASICs	83	117	154	169	220	302
Digital GaAs ASICs	24	42	59	68	97	140
NRE	20	30	36	35	29	46
Devices	4	12	23	33	68	94
Analog/Linear GaAs ASICs	59	75	95	101	123	162
NRE	40	51	53	50	45	48
Devices	19	24	42	51	78	114

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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Table 2

Estimated U.S. GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total GaAs ASICs	78	111	138	146	186	220
Digital GaAs ASICs	20	39	50	55	77	94
NRE	19	29	33	32	26	28
Devices	1	10	17	23	51	66
Analog/Linear GaAs ASICs	58	72	88	91	109	126
NRE	40	50	51	48	43	38
Devices	18	22	37	43	66	88

Source: Dataquest (April 1991)

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Table 3

Estimated Western European GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total GaAs ASICs	4	6	9	15	20	37
Digital GaAs ASICs	2	3	4	7	10	17
NRE	1	1	2	2	2	8
Devices	1	2	2	5	8	9
Analog/Linear GaAs ASICs	2	3	5	8	10	20
NRE	1	1	3	2	2	6
Devices	1	2	2	6	8	14

Source: Dataquest (April 1991)

Table 4

Estimated Japanese GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total GaAs ASICs	0	0	5	8	14	45
Digital GaAs ASICs	0	0	4	6	10	29
NRE	0	0	1	1	1	10
Devices	0	0	3	5	9	19
Analog/Linear GaAs ASICs	0	0	1	2	4	16
NRE	0	0	0	0	0	4
Devices	0	0	1	2	4	12

Source: Dataquest (April 1991)

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Digital GaAs ICs—Historical Shipment Data

Digital GaAs ICs (digICs) grew by approximately 39 percent in 1989, to $163 million worldwide. NRE charges increased nearly 60 percent, to $46 million. The majority of the shipments were made by U.S. companies, with major gains made by the Japanese suppliers. Tables 1 through 5 summarize shipment revenue estimates for GaAs digICs. NRE charges are listed separately.

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Table 1

Estimated Worldwide GaAs DigIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	26	51	71	86	117	163
NRE	20	30	36	35	29	46
Standard Logic	1	5	7	11	12	13
RAMs	1	4	5	7	8	10
ASICs	4	12	23	33	68	94

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

Table 2

Estimated U.S. GaAs DigIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	24	47	60	69	92	107
NRE	19	29	33	32	26	28
Standard Logic	3	4	5	7	8	6
RAMs	1	4	5	7	7	8
ASICs	1	10	17	23	51	66

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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Table 3

Estimated Western European GaAs DigIC Merchant Shipments by Technology (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	2	3	5	8	11	18
NRE	1	1	2	2	2	8
Standard Logic	0	0	0	1	1	1
RAMs	0	0	0	0	0	0
ASICs	1	2	3	5	8	9

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

Table 4

Estimated Japanese GaAs DigIC Merchant Shipments by Technology (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	0	1	6	9	14	38
NRE	0	0	1	1	2	10
Standard Logic	0	1	2	3	3	6
RAMs	0	0	0	0	1	3
ASICs	0	0	3	5	9	19

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

Table 5

Estimated Japanese GaAs DigIC Merchant Shipments by Technology (Billions of Yen)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	0	0.1	0.8	1.1	1.9	5.1
NRE	0	0	0.1	0.1	0.1	1.4
Standard Logic	0	0.1	0.3	0.4	0.4	0.8
RAMs	0	0	0	0	0.1	0.4
ASICs	0	0	0.4	0.6	1.2	2.6

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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GaAs Discretes—Historical Shipment Data

Tables 1 through 5 summarize shipment revenue estimates for GaAs uWave/mmWave discretes by geographic region.

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Table 1

Estimated Worldwide GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	178	228	222	243	291	305
SS Transistors	109	141	135	150	181	188
Power Transistors	59	73	72	77	92	98
Hall Elements, Others	10	14	15	16	18	19

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

Table 2

Estimated U.S. GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	87	112	118	117	131	136
SS Transistors	35	54	61	58	59	60
Power Transistors	51	56	55	57	69	73
Hall Elements, Others	1	2	2	2	3	3

Source: Dataquest (April 1991)

Table 3

Estimated Western European GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	11	14	16	19	22	22
SS Transistors	6	7	8	10	11	11
Power Transistors	4	5	6	7	8	8
Hall Elements, Others	1	2	2	2	3	3

Source: Dataquest (April 1991)

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Table 4

Estimated Japanese GaAs uWave/mmWave Discretes Merchant Shipments (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	80	102	88	107	138	147
SS Transistors	68	80	66	82	111	117
Power Transistors	4	12	11	13	15	17
Hall Elements, Others	8	10	11	12	12	13

Source: Dataquest (April 1991)

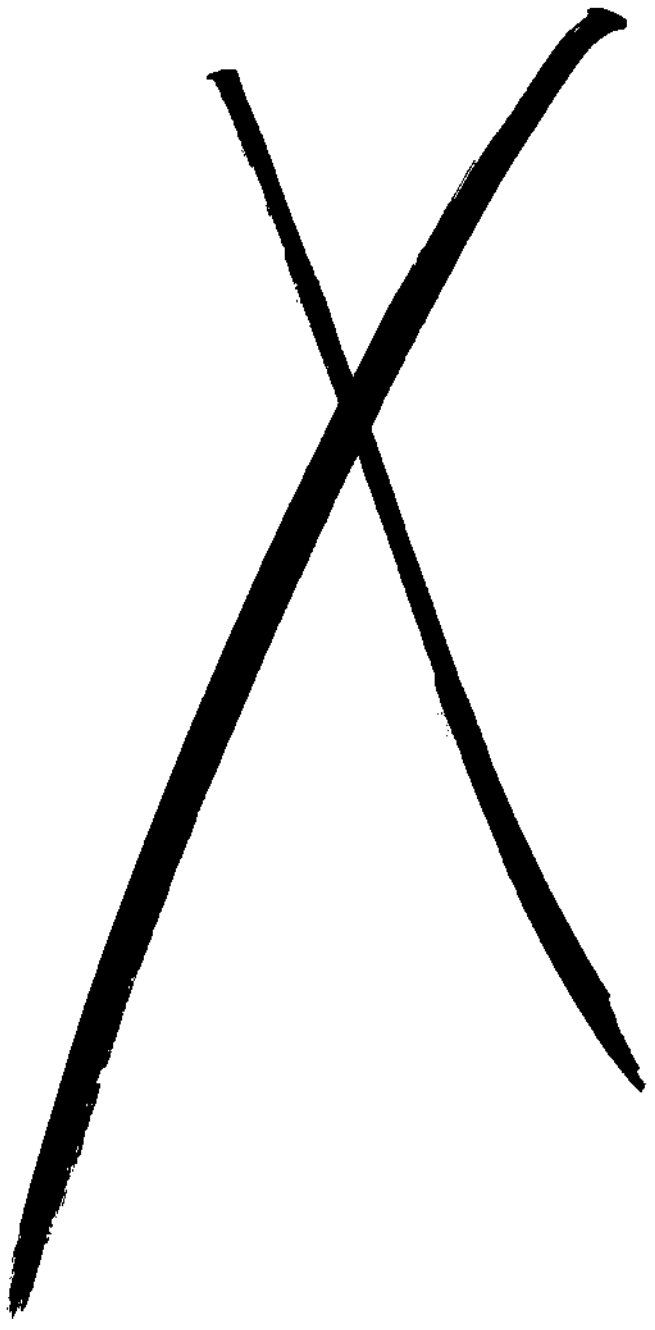
Table 5

Estimated Japanese GaAs uWave/mmWave Discretes Merchant Shipments (Billions of Yen)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	20.0	17.0	12.7	13.9	19.0	19.8
SS Transistors	17.0	13.4	9.5	10.7	15.3	15.8
Power Transistors	1.0	2.0	1.6	1.7	2.1	2.3
Hall Elements, Others	2.0	1.7	1.6	1.5	1.7	1.8

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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Analog/Linear GaAs ICs—Historical Shipment Data

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Tables 1 through 5 summarize shipment revenue estimates for analog/linear GaAs ICs. Estimates for NRE charges are separated from device shipment figures.

Table 1

Estimated Worldwide Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	80	107	138	157	187	242
NRE	40	51	53	50	45	48
MMIC amps	12	17	21	28	31	42
ASICs	19	24	42	51	78	114
Other	9	15	22	28	33	38

Source: Dataquest (April 1991)

Table 2

Estimated U.S. Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	78	101	124	137	159	180
NRE	40	50	51	48	43	38
MMIC amps	11	14	17	22	24	27
ASICs	18	22	37	43	66	88
Other	9	15	19	24	26	27

Source: Dataquest (April 1991)

Table 3

Estimated Western European Analog/Linear GaAs Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	2	5	11	15	17	30
NRE	0	1	2	2	2	6
MMIC amps	1	2	3	4	4	5
ASICs	1	2	4	6	8	14
Other	0	0	2	3	3	5

Source: Dataquest (April 1991)

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Table 4

Estimated Japanese Analog/Linear GaAs Merchant Shipments (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	0	1	3	5	11	32
NRE	0	0	0	0	0	4
MMIC amps	0	1	1	2	3	10
ASICs	0	0	1	2	4	12
Other	0	0	1	1	4	6

Source: Dataquest (April 1991)

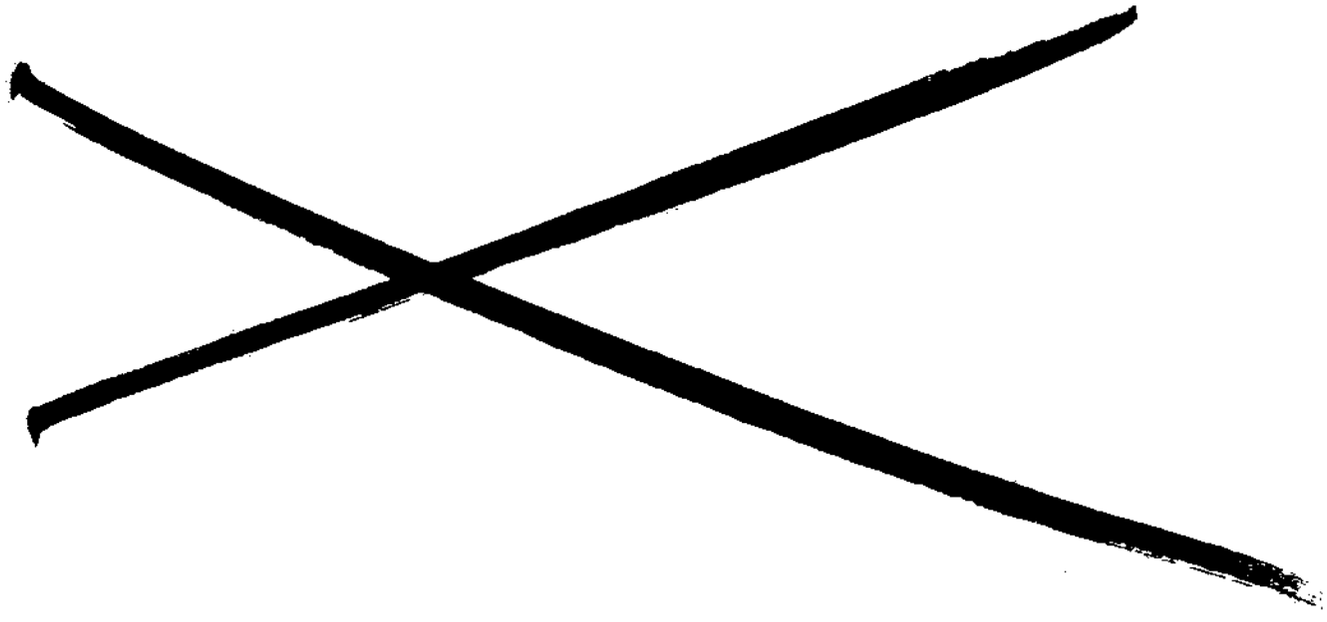
Table 5

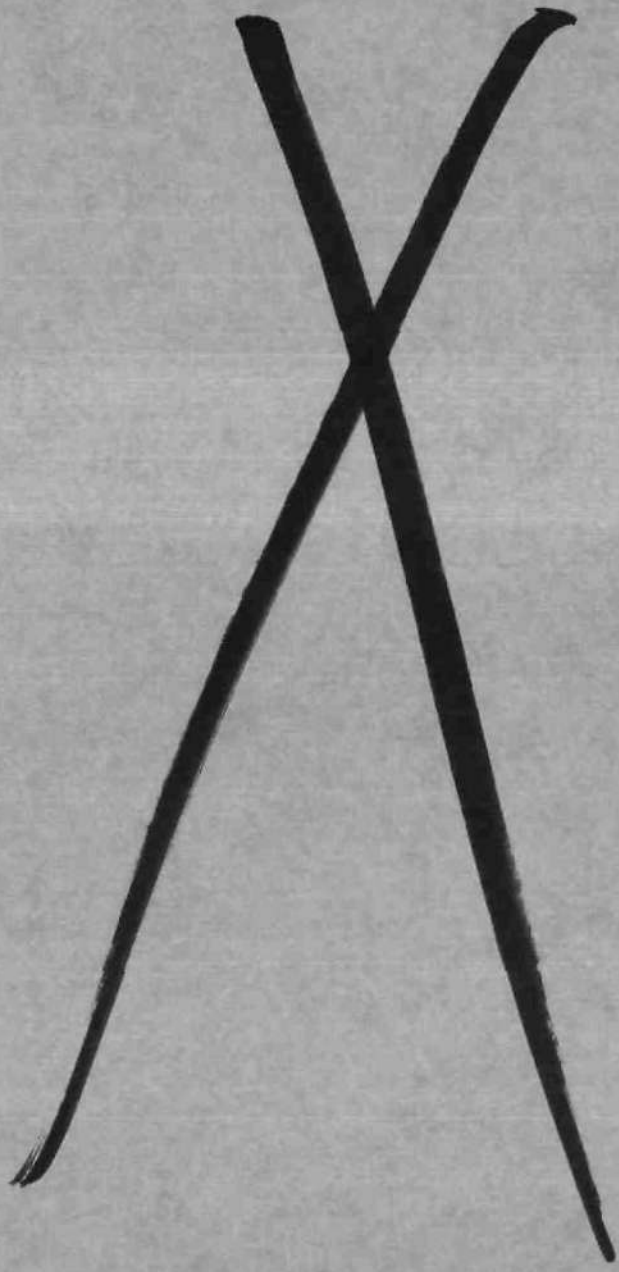
Estimated Japanese Analog/Linear GaAs Merchant Shipments (Billions of Yen)

Category	1985	1986	1987	1988	1989	1990
Analog/Linear ICs	0	0.1	0.4	0.65	1.52	4.32
NRE	0	0	0	0	0	0.54
MMIC amps	0	0.1	0.1	0.23	0.41	1.35
ASICs	0	0	0.1	0.23	0.55	1.62
Other	0	0	0.1	0.19	0.55	0.81

Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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GaAs ASICs--Executive Summary

INTRODUCTION

GaAs analog integrated circuits (ICs), especially microwave monolithic ICs (MMICs), traditionally have required a high degree of customization to meet the customers' needs. Because the recent growth of applications has resulted in a shortage of design talent, the industry has sought more efficient use of this talent. Thus, ASIC (application-specific integrated circuit) approaches to chip design, developed during the last 20 years in silicon ICs, are being adapted to GaAs ICs.

In the analog area, the standard cell approach was pioneered by Pacific Monolithics and proved that GaAs ASIC MMICs can be worst-case designed for production at significant cost savings to the customer. In the digital segment, GigaBit Logic and others have developed gate arrays exceeding 15,000-gate density, with TTL and ECL interface options.

This section focuses on GaAs digital and analog, including microwave and millimeter wave, ASICs. It includes discussions of products, competitors, markets, and applications, and summarizes some of the major issues involved in this relatively new, rapidly evolving field.

TECHNOLOGY

GaAs offers the following advantages over silicon in ASIC technology:

- Integration of photonic and microwave electronic functions into a single chip
- Absolute speed
- Superior speed-power product
- Greater radiation resistance
- Wider operating-temperature range
- Simpler production process (compared with ECL and BiCMOS)

The primary disadvantages of GaAs ASICs at present are:

- Lower functional complexity at a given production maturity level
- Interconnection cost and complexity sometimes greater

The first monolithic microwave integrated circuit (MMIC) patent was applied for in 1966. Since then, microwave ASICs have led the evolution of GaAs and other III-V compound IC technology toward ever-increasing levels of performance.

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GaAs ASICs--Executive Summary

GaAs ASIC technology is delivering the system performance advantages inherent in its chemistry. GaAs analog ASICs can be designed to function up to and beyond 30 GHz. Gates using D-MESFET structures are providing loaded propagation delays of less than 50ps at power levels 50 percent to 75 percent below that of ECL gates. New structures promise delays of 15ps and lower.

A good example of the advantages of GaAs ASIC is found in EW applications. GaAs ASICs now allow designers to place high-density threat detection and jamming capability into heretofore inaccessible places in aircraft structures such as wingtips, nosecones, and leading edges of flying surfaces.

PRODUCTS

Currently available GaAs ASICs include gate arrays, custom SRAMs, and standard-cell MMICs. As of August 1990, digital GaAs ASICs with gate counts greater than 30,000 gates per chip had been satisfactorily tested, and 22,000-gate ASICs were in production.

Gate Arrays

Gate arrays represent the major ASIC effort to date in GaAs digICs. TriQuint, Vitesse, and other US suppliers, as well as one UK supplier, have chosen GaAs gate arrays as a major experience vehicle. Customers are increasingly using these devices for the usual reasons attributed to gate array acceptance:

- Reduced system size and part count
- Lower system production costs
- Improved system security
- Shortened product start-up cycle
- Enhanced system performance and reliability
- Lower cost of customer ownership

Table 2 and Table 3 in the "Digital GaAs IC Products" section summarize GaAs gate array products and cost model details, respectively.

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GaAs ASICs--Executive Summary

Analog/linear GaAs ASIC products offer the same advantages over standard devices as in silicon technology, namely:

- Improved performance via tailored design
- Improved quality and reliability through fewer wire bonds and discrete components
- Reduced size, weight, and power

GaAs analog/linear ASIC products may include two or more functions in a single chip, as follows:

- Amplifiers—Transimpedance, preamps, AGC amps, op amps
- Converters—A/D, D/A, sample and holds, phase-locked loops
- Analog signal conditioners—Mixers, tuners, switches, doublers
- Oscillators, e.g., VCOs
- Comparators

MARKETS

The worldwide market for GaAs ASICs was approximately $225 million in 1989; an estimated $74 million of this was for nonrecurring (NRE) charges. The market is expected to grow at approximately 30 percent CAGR through 1994, to an estimated $819 million.

The GaAs ASIC markets and their typical applications are:

- Military/Government—Radar, lidar, satellite communications, ECM and EW equipment, fiber-optic links, GPS receivers
- Supercomputers—CPU logic, interface logic, register files, cache memory
- Communications—TVRO, commercial satellites, cellular phones, fiber links
- Instrumentation—Spectrum analyzers, microwave testers, digital oscilloscopes, surveying equipment
- Consumer—Compact discs, video discs, HDTV, small-boat navigation equipment
- Automotive—Collision-avoidance radar, radar detectors, position location units

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GaAs ASICs--Executive Summary

COMPETITORS

The companies that are presently supplying GaAs ASICs to the merchant market are listed in Table 1. The leaders among the start-ups include GigaBit Logic, Pacific Monolithics, TriQuint, and Vitesse. Some companies in the table had not announced products at press time; others supply only to one or a very limited number of customers. Significant activity is under way in the development of alternate sourcing and other technology partnerships and agreements; see Table 2 for examples.

Table 1

Examples of GaAs ASIC Suppliers

United States	Japan	Western Europe
Alpha Industries	Fujitsu	LEP (Philips)
California Eastern Labs (NEC)	NEC	Plessey
Gazelle	Sumitomo	Siemens
GigaBit Logic	Toshiba	Thomson CSF
Harris		
Honeywell		
ITT GTC		
M/A-COM		
Pacific Monolithics		
Rockwell		
TriQuint		
Vitesse		

Source: Dataquest
August 1990

More than a dozen foundries are available to serve the growing customer base for GaAs analog/linear ASICs and custom products. Additionally, there are many captive suppliers of GaAs ASICs, some of which are teamed in support of the DOD MIMIC initiative. These are tabulated in the "GaAs Analog/Linear IC" section.

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Table 2

GaAs ASIC Sourcing Agreements and Technology Partnerships

Companies	Nature of Agreement
AT&T/M/A-COM	Jointly offering MMIC products and foundry services; jointly developing heterostructure processes
Pacific Monolithics/TriQuint	TriQuint processes wafers for PM
Pacific Monolithics/COMSAT Labs	Circuit design exchange
Rockwell/IBM	DigIC and opto device development
Cray/GigaBit Logic	Sole-source pact on standard cell gate arrays and memories
Gazelle/TriQuint	TriQuint processes wafers for Gazelle
GigaBit Logic/NKT	European design center
Pacific Semiconductor/TriQuint	Joint ownership of patents on process technology and logic topologies
TRW/TriQuint	Class S ASICs
Fujitsu/Vitesse	E/D gate array alternate sourcing
Ford Microelectronics, IBM, Singer, COMSAT, Pacific Monolithics, TriQuint	ASIC communications, radar, and support chips
TriQuint/Rockwell	Alternate sourcing of QLSI CBICs

Source: Dataquest
August 1990

ISSUES

The issues of threshold voltage variations, materials quality, and related problems resulting in depressed yields have, for the time being, been resolved well enough to allow economical production of GaAs digital LSI and VLSI chips. Testing and yield enhancement continue to demand significant resources, however. The issue of multiple sourcing received considerable attention in 1989 from the GaAs IC user base.

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GaAs ASICs--Executive Summary

The major issues facing suppliers and users of GaAs ASICs at the end of 1989 were:

- Market development
- Maintaining growth in VLSI density levels at a reasonable pace with respect to progress in silicon technology
- Testing
- Export controls
- Design considerations:
  - Monolithic versus hybrid trade-offs
  - Decreasing the risk of system obsolescence
  - Transmission line environment considerations
  - Design tolerance of parametric variations
  - Test problems due to lack of high-performance equipment
- Frequency spectrum crowding
- Product availability and cost:
  - Impact of international competition
  - Impact of industry structural changes
- Safety issues, including potential radiation hazards

For more than a decade, forecasts of the GaAs ASIC market have proven, in retrospect, to be optimistic. Of the issues discussed here, market development holds the key to industry growth; solutions to the other problems will follow. History may yet prove that the period of the late 1980s was the turning point at which market acceptance of GaAs technology increased above the level required for sustained rapid industry growth.

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Table 1 shows Dataquest's forecasts for the GaAs ASIC market. In the table, nonrecurring engineering (NRE) charges are shown separate from device sales. The forecast assumes sustained materials quality improvements, continued open-market availability of DF wafers, a successful DOD-sponsored MIMIC program funded in excess of $500 million over seven years, and no predatory pricing by major suppliers.

Table 1

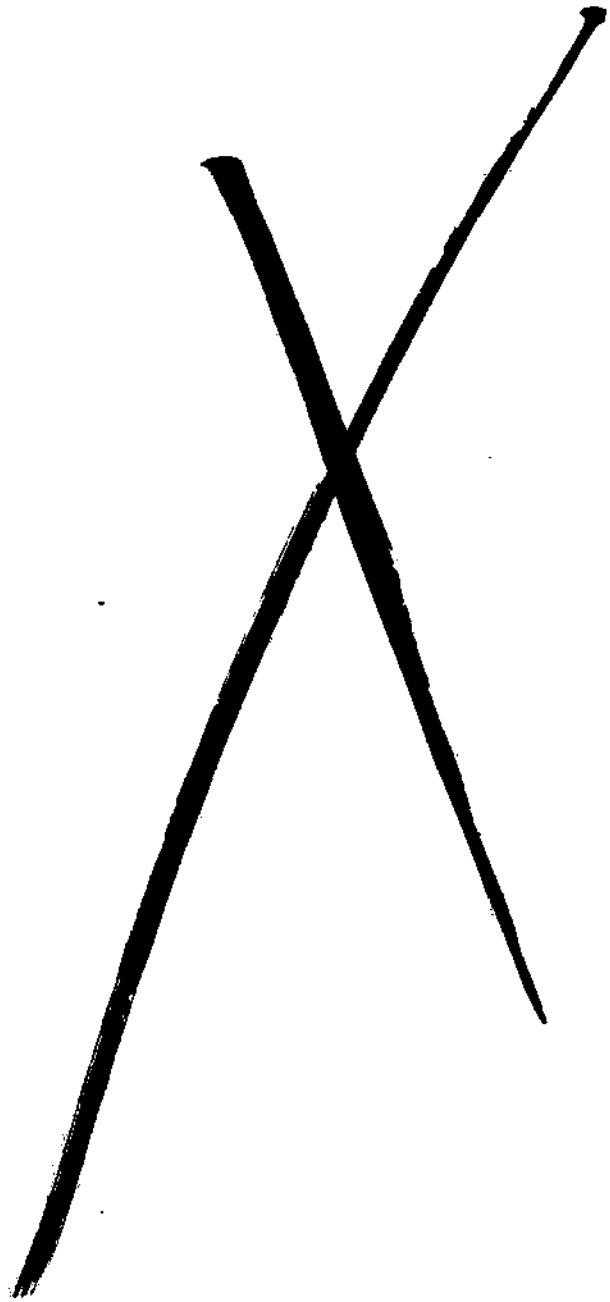
Worldwide GaAs ASIC Merchant Consumption Forecast
(Millions of Dollars)

Category	1989	1990	1991	1992
Total GaAs ASICs	220	302	410	515
Digital GaAs ASICs	97	140	192	252
Devices	68	94	144	204
NRE	29	46	48	48
Analog GaAs ASICs	123	162	218	263
Devices	78	114	171	214
NRE	45	48	47	49

Category	1993	1994	1995	CAGR (%) 1990-1995
Total GaAs ASICs	662	847	948	25.7
Digital GaAs ASICs	354	484	534	30.7
Devices	304	433	484	38.8
NRE	50	50	50	0.8
Analog GaAs ASICs	308	363	414	20.6
Devices	256	310	354	25.4
NRE	52	53	60	4.6

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (May 1991)

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GaAs ASICs--Emerging Technology and Trends

EMERGING TECHNOLOGY

Emerging technology for GaAs ASICs may be categorized as oriented toward improving materials, processes, devices, chip functions, or software tools. Examples of these technologies include:

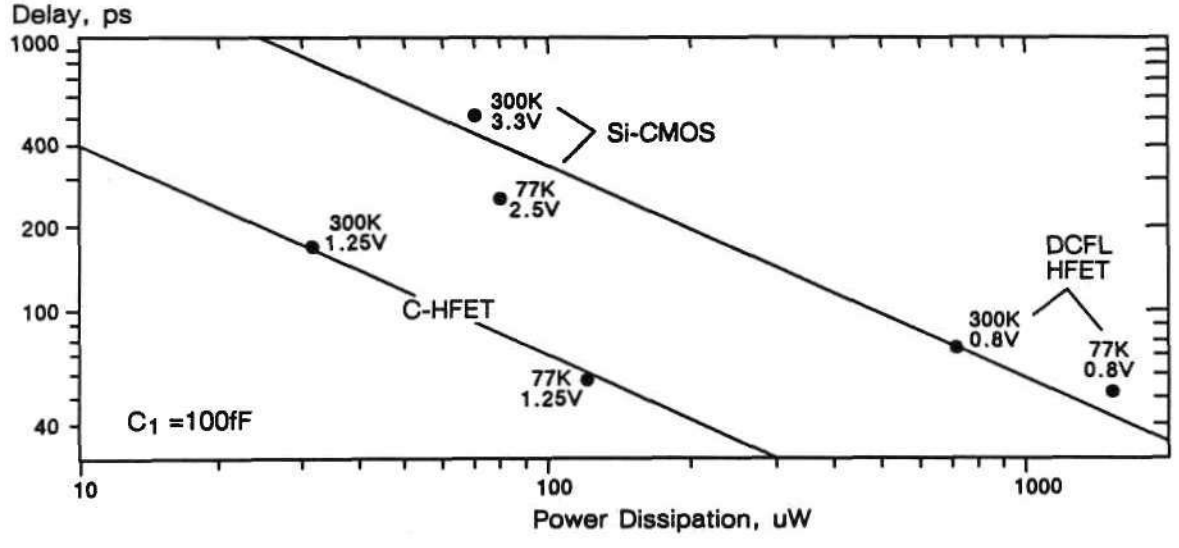
- Complementary Heterostructure FET (C-HFET) logic and heterojunction bipolar transistors (HBTs), which will lead to improved cost/performance ratios
- GaAs-on-Si and NDF 4-inch wafers, which may lead to higher levels of integration, thus improving cost/performance ratio still further
- More efficient and precise circuit models, leading to shorter development cycles

C-HFET Logic

The potential power savings of C-HFET logic at the speeds available in n-channel DCFL HFET circuits is substantial; savings are estimated at up to 90 percent in one IBM study. Computer simulations indicate that C-HFET circuits of 30,000-gate complexity operated at 1.25V power supply would provide loaded gate delays below 150ps (FI=3, FO=3) at a chip power dissipation of less than 5 watts. Figure 1 compares C-HFET performance with that of DCFL HFET and silicon CMOS at room temperature and at 77°K.

Figure 1

GaAs C-HFET Performance Comparison



Source: Dataquest (August 1990)

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HBTs

HBTs represent a substantial potential for improved logic speed, at efficiency (speed-power product) several times that of silicon ECL when both are taken to the limits of lithography. Some of the recent development work in this technology is very promising, as the following example indicates.

Using 2u x 5u (relatively coarse) emitter dimensions and low-resistance emitter caps, NTT fabricated vertical self-aligned AlGaAs/GaAs HBTs that were operated to 80 GHz. A 21-stage ECL ring oscillator based on this approach showed 5.5ps delay per stage at 25°C. NTT plans to scale the design using tighter geometries, to achieve even higher performance.

Rockwell and IBM have a technology agreement that has resulted in the development of a 5,090-transistor gate array. This effort is expected to have a major impact on computer mainframe designs.

GaAs-on-Si

The first paper on GaAs-on-Si was presented by MIT researchers in 1981 in the IEEE Electron Device Letters. Since then, the potential for large-diameter wafers for GaAs manufacture and for monolithic integration of photonic and electronic functions at low cost has attracted R&D talent and investment capital.

Kopin Corporation has disclosed that it has sampled 6-inch GaAs-on-Si wafers. Kopin started shipping 4-inch production wafers in December 1987. The growth of GaAs-on-Si wafers on a production basis is described by John C.C. Fan, founder of Kopin, as an "enabling technology for future GaAs market growth."

Other companies and groups involved in GaAs-on-Si technology include AT&T Bell Labs, Ford Microelectronics, GTE, Hewlett-Packard, MIT, NTT, Oki, Spire Corporation, TI Materials Science Laboratory, and the University of Illinois. Examples of their activities are as follows:

- Ford Microelectronics has produced devices and plans products that combine III-V and II-VI materials on Si substrates up to 200mm (8-inch) diameter.
- TI initially fabricated 1K SRAMs using GaAs-on-Si in 1986.
- In 1987, University of Illinois researchers fabricated the first reported GaAs-on-Si continuous-wave (CW) lasers that operate at room temperature.

Much research is under way to determine whether GaAs-on-Si CW lasers can be produced at costs acceptable to the market. Should long life and reproducibility be established, GaAs CW lasers would be obsoleted rapidly by GaAs-on-Si. This in turn would foster significant high volumes of innovative digital IC products, such as optically bussed A/D-D/A converters and interface logic chips.

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GaAs ASICs--Emerging Technology and Trends

TRENDS

System designers with more than ten years of practical experience are well aware of the innovations achievable with semiconductor ASICs. They also appreciate the concept of "overnight obsolescence" brought on by intense competition among chip suppliers. Cost-effective GaAs VLSI is causing a similar rapid evolution of ASIC (and therefore system) designs.

Multitechnology Logic Systems Design

In the 1960s, TTL-compatible PMOS was developed. This allowed the designer for the first time to use the best available bipolar and MOS functions in a single ASIC chip design. Bipolar ECL-to-TTL and TTL-to-ECL interface chips appeared at about the same time. In the 1970s, IC users became accustomed to mixing bipolar analog/linear, TTL, and NMOS (or ECL and NMOS) logic and memory functions on board designs for major systems; later, CMOS was added to the list of options.

The advent of cost-effective GaAs ASIC functions has expanded the users' options to include any desired combination of ECL, TTL, NMOS, CMOS, and GaAs electronics as well as photonics functions. Thus, the systems house (and each of its competitors) has a wider variety of design approaches than ever before.

Higher Performance and Lower Power

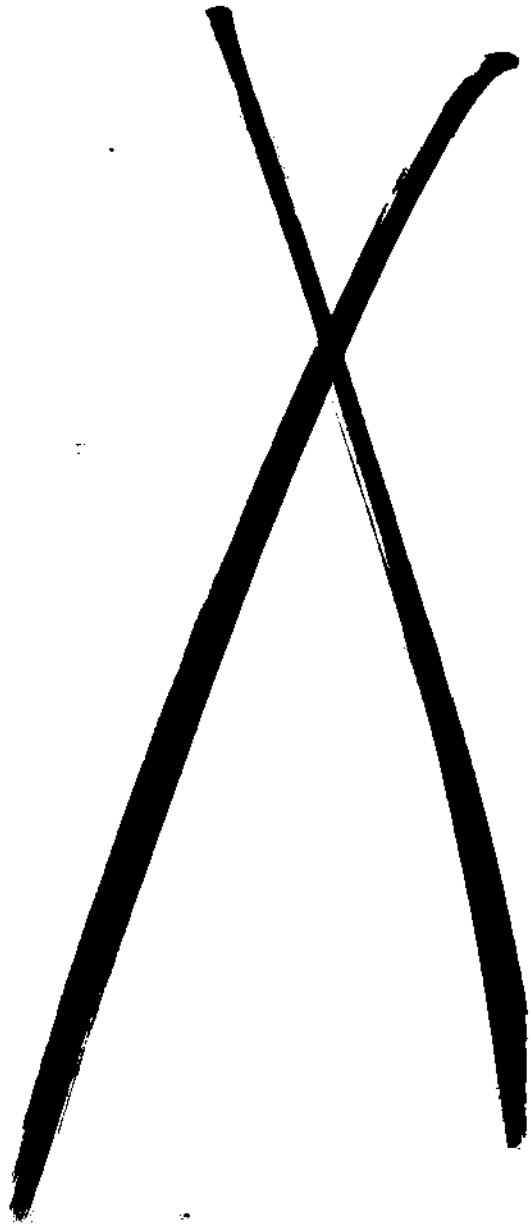
System designers can now take advantage of GaAs analog/linear and digital ASICs that provide both higher speed and lower power than their silicon counterparts. It is now possible to purchase gate arrays that allow a 2X-speed advantage over ECL at one-half the power consumption of the same ECL function. As geometries shrink, this differential will remain available. The message to the system designer is, "Consider GaAs as an alternative; the competition probably is already doing so," as is borne out by the activities under way at almost all of the major computer and workstation houses.

Density Trends

In 1989, production GaAs ASICs were based on processes featuring minimum geometries of approximately 1 micron (1u). Almost all of the processes are scalable to less than 0.25u rules, which will result in rapid evolution of chip density by a factor of four. Thus, 30,000 to 100,000 gate arrays represent relatively straightforward product refinements without a need for changing IC production equipment. Astute ASIC users requiring leading-edge performance now have an excellent opportunity to upgrade their equipment designs by taking advantage of expected near-term GaAs ASIC chip evolution.

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GaAs ASICs--Applications and User Issues

APPLICATIONS

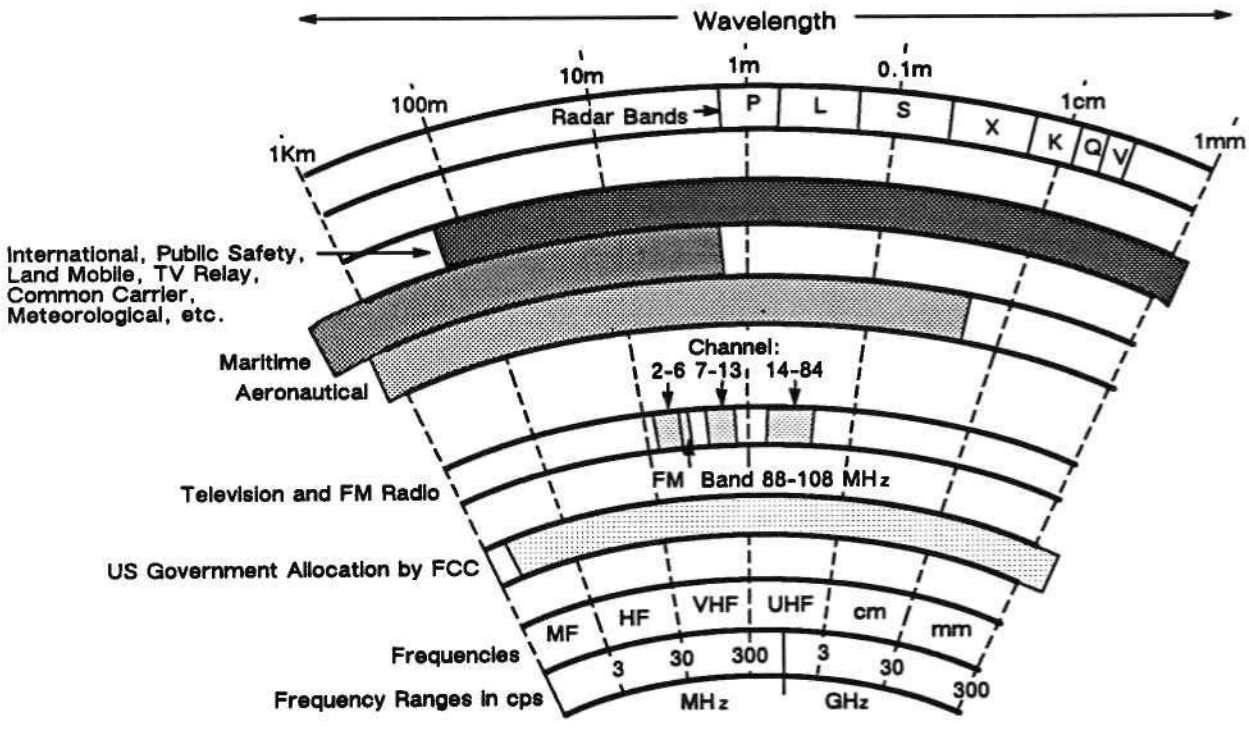
The unique properties of GaAs and other III–V compounds allow solutions to technical problems that were heretofore not economically solvable. Primary examples are found in the fields of fiber–optic and satellite communications, supercomputers, high–speed graphics, radar systems, high–speed test/measurement, and specialized military and government electronics.

Military and government applications, including aerospace, provided the initial impetus for compound semiconductor technology development. Among these are satellite communications, electronic warfare, electronic countermeasures, smart munitions, surveillance, and high–speed signal processing.

This section gives examples of the growing number of diverse applications for GaAs ASICs, some of which are shown in Figure 1. The problem of interference among applications is increasingly acute as the frequency spectrum becomes crowded; precise control of operating frequencies and radiation patterns are major system design considerations. As further cost improvements are realized, end uses are increasingly extending into the full spectrum of markets—telecommunications, computer, instrumentation CAD/CAE/CAM, artificial intelligence, robotics, military/aerospace, automotive, and consumer.

Figure 1

Applications by Operating Frequency



Note: Only portions of the indicated bands are allocated as shown, to avoid frequency clutter

Source: Aztek Associates

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USER ISSUES

Alternate Sourcing

Dataquest believes that there will be a continuing stream of alternate-source agreements over the next three years. Unfortunately, there are genuine alternate sources and there are alternate sources that exist in name only.

The source of this dilemma centers around the process technology. Process development is moving rapidly, and it is difficult for both the supplier and the user to discern which technology will dominate, making it difficult to choose good alternate sources. Perhaps the best advice when picking prime and alternate sources is to carefully examine how many standard products the supplier is building in the process--or, if the supplier is an ASIC company, how large an R&D commitment the supplier has made. In both cases, if an ASIC technology can be linked to a family of standard products or to heavy R&D investment, it reflects a very deep commitment.

Supplier-User Interface

GaAs ASICs offer different expectations for suppliers and users. Most suppliers would like to sell their products without large investments in EDA equipment, engineering talent, and a network of design centers. The user, on the other hand, wants to transform a design into hardware at the lowest possible cost and as fast as possible. Or, to say it another way, both parties would like to have a standard product with the flexibility of GaAs ASICs. Unfortunately, GaAs ASIC technology does not offer such an ideal.

User Wants

Most customers who buy GaAs ASICs want the following:

- Quick delivery of the prototype units
- Easy-to-use EDA tools that require a minimum amount of time to learn
- Prototype units that work the first time
- Low development and production costs
- Convenient design centers and training

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Supplier Wants

Most suppliers would like:

- Minimum user involvement
- Maximum production volumes
- Few design changes

The Moment of Truth—First Prototype Units

Nowhere do all of the above issues become more evident than in first prototype units. It is here that both parties must face all the past planning errors. For example, if simulation has not been done properly during the design cycle, the prototype units will not meet specification; thus, the errors must be corrected, adding to the development schedule and necessitating more user involvement.

Dataquest has noted two major approaches to simulation. One way is to incorporate testability into the design; the "ASIC Overview" section in the SIS Products and Markets binder discusses this approach in some detail. The other approach considers adding test circuitry to be a waste of time and money. Most of the large GaAs ASIC suppliers require simulation, while the smaller companies take a more flexible position, examining each design case by case.

Regardless of which approach is used, it is generally agreed that there will be a great deal of activity in the development of tools to aid simulation. Most workstation and ASIC manufacturers are developing products to improve simulation.

Decentralizing the Design Function

With the proliferation of design centers, we believe that over the next few years, users will do more GaAs ASIC designs. This will occur largely because it will:

- Widen the base of engineers who can design products
- Make maximum use of expensive capital equipment that ASIC suppliers must buy
- Disperse the risks for both user and supplier, since both contribute to the design effort

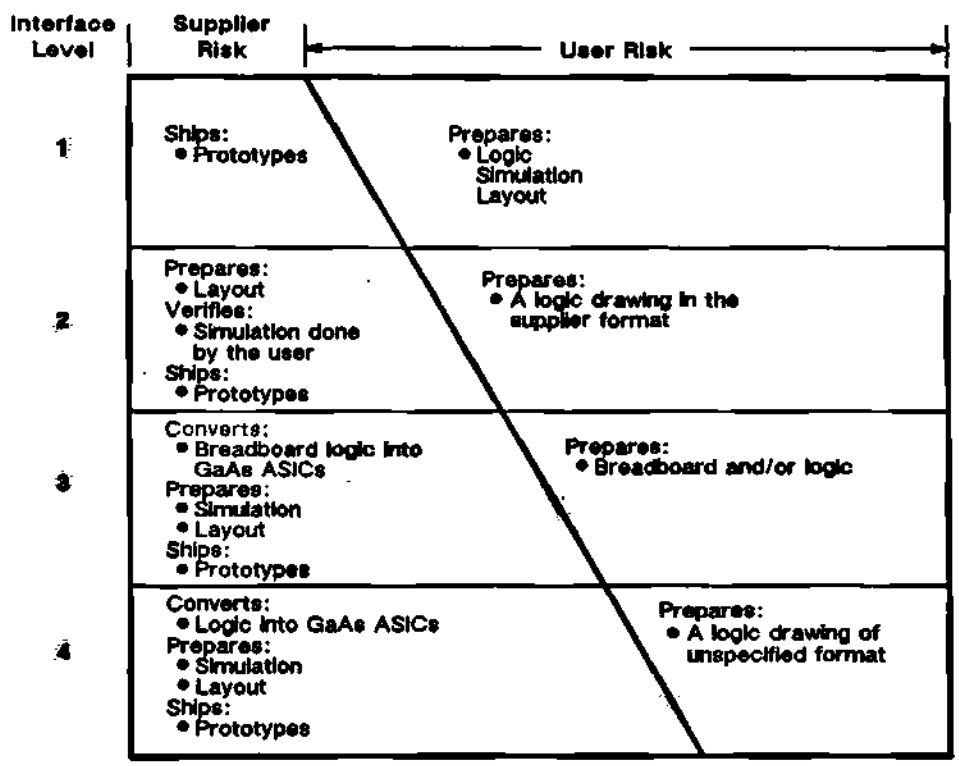
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Figure 2 shows the proportionate risks associated with four common interface levels between a user and a supplier. Each level centers on the risk of handling a complete description of the product. At level 1, the user assumes the majority of the responsibility and risk, while the supplier is most at risk at level 4. Level 3 depicts an interface that is still used but that we believe is falling out of favor. Most users are choosing level 2, largely because the interface can be quite explicit if an EDA workstation is used. In fact, it is widely accepted that the emergence of third-party workstations has established a de facto standard. Most of the popular workstations offer this equipment with cell libraries from various major suppliers, thus allowing the user to design the product to interface with several suppliers. Regardless of which interface is chosen, the strong and unrelenting trend is toward giving the user a very active role in the design of ASICs.

Figure 2

Proportionate Risks at Supplier/User Interface Levels



Source: Dataquest (August 1990)

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Electronic Design Automation

Electronic design automation (EDA) is a very broad subject and is sometimes confusing, especially when used in reference to the design of GaAs ASICs. The terminology can even take on different meanings at different points in the design process. Table 1 illustrates a typical design process, starting with creation of a logic diagram and ending with generation of the phototooling used to fabricate an ASIC. Listed with each step are the most common hardware and software used at that step. For example, a workstation may be a Daisy, Mentor Graphics, or Valid Logic, and the 32-bit computer may be a Digital Equipment VAX 11/750 or 780, or an IBM 3033 or 3081. Recently, personal computer (PC) based workstations have emerged that can be used to capture the logic schematic and do prerouting logic simulation. These low-cost systems are expected to become very popular for GaAs ASIC designs below 4,000 gates, as the feature performance of these systems improve. To add to the confusion, software can be third party, that is, software that is sold by independent software companies or programs developed by the hardware company for its own equipment. In some cases, the GaAs ASIC supplier may provide a family of programs. Examples of common third-party simulators are TEGAS, CADAT, and SILOS. Most suppliers offer their own programs for place and route.

Table 1

GaAs ASICs Design Process

	Task	EDA Hardware
Front End	Capture logic schematic	PC-based workstation and 32-bit computer or EDA workstation
	Simulate logic, schematic, and fault detection	32-bit computer or EDA workstation
	Auto place and route	32-bit computer and plotter
Back End	Resimulate and continuity checks	32-bit computer or EDA workstation
	Create phototooling	32-bit computer

(Continued)

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Table 1 (Continued)

GaAs ASICs Design Process

	EDA Software
Front End	Workstation application programs or simulator logic capture programs
	TEGAS, SILOS, SIMON, SPICE, CADAT
Back End	Place and route software GDSII, GARDS
	DRC, ERC, DRACULA, HILO
	TEGAS test program and pattern generator programs

Source: Dataquest
August 1990

Front End and Back End

Another set of common terms used to segment the design effort are front end and back end. Although the exact meaning varies from company to company, front end usually refers to the design effort, starting with logic capture and ending with simulation. Back end refers to the place and route through creation of the phototooling used in fabrication. Regardless of which phase of the design process is under consideration, we have noted that EDA technology has changed the design process by the introduction of:

- Low-cost 32-bit computers
- Low-cost workstations for capturing the logic schematic
- High-performance software for placement, route, and simulation

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We also believe that EDA companies will continue to enhance their products. For example, many of the workstation companies are working on capturing a portion of the back-end design. Some GaAs ASIC suppliers are expanding their simulators to take on larger arrays and even multiple arrays, while other companies are developing flexible cell libraries to handle on-chip ROM and RAM. All this suggests that the EDA systems will experience very rapid changes over the next few years.

As with any technology, progress in dealing with the issues involved in the application of GaAs ASICs requires diligence, patience, and considerable effort. The rewards are substantial; Cray Research has maintained its lead in supercomputers with the application of GaAs ASICs to its CRAY-3.

At present, material defects and process variations cause wafer probe yields below 50 percent for many VLSI-density GaAs ASIC devices. Combined with relatively high substrate cost, custom test equipment requirements, and high package costs, the results are functional density and pricing that limit GaAs ASICs to the highest-performance applications where silicon ECL is the alternative technology.

Decreasing the Risk of System Obsolescence

The advent of cost-effective GaAs digital functions has expanded the ASIC users' options to include any desired combination of ECL, TTL, NMOS, CMOS, and GaAs. Thus the systems house and its competitors have a wider variety of design approaches than ever before, and they must carefully make elaborate tradeoff studies before risking a hardware design to overnight obsolescence by new silicon devices from any of more than 200 suppliers. Unlike baseball, this game can be over before the player ever gets to the field. Astute users will take advantage of the unique properties of GaAs ASICs in systems approaches that can be made very resistant to obsolescence by silicon evolution.

Achieving VLSI

The future growth rate of the digital GaAs ASIC market is heavily dependent on converging with the level of integration of high-performance silicon devices. The primary pressure toward VLSI is caused by the significant percentage of gate performance loss due to interchip interconnection impedance constraints. In addition, high-reliability, multichip, controlled impedance packaging is complex and expensive. The largest barrier to be overcome is VLSI yield, which was, until recently, limited by starting-material quality and, to a greater extent, by processing and worst-case design limitations.

Transmission Line Environment

When choosing a GaAs ASIC family, the user must determine whether expertise exists in-house or is to be developed, if GaAs is to be used to the maximum performance advantage. GaAs ASICs allow operation at frequencies requiring terminated-line interconnections. Although this problem can be postponed by using TTL interface levels

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in the near term, sooner or later it must be confronted by those pursuing the performance market. All of the major computer houses have developed the necessary expertise within their ECL design groups. Other companies that grew up on NMOS or TTL and gravitated toward CMOS will face a design cost barrier in the future; the height of this barrier increases with time.

Threshold Voltage Control

Threshold voltage control is a major difficulty that is receiving increased attention by both designers and producers of GaAs ASICs. The development of a good, low-cost, gate-insulation methodology will reduce reliance on Schottky structures and their related threshold voltage variations. Better CAD tools and device models have been developed, but continued progress is required.

Testing

Testing is still a problem area in GaAs ASIC production, and suppliers such as Gigabit Logic have been forced to develop in-house test capability. This area represents a market opportunity for the first company to successfully build a multi-GHz LSI/VLSI test system that can be priced within reach of the more than 500 users of GaAs ASICs.

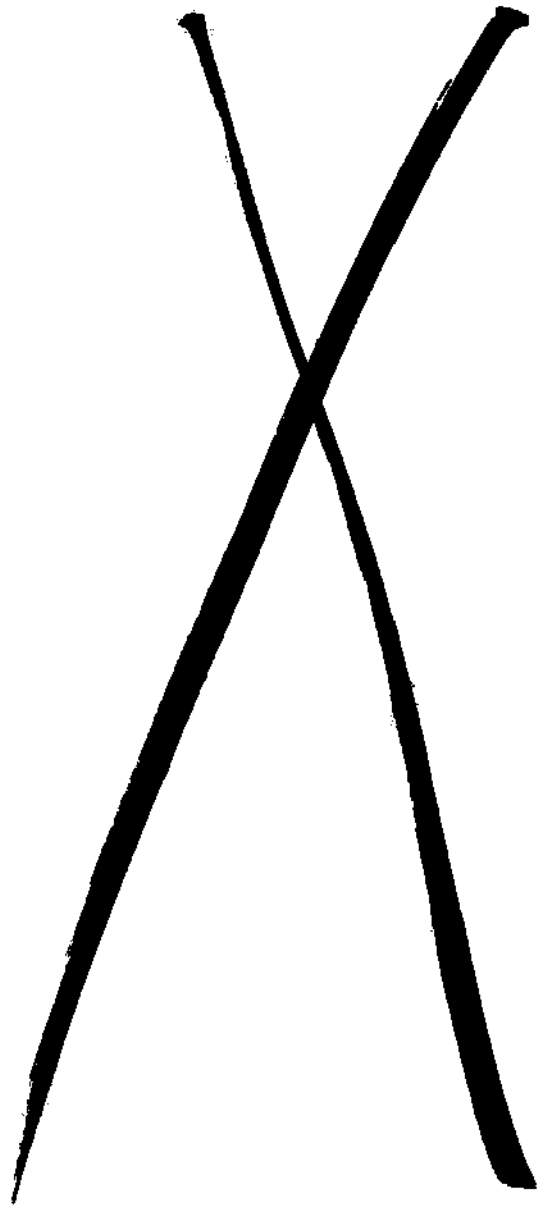
Export Controls

Because of the extensive use of GaAs and other III-V semiconductors in some types of military equipment, export of devices can be a major issue. This is a problem, or a potential problem, for suppliers worldwide, not just for the US suppliers.

International Competition

Some Japan-based potential supplier companies are believed to be deferring GaAs ASIC merchant market entry until they have met their internal needs for parts for fifth-generation computers and other critical applications. This would strengthen Japan's position in the world computer marketplace.

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GaAs ASICs—Historical Shipment Data

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Tables 1 through 4 summarize historical shipment estimates for GaAs digital and analog/linear ASICs. In the tables, estimated NRE charges are shown separate from device shipment figures.

Table 1

Estimated Worldwide GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total GaAs ASICs	83	117	154	169	220	302
Digital GaAs ASICs	24	42	59	68	97	140
NRE	20	30	36	35	29	46
Devices	4	12	23	33	68	94
Analog/Linear GaAs ASICs	59	75	95	101	123	162
NRE	40	51	53	50	45	48
Devices	19	24	42	51	78	114

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

Table 2

Estimated U.S. GaAs ASIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total GaAs ASICs	78	111	138	146	186	220
Digital GaAs ASICs	20	39	50	55	77	94
NRE	19	29	33	32	26	28
Devices	1	10	17	23	51	66
Analog/Linear GaAs ASICs	58	72	88	91	109	126
NRE	40	50	51	48	43	38
Devices	18	22	37	43	66	88

Source: Dataquest (April 1991)

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Table 3

Estimated Western European GaAs ASIC Merchant Shipments by Technology (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total GaAs ASICs	4	6	9	15	20	37
Digital GaAs ASICs	2	3	4	7	10	17
NRE	1	1	2	2	2	8
Devices	1	2	2	5	8	9
Analog/Linear GaAs ASICs	2	3	5	8	10	20
NRE	1	1	3	2	2	6
Devices	1	2	2	6	8	14

Source: Dataquest (April 1991)

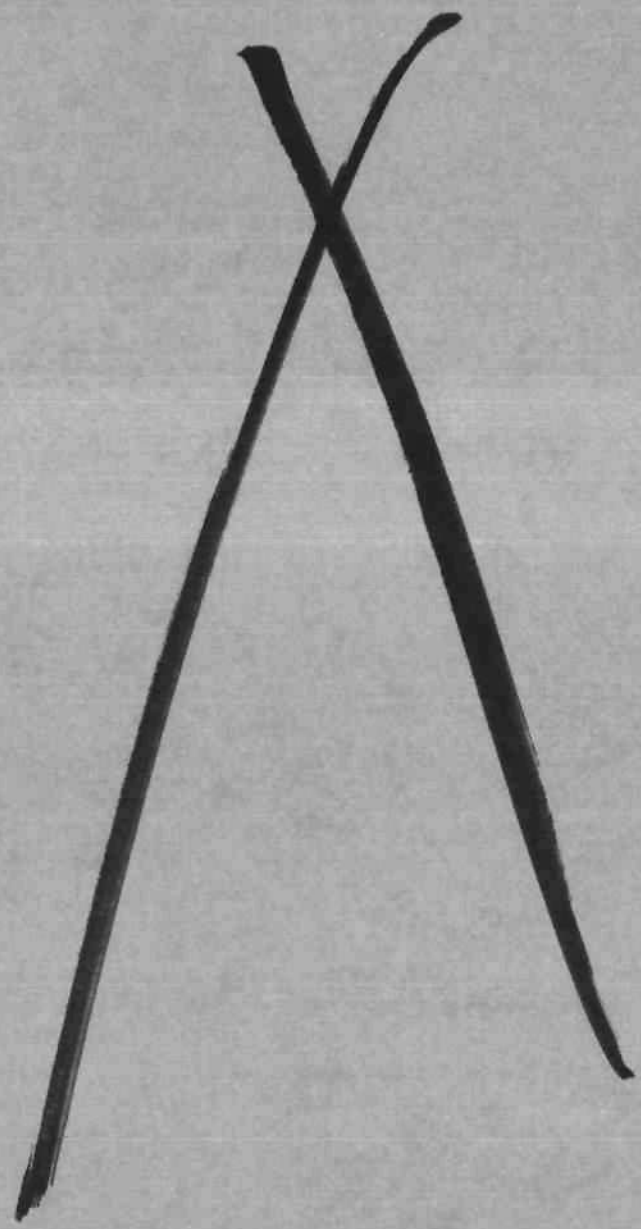
Table 4

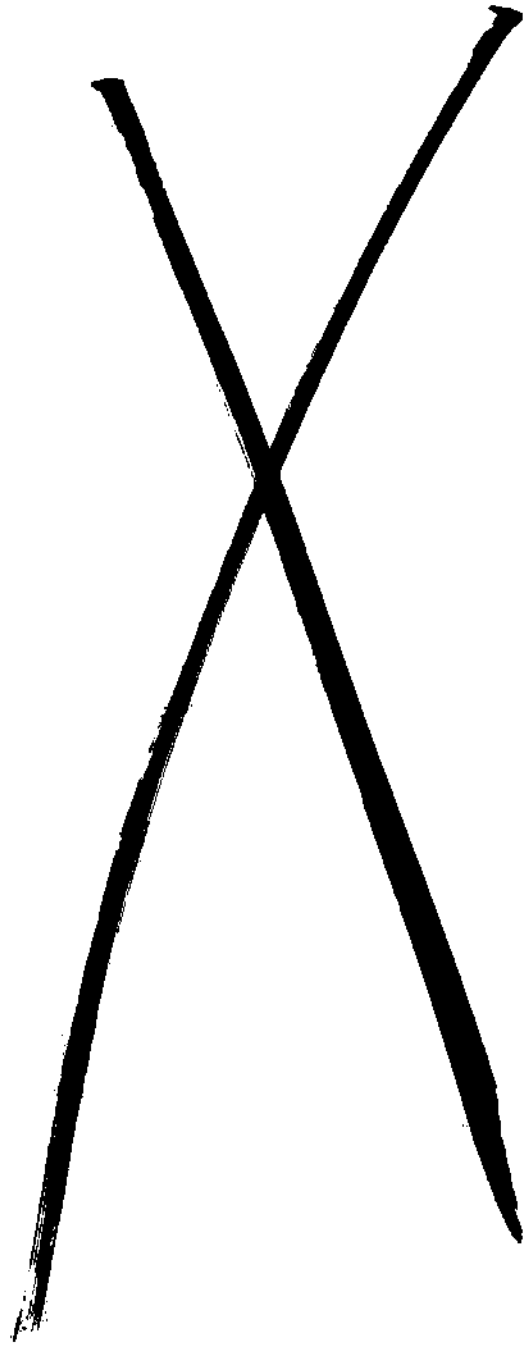
Estimated Japanese GaAs ASIC Merchant Shipments by Technology (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total GaAs ASICs	0	0	5	8	14	45
Digital GaAs ASICs	0	0	4	6	10	29
NRE	0	0	1	1	1	10
Devices	0	0	3	5	9	19
Analog/Linear GaAs ASICs	0	0	1	2	4	16
NRE	0	0	0	0	0	4
Devices	0	0	1	2	4	12

Source: Dataquest (April 1991)

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Digital GaAs ICs—Executive Summary

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INTRODUCTION

GaAs digital integrated circuits (digICs) are causing a major evolution of systems, raising performance to record heights. The CRAY-3 supercomputer uses more than 70,000 GaAs IC chips to achieve 2ns instruction cycles (64-bit words). This section focuses on GaAs digIC technology, products, competitors, markets, and applications, and summarizes some of the major issues involved in this exciting, rapidly growing field.

TECHNOLOGY

GaAs offers the following advantages to digital IC technology, compared with the properties offered by silicon:

- Absolute speed improvement of three to five times
- Superior speed-power product, three to five times more efficient
- Processing less complex than that used in silicon IC fabrication
- Greater radiation resistance
- Wider operating temperature range
- More efficient integration of photonic functions
- Photonic and electronic functions integratable on a single chip

The primary disadvantages of GaAs digICs now are:

- Substrate cost relatively higher than silicon
- Lower functional complexity at a given product maturity level

Digital GaAs technology is delivering the system performance advantages inherent in its physical structure. Gates using E/D-MESFET structures are providing loaded propagation delays of less than 50ps at power levels 50 percent to 75 percent below that of comparable ECL gates. New structures promise delays of less than 10ps.

PRODUCTS

The recent rate of integration of GaAs digICs has been approximately 4x density per year, and the limits of lithography are at least several years away. As of December 1990, the largest reported GaAs SRAM had a density of 64 Kbits (approximately 100,000 transistors). The largest production gate array was more than 100,000 gates.

Gate Arrays

Gate arrays represent the major ASIC effort to date in GaAs digICs. TriQuint, Vitesse, and other U.S. suppliers; Fujitsu (Japan); and Plessey (the United Kingdom) have chosen GaAs gate

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arrays as a major experience vehicle. Customers increasingly are using these devices for the usual reasons attributed to gate array acceptance, as follows:

- Reduced system size and parts count
- Lower system production costs
- Improved system security
- Shortened product start-up cycle
- Enhanced system performance and reliability
- Lower cost of customer ownership

Tables 1 and 2 in the "Digital GaAs ICs Products Analysis" section summarize GaAs gate array products and cost model details, respectively.

SRAMs

As in silicon technology, RAMs represent an excellent vehicle for accumulating experience and acquiring efficiency of scale. Fujitsu, LEP (France), Rockwell, and Vitesse have chosen this approach for the merchant market, as have NTT, Matsushita, Mitsubishi, and other major Japanese houses for captive use. Table 3 in the "Digital GaAs ICs Products Analysis" section summarizes available SRAM data, and Table 4 of that section details an SRAM cost model.

Standard SSI/MSI Logic

ANADIGICS, Gazelle, Hitachi, NEC, Oki, TriQuint, Vitesse, and others now offer standard logic devices based on GaAs technology. Some suppliers approached the SSI/MSI market as if ECL replacement were the objective; the results were disappointing. Present product offerings in standard logic are very limited, and second-sourcing is almost nonexistent.

TriQuint, Vitesse, and others have offered both TTL and ECL interface options, such that on-board mixing with silicon TTL, NMOS, CMOS, and/or ECL is achievable. This approach is facilitating user acceptance of GaAs logic devices.

PLDs

In mid-1988, Gazelle announced availability of the first production GaAs PLD. The initial product, a factory-programmable 22V10, is a high-speed replacement for the silicon TTL and CMOS 22V10s offered by AMD, Cypress, and others. This product is gaining rapid market acceptance in a broad range of applications.

MARKETS

The worldwide market for GaAs digICs exceeded $100 million in 1990, an estimated $30 million of which was for nonrecurring engineering (NRE) charges. The market is expected to grow at a compound annual growth rate (CAGR) of more than 40 percent through 1994.

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COMPETITORS

The companies now supplying GaAs digICs to the merchant market are listed in Table 1. Leaders among the start-ups include Gazelle, TriQuint (including GigaBit Logic), and Vitesse. Some companies in the table had not announced standard products at press time; others supply only to one or a very limited number of customers. Significant activity is under way in the development of alternate sourcing and other technology partnerships and agreements; see Table 2 for examples.

Table 1

GaAs DigIC Suppliers

United States	Japan	Western Europe
Alpha Industries	Fujitsu	LEP (Philips)
ANADIGICS	Hitachi	Plessey
AT&T	Mitsubishi	Thomson-CSF
California Eastern Labs (NEC)	NEC	
Gazelle	Oki	
ITT GTC	Toshiba	
McDonnell Douglas		
Rockwell		
Texas Instruments		
TriQuint (includes GigaBit Logic)		
Vitesse		

Source: Dataquest (February 1991)

Table 2

GaAs DigIC Sourcing Agreements and Technology Partnerships

Companies	Nature of Agreement
Rockwell/IBM	HBT and opto device development
AMD/Vitesse Semiconductor	GaAs communications chip architectures
Ford, IBM, Singer, Comsat, Pacific Monolithics, TriQuint	ASIC communications, radar, and support chips
Gazelle/TriQuint	Foundry support
TriQuint/Seattle Silicon	ECL ALU development
TI/CDC	DARPA 32-bit microprocessor
TriQuint/GigaBit Logic	Merger of the two companies
TRW/TriQuint	Class S ASICs
TRW/Vitesse Semiconductor	Class S products
Vitesse/Fujitsu	Alternate sourcing, product development
Vitesse/GE	ICs for military test equipment
Vitesse/Thomson CSF	Alternate sourcing of Fury Series gate arrays

Source: Dataquest (February 1991)

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ISSUES

The technology issues of threshold voltage variations, materials quality, and related technical problems have been resolved well enough to allow economical production of GaAs digital LSI and some VLSI chips.

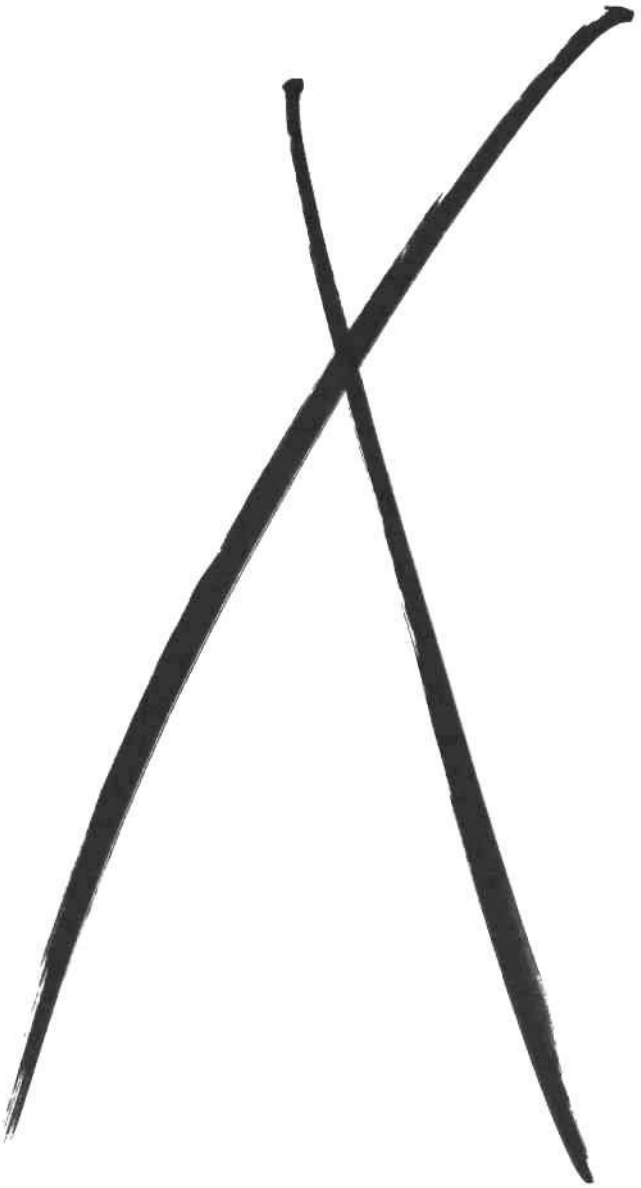
The issue of multiple sourcing continues to receive considerable attention from the supplier base. This issue is delineated in the section on Digital GaAs IC competitive analysis.

The major issues that continue to face suppliers and users of GaAs digICs as of the end of 1990 were the following:

- Market development
- Endurance of suppliers
- Advancing VLSI density levels at a reasonable pace (particularly memories)
- Future impact of GaAs HBT technology on E/D MESFET-based products
- International competition
- Testing
- Export controls

Of the issues cited above, market development is the key to industry growth; solutions to the other problems will follow.

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Digital GaAs ICs—Forecast

Table 1 forecasts the market for GaAs digital ICs (digICs). In the table, NRE charges are separated from device sales. The forecast assumes sustained materials quality improvements, continued open-market availability of defect-free wafers, and no predatory pricing by major suppliers.

The 1991 forecast is significantly reduced from 1990, primarily because of the de-emphasis of GaAs digital ICs by several major potential users and the failure of programmable GaAs ICs to establish a major market.

Table 1

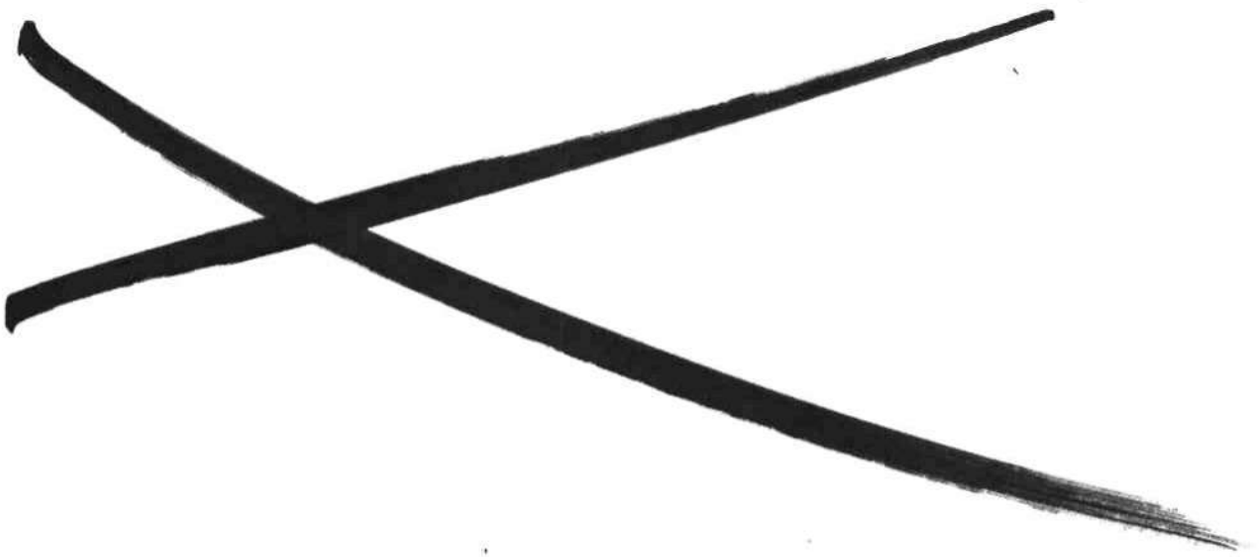
Worldwide GaAs Merchant Consumption Forecast by Technology
(Millions of Dollars)

Category	1989	1990	1991	1992	1993	1994	1995	CAGR (%) 1989-1995
Digital GaAs ICs	117	163	224	359	475	592	660	33.4
Devices	88	117	176	311	425	542	610	38.1
NRE	29	46	48	48	50	50	50	9.5

Source: Dataquest (May 1991)

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Digital GaAs ICs—Product Analysis

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GaAs DIGIC LOGIC FORMS

As in silicon technology, there is a continuing movement to higher-performance structures in III-V compound semiconductor technology. The workhorse technologies today are gate structures based on D-MESFET and E/D MESFET devices. The most frequently used gate designs are referred to as BFL, CCFL, SCFL, and similar acronyms, which are defined and explained in this section.

Many GaAs experts believe that selectively doped heterostructure transistors (SDHT or HEMT) will prevail over MESFET structures where ultimate performance is the primary design consideration. Other analysts believe that bipolar heterostructures, usually referred to as heterojunction bipolar transistors (HBTs), will prevail in the high-speed domain of the future, much the same as with ECL versus CMOS speeds in the silicon world of today. However, more development work lies ahead before HBT LSI/VLSI structures can be mass produced.

HEMT is an extension of work performed mainly at Bell Labs in the 1970s. Others (including Cornell University, Fujitsu, Honeywell, IBM, Thomson-CSF, and the University of Illinois) have performed research in this area and have coined such acronyms as HEMT, HFET, MODFET, and TEGFET in reference to the same basic structure. The most advanced form of HEMT is believed to be the (molecular-beam epitaxy) MBE-grown AlGaAs/GaAs approach. The first static RAM using HEMT structures was reported by Rockwell in 1984 and was based on a 6-T cell consuming less than 100uW/cell at t_{aa} of 1.1ns.

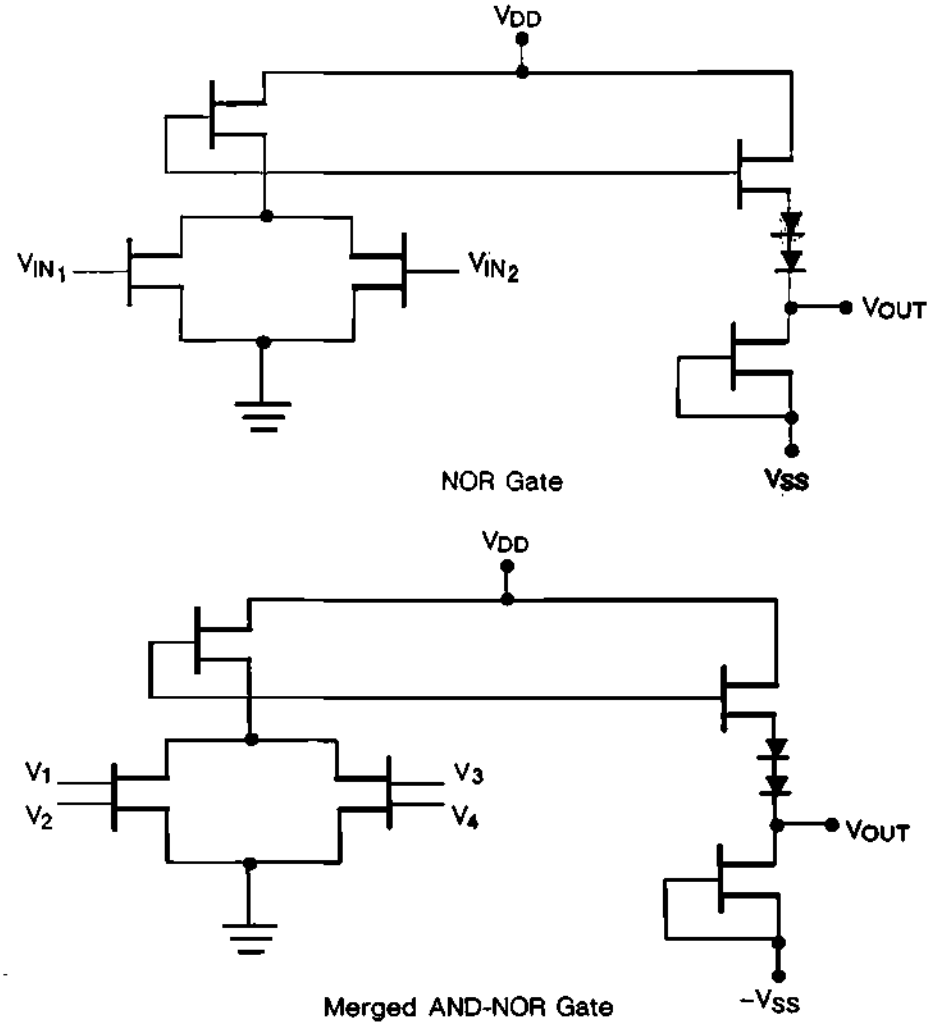
Buffered FET Logic (BFL)

BFL was the first GaAs logic circuit design to be produced and remains one of the most popular forms. It uses D-MESFET, which requires two power supplies and operates at relatively high power levels. This results in very good speed characteristics and drive capabilities as compared with other logic forms. Figure 1 is a schematic of a BFL gate.

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Figure 1

Buffered FET Logic (BFL)



Source: Honeywell GaAs IC Product Center

Capacitor-Coupled FET Logic (CCFL)

CCFL offers lower power and circuit complexity than BFL. However, it does not function below frequencies of several KHz, which limits its application and, therefore, its ability to become a widely used standard.

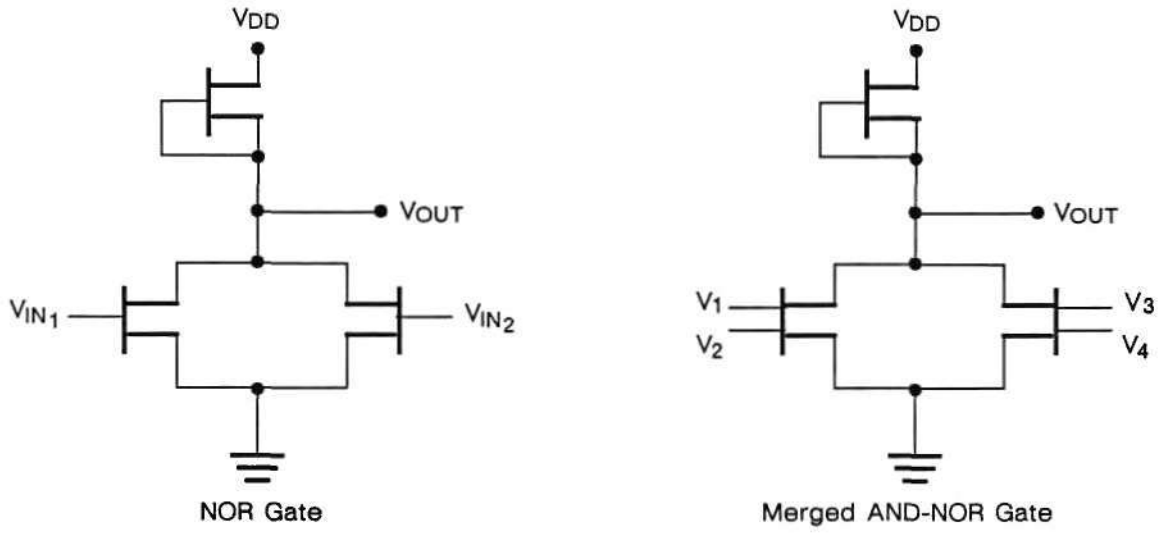
Direct-Coupled FET Logic (DCFL)

DCFL has the simplest of the E-MESFET structures, which makes it popular for LSI design applications. However, enhancement mode device process control is believed by many industry participants to be more difficult than that of depletion devices, although recent progress shows promising results. This situation is not unlike the situation existing with P-channel MOS and N-channel MOS silicon devices in the late 1960s, and continuing rapid change is likely. Figure 2 is a diagram of a DCFL gate.

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Figure 2

Direct-Coupled FET Logic (DCFL)



Source: Honeywell GaAs IC Product Center

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Schottky Diode FET Logic (SDFL)

SDFL offers speed similar to BFL but at lower power dissipation. The relatively small Schottky diodes complicate its manufacturing procedure relative to that of DFL. Like BFL, SDFL requires two power supplies and functions over the full frequency range, from DC to multi-GHz (refer to Figure 3).

Low-Power FET Logic (LPFL)

An LPFL gate structure is similar to that of an SDFL gate. LPFL offers performance and power dissipation factors ranging between those of BFL and SDFL gate forms.

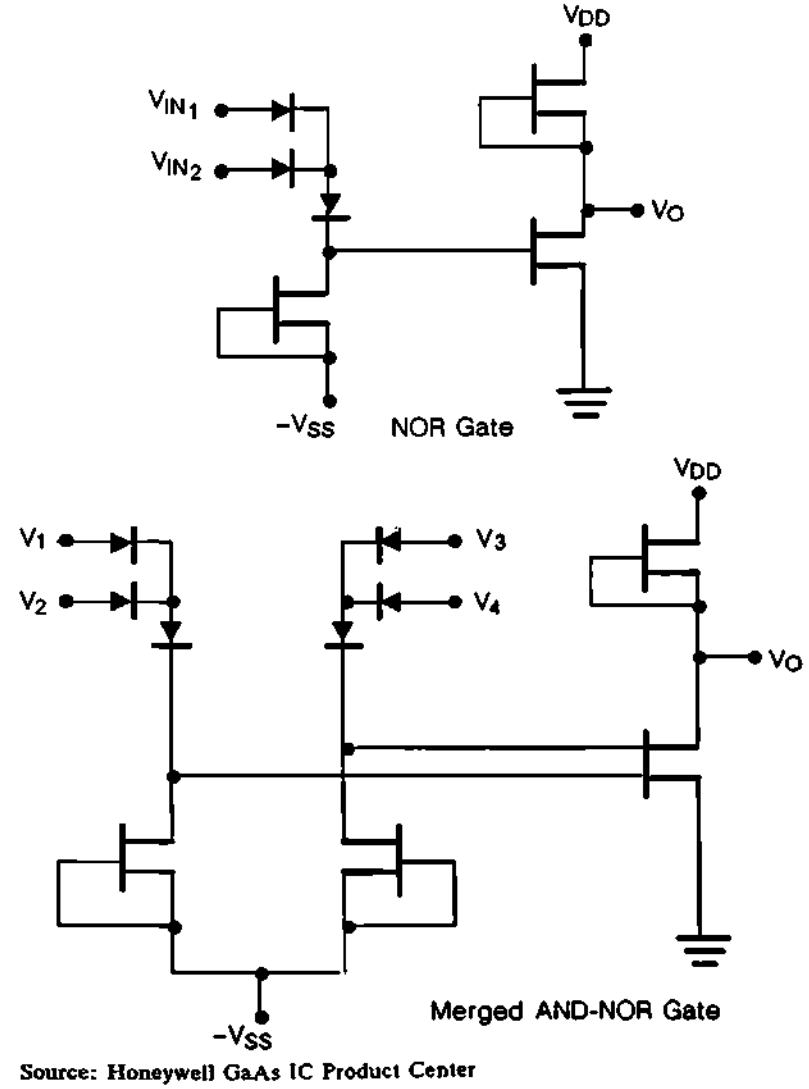
E/D-MESFET Logic

Enhancement-depletion GaAs logic offers the most near-term promise for realizing LSI/VLSI circuit complexities. This logic form was first popularized by Vitesse Semiconductor Corporation and is being adopted by an increasing number of suppliers. It is believed that over the next few years, E/D technology will dominate the high-complexity (LSI/VLSI) GaAs IC arena.

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Figure 3

Schottky Diode FET Logic (SDFL)



Source: Honeywell GaAs IC Product Center

IC LOGIC FUNCTIONS

Beyond the SSI devices introduced by several suppliers in recent years, GaAs logic function activity has been focused in five areas:

- ASICs, particularly gate arrays and standard cell arrays, have received a great deal of attention because of the custom nature of many of the military and government programs for which GaAs logic functions were initially used.
- Gate arrays, a special type of ASIC, have evolved to at least 30K-gate density in high-volume production, and materials improvements are expected to allow advancement beyond 100K gates by mid-1991.
- PLDs, another ASIC form, have been introduced.

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RAMs (particularly SRAMs) have progressed to 64K density levels, capable of speeds far in excess of those achievable in silicon.

- PROMs are now available in 4K density, as are ROMs to 8K density.

ASICs

Application-specific digital GaAs integrated circuits (ASIC digICs) offer a relatively attractive means of evolving system designs from the silicon world to the III-V world. Several companies, including recent start-ups, have mounted substantial R&D and manufacturing programs to support GaAs ASICs. These include Gazelle, Plessey, TriQuint, and Vitesse as well as many captive activities in companies such as McDonnell Douglas Microelectronics Center and Toshiba.

TriQuint and others are marketing multiuser prototype programs that allow several customers to design devices to the respective suppliers' ground rules and receive first prototype devices from wafers fabricated during a single run. To accomplish this, the vendor assigns standardized reticle areas (e.g., 80 mils x 80 mils) for chip locations such that several customers' chips can be interspersed on the same wafer. This represents a major breakthrough in economy of scale in developing new GaAs devices. The cost savings to the user can be on the order of 50 percent to 80 percent per wafer run.

GATE ARRAYS

Gate arrays constitute a subset of ASICs. In 1985, several developments occurred that subsequently had a major impact on the direction of the GaAs gate array market. Commercially available devices were introduced by GAIN Electronics, Honeywell, Plessey, and TriQuint. (Honeywell and GAIN later withdrew from the commercial market.) Of these devices, the most complex was the GAIN device at a density of 3,500 equivalent gates.

GaAs LSI/VLSI Gate Arrays Advance into Production

A 6,000-gate GaAs gate array was developed by Toshiba VLSI Research Center at Saiwai-ku, Kawasaki, Japan, in 1987 as a part of the MITI Scientific Computing Systems Program. The array used a conventional SCFL structure to implement 232 rows by 26 columns of cells. A test structure with serial-parallel-serial registers occupying 80 percent of the die consumed 952mW when operated at an 850-MHz data rate. The die size was 8 x 8mm^2.

In September 1987, TriQuint announced the availability of the TQ3000, a 3,000-equivalent-gate GaAs gate array that is based on the company's Q-ED foundry process. The product uses 50 percent less power than the fastest ECL and operates at clock rates two to three times faster. In 1989, TriQuint extended the family to 10,000-gate chips. TriQuint now offers throughput time of 13 to 15 weeks from customer design input to delivery of tested parts, assuming no design reiteration.

In November 1988, GigaBit (now merged with TriQuint) announced availability of a 10,000-gate cell-based array. The chips feature speed options to 22ps/gate (fanout of 1) and three-layer metal interconnections. The device is priced competitively with ECL at less than five cents per gate in production quantity.

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In late 1989, Vitesse introduced additions to its "Fury" series of gate arrays, advancing density to 30,000 gates per chip. GigaBit Logic extended its standard cell family to densities above 15,000 gates in 1989.

Table 1 is a summary of developments in GaAs gate arrays as of late 1990. All of the suppliers identified in the table have fabrication capability, although some of the devices tabulated are not offered to the merchant market at this time. Ford Microelectronics and Harris de-emphasized GaAs digital ICs in 1989, and GAIN withdrew from the market in October 1988. At press time, the merger of GigaBit Logic into TriQuint was in progress.

In 1990, Fujitsu announced alternate-sourcing of the Vitesse Fury series. Vitesse announced 100,000-gate FS-series arrays and projected availability of 350,000-gate (60 percent usable) arrays by July 1991 in prototype quantities.

Table 1

GaAs Gate Array Products and Developments
1990

Company	Gate Count	Process	Gate Delay (ps)	Gate Power (mW)	I/Os	Comments
			1990			
Fujitsu	45,600	HEMT	33	0.24	160	DCFL gates
Rockwell	500	HBT	26	4	68	1.4μ x 3.0μ emitters
Sony	11,880	J-FET	21	0.4	80	"Sea-of-gates"
Vitesse	100,000+	E/D	130	NA	196	60% usability
			1989			
Fujitsu	3,000-30,000	E/D	130	NA	196	Alternate source to Vitesse
GigaBit Logic[1]	15,000+	HMED	50	Variable	96	Standard cell based
TriQuint	10,000+	Q/ED	NA	NA	84	Toggle rate to 2 GHz
Vitesse	30,000+	E/D	130	NA	196	Macro library support
			1988			
GigaBit Logic	10,000	HMED[2]	50	Variable[3]	96	Standard cell based
TriQuint	6,000	Q/ED	NA	NA	84	Toggle rate to 2 GHz
TriQuint	4,200	Q/ED	130	0.75	84	Toggle rate to 1 GHz
TriQuint	3,000	Q/ED	130	0.75	64	Toggle rate to 1 GHz
TriQuint	2,000	Q/ED	130	0.75	40	Toggle rate to 1 GHz
Vitesse	13,376	E/D	130	1.1	196	Macro library support

(Continued)

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Table 1 (Continued)

GaAs Gate Array Products and Developments
1990

Company	Gate Count	Process	Gate Delay (ps)	Gate Power (mW)	I/Os	Comments
			1987			
GAIN	7,000	E/D	100	0.5	204	Product code GFL7000
Vitesse	4,500	E/D	160	0.15	120	Product code VSC4500
TriQuint	3,000	E/D	130	0.75	64	Product code TQ3000
Ford	1,000	E/D	100	0.7	34	Product code 21G06
Toshiba	6,000	SCFL	NA	NA	NA	Die size 8 x 8mm^2
			1986			
TI	4,000	5uHI^{2}L	400	1.4	134	Operates at +200°C
NEC	3,000	D-MESFET	56	2.3/4.6	136	CML interface
Fujitsu	1,500	E/D HEMT	85	4	88	8x8 multiplier
			1985			
TI/Honeywell	5,000+	E/D, SDHT	NA	NA	NA	DARPA project; std. cells
Toshiba	2,000	E/D	42	0.5	32	
Oki	1,000	E/D	63	0.3	32	8x8 multiplier
GE/Harris	300	D-MESFET	100	NA	48	Manchester decoder
			1984			
Toshiba	1,050	E/D	100	200	56	6x6 multiplier
TI	1,024	HBT	400	1.0	64	CRL development
Rockwell	430	D	237	1.3/2.8	NA	732-cell array

[1]Merger of GigaBit and TriQuint under way at press time.
[2]High Margin Enhancement Depletion
[3]Gate power is selectable by implant dose
NA = Not available
Source: Aztek Associates

Gate Array Cost Model

A cost model for a 30,000 VLSI GaAs gate array is given in Table 2. The model assumes a mid-1991 wafer cost for 4-inch DF wafers at $220 each. Other assumptions are noted in the table. The model illustrates a break-even price capability of less than one cent per usable gate at sufficient volume.

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Table 2

GaAs 30K VLSI Gate Array Cost Model

Wafer Sort	Cost
4-inch wafer cost = $220, fab cost = $340, fab yield = 70% good wafers; therefore, the fab cost per gross die (fab wafer cost/82 die locations) is:	9.76
Wafer sort cost per gross die:	0.80
Cost per gross die through wafer sort:	10.56
Therefore, cost per net die at wafer sort yield of 25% is:	42.24
Assembly	
Cost of die through wafer sort:	42.24
Assembly cost per wafer sort die (incl. pkg. cost):	16.00
Therefore, cost per assembled die at 90% assembly yield is:	64.71
Final Test	
Assembled die cost:	64.71
Test time/device = 180 seconds	
Test cost/unit (cost/hr./devices tested/hr.):	6.00
Final test yield = 80%	
Therefore, cost per final tested unit is:	88.39
Mark, Pack, Ship	
Operation cost at 99.9% yield:	1.50
Therefore, total variables cost per net unit is:	89.98
Assume overhead* = 125%	
Therefore, break-even cost per unit is:	202.46

*The term "overhead" as used here includes all other costs of growing a viable business, e.g., R&D, marketing, selling, accounting, other indirect labor, and related costs and expenses.
Source: Dataquest (February 1991)

SRAMs

For GaAs to penetrate the EDP market successfully, very high speed static RAMs (SRAMs) must be introduced into the commercial merchant market at a density level appropriate to the time of introduction. Initially, much effort has been focused on reproducible SRAMs at the 1K and 4K density levels, and the rate of progress has been disappointing to users.

The state of the art for 4K SRAM devices by mid-1987 was t_a of less than 3ns. SRAMs of 4K density were available from GigaBit Logic by late 1987. Other 4K developers include Fujitsu, Hitachi, Honeywell/Rockwell, NEC, and TI. Fujitsu, McDonnell Douglas, NEC, Rockwell, and others have reported work on GaAs 16K and 64K SRAMs.

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Japan's MITI Continues Sub-ns and Low-Voltage SRAM Development Support

Fujitsu Laboratories, Ltd. (owned by Fujitsu, Ltd.), Atsugi, Japan, has implemented a 500ps address-access-time 1Kx4 SRAM using GaAs E/D DCFL HEMT processing with 0.6μ gates. Chip power dissipation is 5.7 watts; die size is 2.8 x 3.6mm^2. A 64K SRAM based on an extension of this approach has access times of 1.2ns and dissipates 5.9 watts.

Hitachi Central Research Lab, Tokyo, Japan, has fabricated a GaAs 4K SRAM with 1ns access time. The Hitachi MESFET process uses 0.7μ gate lengths, resulting in cells with 60 to 80 fC critical charge.

A low-voltage 4Kx4 GaAs SRAM was developed at Mitsubishi's LSI R&D Laboratory, Itami, Hyogo, Japan. Test devices, using 1.0u E/D DCFL SAG MESFET process and dual-layer metal, operated at 1.0V power supply voltage, t_{aa} of 11ns max and P_D of 1.0W. The 5.79 x 4.73mm^2 die incorporates four blocks, each containing 128 x 32 memory cells. Cell size is 31.5 x 24um^2. Both of the sub-ns GaAs SRAM design efforts and the low-voltage SRAM efforts at Hitachi and Mitsubishi are supported by MITI's National R&D Program on Scientific Computing Systems.

TriQuint, McDonnell Douglas, Rockwell, and Vitesse SRAMs

TriQuint and Vitesse are producing ECL-compatible GaAs SRAMs, and Vitesse now offers a TTL version of its 256x4 SRAM that is a 4ns-cycle plug-in replacement for the 93422. McDonnell Douglas made a presentation at the 1988 GaAs IC Symposium in which it described a production 16K SRAM designed for rad-hard applications.

The Rockwell 16Kx1 SRAM chip reported in 1987 remained the highest-density production GaAs SRAM reported as of late 1990. The device design constraints included manufacturability, low standby power, and large DC margins at the expense of speed. The chip contains more than 250,000 circuit elements. The process involves D-MESFET technology, ion-implanted channels, proton-implanted isolation, DSW lithography, RIE vias, and ion-implanted cermet resistors.

At the 1987 GaAs IC Symposium, Vitesse demonstrated its TTL-interface VS12G422T SRAM with 4ns t_{aa}, approximately twice as fast as its silicon counterpart. The chip is pin-compatible with the silicon standard TTL 93422 SRAM. It was initially priced at $70 each in 1,000-piece quantities. At the 1988 GaAs IC Symposium, GigaBit described a 3ns-cyle 4K SRAM available, in production quantities, below $50. Neither company had announced higher-density SRAMs as of December 1990, although Vitesse offers SRAM cells in its Fury and FS series gate arrays.

SRAM State of the Art

Table 3 is a summary of 1987/1988 major GaAs SRAM product announcements and developments. The performance and other salient characteristics of the devices indicate the nature of the end equipment. The Japanese chips are speed oriented at the expense of power, radiation hardness, and other parameters; these are expected to be used by Amdahl in the United States and by Fujitsu, Hitachi, NEC, and other Japanese large-scale mainframe houses. There were no major GaAs SRAM announcements in 1989 or 1990.

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Table 3

GaAs Static RAMs
Announcements and Developments in 1987/1988

Company	Type	Part No.	t_{aa}	P_D	Comments
Ford	256x4	41G01	3ns		Latched address & data
Ford	Two-port, 64-bit	41G06	3ns	1W	ECL 100K-compatible; 28-pin LCC
Fujitsu Labs	1Kx1		870ps	360mW	1.5u E/D HEMT
Fujitsu Labs	1Kx4		500ps	5.7W	0.5u E/D DCFL HEMT; die size 2.8 x 3.6mm^2
GigaBit*	256x4	12G014	2.5ns	2W	Registered ECL I/Os; 40-pin LCC
GigaBit	1Kx4		2.9ns	2W	HMED (high-margin E/D) process
Hitachi CRL	4K		1ns		60-80 fC critical charge 0.7u gate length
Honeywell	256x4		3ns	150mW	E/D MESFET, 110x110 sq. mil die
McDonnell Douglas	1Kx4		10ns	200mW	Complementary E-JFET; 18mW standby power
McDonnell Douglas	4Kx4		15ns	1W	Complementary E-JFET; 105,000 transistors
Mitsubishi LSI R&D Lab	1Kx4		7ns	850mW	1.0u E/D DCFL SAG MESFET Dual-layer metal; 1.6V power supply
Mitsubishi LSI R&D Lab	4Kx4		11ns	1.0W	1.0u E/D DCFL SAG MESFET Dual layer metal; die size 5.79 x 4.73mm^2
Rockwell	1K		600ps		E/D HEMT
Rockwell	16K		25ns	200mW	D-MESFET, 40 x 40u^2 cell works at -60°C to +90°C
TI	1K		600ps	0.5W	GaAs-on-Si substrate; operates at 77°K and 1.6V/290mW
Vitesse	256x4	VS12G422T	4ns	1W	Pin-compatible with TTL 93422; 22-pin ceramic
Vitesse	256x4	VS12G422E	3ns		Pin-compatible with ECL 100422
Vitesse	1Kx4	VS12G174	3ns		ECL-compatible; LCC pkg.

*Merger of GigaBit and TriQuint under way at press time.
Note: Blank spaces indicate information did not exist or was not available.
Source: Dataquest (February 1991)

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SRAM Cost Model

A cost model for a 4K GaAs static RAM is given in Table 4. The model is based on satisfactory availability of 4-inch DF wafers in mid-1990 at $280 each in limited-volume production quantities. Other assumptions are noted in the model. The model illustrates a break-even price capability of less than one cent per bit in volume.

Table 4

GaAs 4K Static RAM Cost Model

Wafer Sort	Cost
4-inch wafer cost = $280, fab cost = $385, fab yield = 70% good wafers; therefore the fab cost per gross die (fab wafer cost/450 die locations) is:	2.11
Wafer sort cost per gross die:	0.65
Cost per gross die through wafer sort:	2.76
Therefore, cost per net die at wafer sort yield of 50% is:	5.52
Assembly	
Cost of die through wafer sort:	5.52
Assembly cost per wafer sort die (incl. pkg. cost):	4.00
Therefore, cost per assembled die at 90% assembly yield is:	10.58
Final Test	
Assembled die cost:	10.58
Test time/device = 1 minute	
Test cost/unit (Cost/hr./devices tested/hr.):	2.00
Final test yield = 80%	
Therefore, cost per final tested unit is:	15.73
Mark, Pack, Ship	
Operation cost at 99.9% yield:	1.50
Therefore, total variables cost per net unit is:	17.24
Assume overhead* = 125%	
Therefore, breakeven cost per unit is:	38.80

*The term "overhead" as used here includes all other costs of growing a viable business, e.g., R&D, marketing, selling, accounting, management, and other costs and expenses.
Source: Dataquest (February 1991)

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DRAMs

There has not yet been any report of a GaAs LSI/VLSI DRAM, although work has been accomplished in DRAM cell development. Apparently the problems of wide-threshold variations and other noise considerations have limited the RAM designers to SRAM designs based on multitransistor, cross-coupled latch cells. The current philosophy expressed by several experts is that the cost of GaAs or GaAs-on-silicon substrates and relatively low efficiency of scale of GaAs manufacturers (relative to silicon) will deter DRAM development for several years or more.

Dataquest believes that by the mid-1990s sufficient progress will have been made to allow focus on chip designs based on 3-, 2-, or single-transistor dynamic RAM cells. This is expected to materialize only if a strong demand develops among users. We also believe that, like their silicon counterparts, such devices would use refresh techniques and cell redundancy to reduce chip power per cell and minimize bit cost.

NTT the First to Report a GaAs ROM

NTT was the first company to report (in 1987) the demonstration of a GaAs read-only memory (ROM). The company's Electrical Communications Labs (Kanagawa, Japan) has developed an ECL-compatible GaAs 512x8 ROM. The chip has t_a of 1.2ns; P_D is 3.75W. The ROM uses 0.5u-gate E/D DCFL technology.

GigaBit Logic (now merged with TriQuint) has manufactured a 4K GaAs masked ROM since 1988.

OTHER LOGIC

Other GaAs logic forms include fiber-optic logic chips, prescalers, registers, bit slices, and microcontrollers. Table 5 gives details of typical GaAs digIC products with at least three years of production history.

Dataquest believes that the marketplace will welcome additional sources offering a wider variety of logic functions. Dataquest's analysis indicates that the success-determining factors include careful interaction with the potential future customer base on selection of the most nearly optimum set of logic functions, interface standards, self-testing techniques, and packaging methodology.

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Table 5

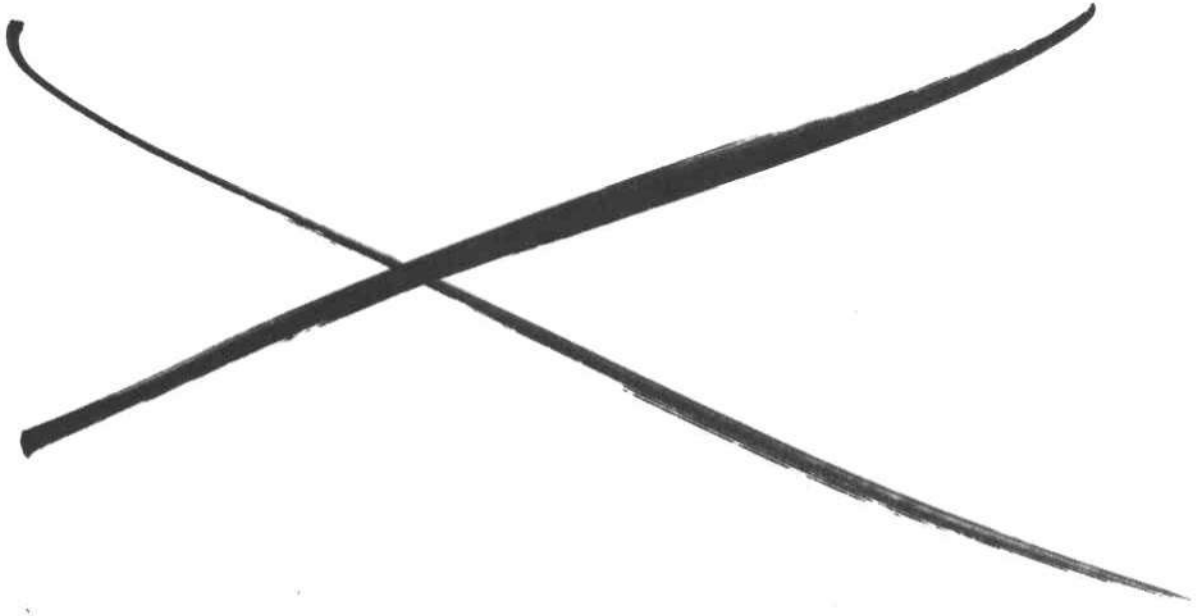
Representative GaAs DigIC Products

Company	Part No.	Description	Comments
ANADIGICS	ADV3040	Divide-by-4 prescaler	3-GHz max. data rate
TriQuint	10G022	Octal register	1.5-GHz max. clock rate
	10G061	4-bit synchronous binary counter	1.5-GHz max. clock rate
	10G045	9-bit parity generator	800ps t_{pd}
	16G040	Clock and data recovery circuit	2-Gbps operation
Vitesse	VE29G01	4-bit microprocessor slice	29000-family architecture 72-MHz max. clock freq.
	VE29G02	Lookahead carry generator	29000-family architecture 200-MHz max. clock freq.
	VE29G10A	Microcontroller	29000-family architecture 100-MHz max. clock freq.
	VS8010 Series	SONET MUX/DEMUX products	1.25-Gbps operation

Source: Dataquest (February 1991)

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Digital GaAs ICs—Competitive Analysis

SUMMARY

Heretofore, competition among GaAs digIC houses has been focused on the development labs more than on the merchant product marketplace, but this is rapidly changing. Companies presently supplying GaAs digICs to the merchant market are listed in Table 1. The leaders among the start-ups include Gazelle, TriQuint, and Vitesse. Some companies involved in GaAs digICs had not announced standard products at press time, while others supply only to one or a very limited number of customers. Dataquest expects this lineup of suppliers to continue to evolve into the mid-1990s.

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Table 1

GaAs DigIC Suppliers

United States	Japan	Western Europe
Alpha Industries	Fujitsu	LEP (Philips)
Anadigics	Hitachi	Plessey
AT&T	Mitsubishi	Thomson-CSF
California Eastern Labs (NEC)	NEC	
Gazelle	Oki	
ITT GTC	Toshiba	
McDonnell Douglas		
Rockwell		
Texas Instruments		
TriQuint (including GigaBit Logic)		
Vitesse		

Source: Dataquest (February 1991)

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MULTIPLE SOURCES AND PARTNERSHIPS IN GaAs DigICs

Some GaAs digIC suppliers have had alternate-source agreements for two or more years. More major alignments and partnerships developed among GaAs digIC suppliers in the late 1980s. This is a positive sign of industry development in support of the needs of those customers demanding multiple sources of IC products and of attempts among suppliers to gain an early competitive advantage. Dataquest believes that these alliances will eliminate or reduce any reticence toward using GaAs at those electronics houses requiring multiple sourcing of critical technology.

Rockwell/IBM

Early in 1987, Rockwell International and IBM entered into an agreement for the cooperative development of high-speed digital and optoelectronic GaAs devices for future computers and telecommunications equipment. The program involves Rockwell's GaAs pilot line at Newbury Park, California; Rockwell development teams at Newbury Park and Thousand Oaks, California; and IBM development teams at East Fishkill and Yorktown Heights, New York. Dataquest sees this agreement as indication that IBM is preparing to take a leadership role in GaAs digIC applications.

Cray/GigaBit

For approximately four years, Cray Research, Inc., has been working with GigaBit Logic, Inc., (now merged with TriQuint) to develop a reliable high-volume source of GaAs devices for use in CRAY-3 computers. Early in 1987, Cray increased the amount of its order for GigaBit GaAs IC chips to be delivered that year to $5.2 million. In 1988, Cray received approximately $7 million worth of GaAs ICs from GigaBit Logic. Cray Research participated in GigaBit Logic's round three financing in May 1987, along with Analog Devices, Inc., Digital Equipment Corporation, and others.

In 1990, Cray acquired GigaBit's 4-inch GaAs fab line, which was moved to Colorado Springs, Colorado, for use in production of CRAY-3 chips.

AMD/Vitesse Semiconductor

In 1986, AMD and Vitesse agreed to a technology exchange involving AMD's 2900 bit-slice family and Vitesse's E/D MESFET GaAs technology. The effort resulted in Vitesse's announcement of its 29G01, 29G10, and other GaAs bit-slice products late in 1986.

TriQuint/Seattle Silicon

TriQuint and Seattle Silicon Corporation have developed a 4-bit GaAs ALU functionally equivalent to the 100181, a 100K ECL chip. Design engineering support was provided by the Washington Technology Center (WTC). The chip is 5.7 times faster than its silicon counterpart and consumes one-half the power.

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TRW/TriQuint

TRW Components International (TRWCI, a subsidiary of TRW, Inc.) and TriQuint have agreed to jointly supply GaAs devices for space applications. The companies are working together on procedures for producing Class S-level GaAs components. TriQuint will provide foundry support.

TRW/Vitesse Semiconductor

On December 8, 1987, TRW and Vitesse announced an agreement whereby Vitesse will supply GaAs wafers, dice, and packaged ASICs to TRWCI for subsequent assembly, qualification, and sale to the Class S space-level market. The agreement also specifies cooperative effort to resolve any radiation problems in the logic and memory circuits.

The Ford ASMMIC Team

Ford Aerospace and Communications Corporation recently described a team effort to enable insertion of microwave/millimeter-wave ICs into widespread system applications. The team consists of Ford Aero, Singer Dalmo Victor Division, IBM Federal Systems Division, Comsat, Pacific Monolithics, and TriQuint. The approach is called ASMMIC, for "application-specific MMIC."

GaAs IC chips based on ASMMIC have been produced and tested to 28 GHz, and new designs to 100 GHz are in process. A reduction in system integration time by a factor of three is claimed for the ASMMIC technology. Typical applications include communications receivers, antennas, radar, and electronic support systems.

Although ASMMIC is initially aimed at analog/linear defense hardware applications, the companies involved are digital hardware houses as well. Dataquest believes that the ASMMIC alliance will prove to be formidable should the team decide to expand into GaAs digICs.

GigaBit/NKT

In September 1988, GigaBit Logic, Inc., and NKT announced formation of a joint venture, GIGA, to serve the European and Israeli markets for digital GaAs ICs. This new company, headquartered in Bronby, Denmark, includes a full-support ASIC design center and management for GigaBit's distributor network for standard products.

NKT is a major conglomerate in Denmark, with 3,600 employees and 1987 revenue of 2.5 billion Danish kroner (approximately $385 million). The NKT Group and associated companies develop and produce a wide variety of electrical, electronic, and other industrial and petrochemical systems and components, including silicon and GaAs circuits for fiber-optic communications. GIGA will incorporate the technical staff, CAD system, and laboratory facilities established by NKT.

With the formation of GIGA, GigaBit Logic was the first U.S. GaAs company to have a full ASIC development capability based in Europe. Dataquest believes that this will favorably impact the rapidly growing GaAs digital IC industry by encouraging European and Israeli systems houses

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to adopt GaAs ASIC technology into next-generation designs. Dataquest expects other U.S.-based GaAs companies to take a similar approach in pursuing the European market by establishing additional ASIC development and distribution management capabilities in European countries.

Gazelle/TriQuint

A $17 million foundry agreement was announced by Gazelle and TriQuint in mid-1988. This agreement covers shipments of wafers/chips for use in Gazelle PLD products, including the factory-programmable GA22V10.

Vitesse/Fujitsu

In October 1989, Vitesse and Fujitsu jointly announced an alternate-sourcing agreement for the Vitesse Fury series of GaAs gate arrays. The agreement includes arrays of 3,000 to 30,000 gates and mixed logic/SRAM chips as well as joint development of additional GaAs VLSI products.

Vitesse/Thomson-CSF

In 1990, Vitesse announced an agreement with Thomson-CSF on the Fury series of GaAs gate arrays. Sources indicate that the nature of this agreement is similar to that of the Vitesse/Fujitsu pact.

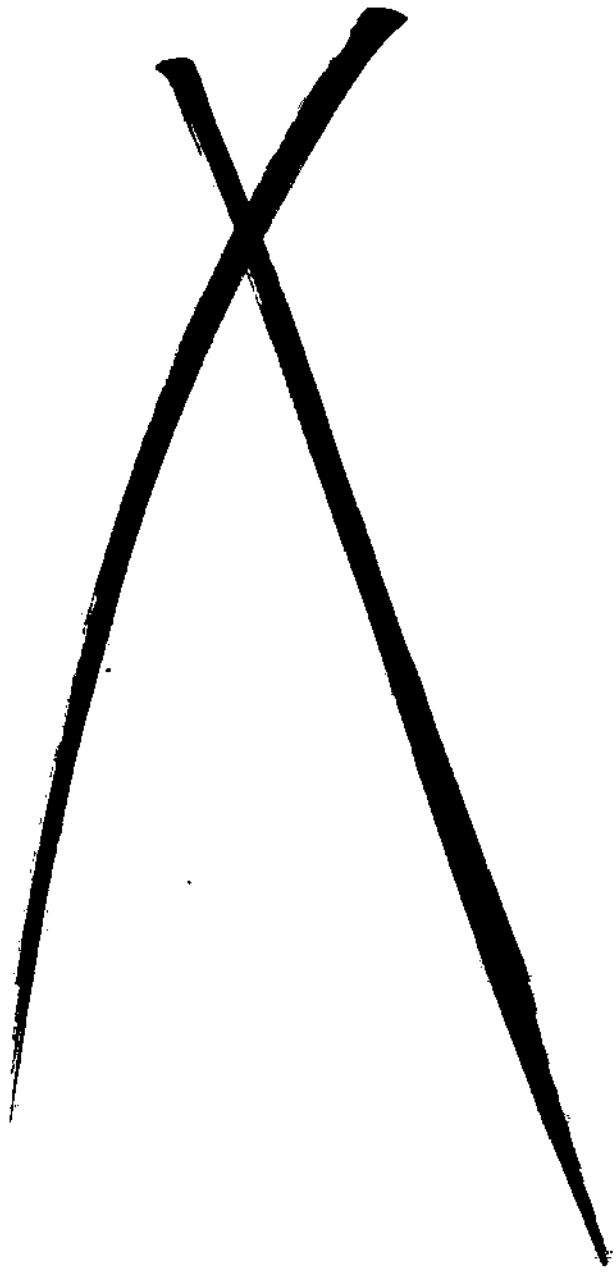
Rockwell/TriQuint

In June 1990, Rockwell announced that it would second-source TriQuint's standard cell familly and develop and offer GaAs ASICs for satellite communications and cellular radio application. The agreement is extendable to cover GaAs gate arrays in the future.

Anadigics/Thomson-CSF

In January 1991, Anadigics and Thomson-CSF signed an agreement involving technology transfer for GaAs ICs used in direct broadcast satellite applications. Last year, Thomson-CSF obtained exclusive European marketing rights for Anadigics' data sheet products.

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Digital GaAs ICs—Emerging Technology and Trends

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EMERGING TECHNOLOGY

The emerging technologies for GaAs digICs may be categorized as process/ device-oriented and chip/function-oriented. Examples of the former are C-HFET (complementary heterostructure FET) logic and HBTs (heterojunction bipolar transistors), which will lead to improved cost/ performance ratios. Examples of the latter are GaAs-on-Si and 4-inch wafers, which may lead to higher levels of integration, improving the cost/performance ratio still further.

C-HFET Logic

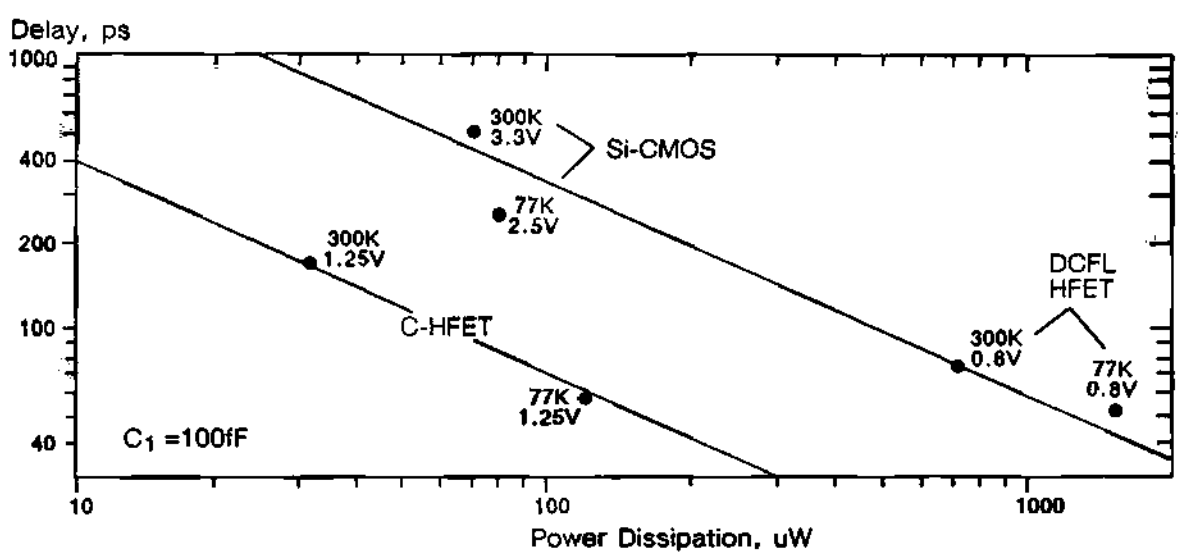
Substantial power savings are possible using C-HFET logic at the speeds available in n-channel DCFL HFET circuits; savings up to 90 percent were projected in one IBM study. Computer simulations indicate that C-HFET circuits of 30,000-gate complexity operated at 1.25V power supply would provide loaded gate delays below 150ps (FI = 3, FO = 3) at a chip power dissipation of less than 5 watts. Figure 1 compares C-HFET performance with that of DCFL HFET and silicon CMOS at room temperature and at 77°K.

HBTs

HBTs offer a substantial potential for improved logic speed at an efficiency (speed-power product) several times that of silicon ECL when both are taken to the limits of lithography. Some of the recent development work in this technology is very promising, as the following example indicates.

Figure 1

GaAs C-HFET, DCFL HFET, and Si CMOS Performance Comparison



Source: Dataquest (February 1991)

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Using 2μ x 5μ (relatively coarse) emitter dimensions and low-resistance emitter caps, NTT has fabricated vertical self-aligned AlGaAs/GaAs HBTs that operate to 80 GHz. A 21-stage ECL ring oscillator based on this approach showed 5.5ps delay per stage at 25°C. NTT plans to scale the design using tighter geometries to achieve even higher performance.

Rockwell and IBM have a technology agreement that includes HBT development. This effort is expected to have a major impact on mainframe designs by the mid-1990s.

GaAs-on-Silicon

The first paper on GaAs-on-Si was presented by MIT researchers in 1981 in the IEEE Electron Device Letters. Since then, the potential for large-diameter wafers for GaAs manufacture and for monolithic integration of photonic and electronic functions at low cost has attracted R&D talent and investment capital.

Kopin Corporation disclosed at the 1989 GaAs IC conference that it had sampled 6-inch GaAs-on-Si wafers. The growth of GaAs-on-Si wafers on a production basis is described by John C.C. Fan, founder of Kopin, as an "enabling technology for future GaAs market growth."

Other companies and groups involved in GaAs-on-Si technology include AT&T Bell Labs, GTE, Hewlett-Packard, MIT, NTT, Oki, Spire Corporation, TI Materials Science Laboratory, and the University of Illinois. Some examples of such companies' and groups' accomplishments include the following:

- TI initially fabricated 1K SRAMs using GaAs-on-Si in 1986.
- Ford Microelectronics produced devices and plans products that combine III-V and II-VI materials on Si substrates of up to 200mm (8 inches) in diameter.
- In 1987, University of Illinois researchers fabricated the first reported GaAs-on-Si continuous-wave (CW) lasers that operate at room temperature.

Much research is under way to determine whether the GaAs-on-Si CW laser concept can be reduced to practice. Should GaAs-on-Si long life and reproducibility be established, GaAs CW lasers would rapidly become obsolete. This in turn would foster significant high volumes of innovative digital IC products, such as optically bused A/D-D/A converters and interface logic chips.

TRENDS

System designers with more than 10 years of practical experience are well aware of the innovations achievable with semiconductor memory and microprocessors. They also appreciate the concept of "overnight obsolescence" brought on by intense competition among chip suppliers. Cost-effective GaAs VLSI will cause a similar rapid evolution of chip (and therefore system) designs.

Multitechnology Logic Systems Design

In the 1960s, TTL-compatible PMOS was developed, allowing the designer to use the best available bipolar and MOS functions in a single system design. Bipolar ECL-to-TTL and TTL-to-ECL interface chips appeared at about the same time. In the 1970s, IC users became

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accustomed to mixing bipolar TTL and NMOS (or ECL and NMOS) logic and memory functions on boards designed for digital systems, and later, CMOS was added to the list of options.

The advent of cost-effective GaAs digital functions has expanded the users' options to include any desired combination of ECL, TTL, NMOS, CMOS, and GaAs. Thus the systems house (and each of its competitors) has a wider variety of design approaches than ever before.

Higher Performance and Lower Power

System designers can now take advantage of GaAs circuits that provide both higher speed and lower power than their silicon counterparts. It is now possible to purchase gate arrays that allow a 2x speed advantage over ECL at one-half the power consumption of the same ECL function. As geometries shrink, this differential will remain available. The message to the system designer is, "consider GaAs as an alternative; the competition probably already is doing so." This is borne out by present design activity under way at many computer, workstation, and communication equipment houses.

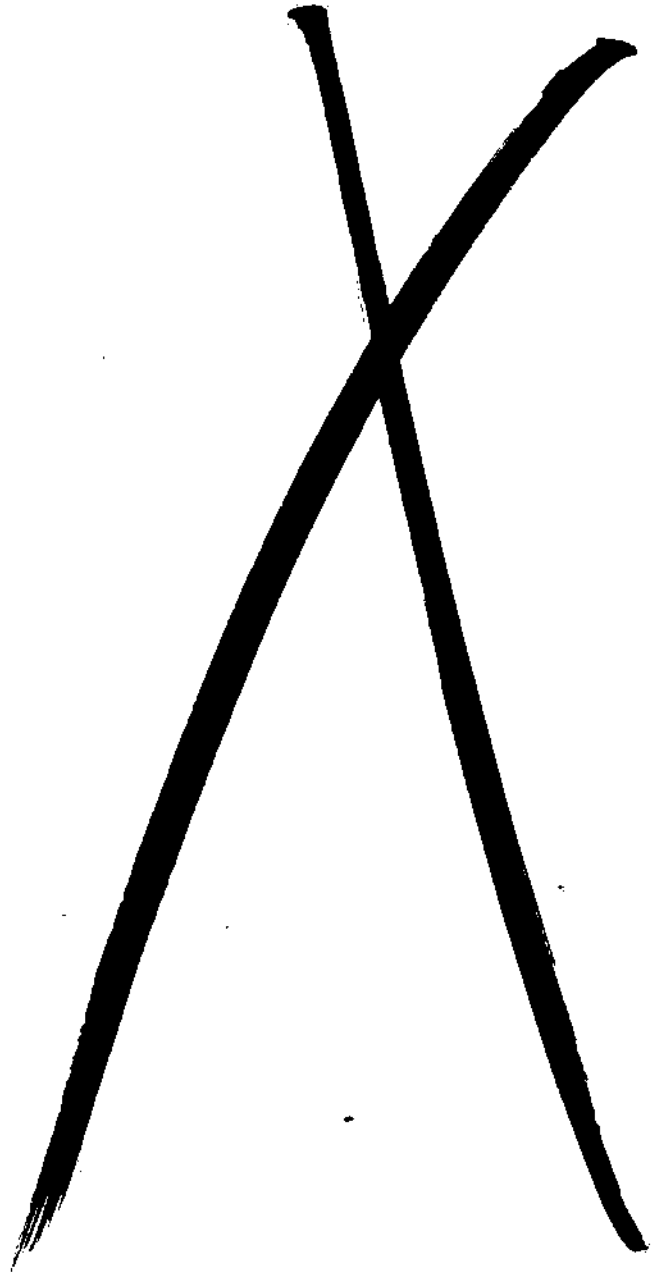
Density

In 1990, the large volume production GaAs digICs were based on processes featuring minimum geometries down to approximately 0.6 micron. Almost all of the processes are scalable to less than 0.25μ rules, which will result in rapid evolution of chip density by a factor of four. Thus, 64K SRAMs and 100K gate arrays represent relatively straightforward product refinements without a need for changing IC production equipment. Astute IC users requiring leading-edge performance now have an excellent opportunity to upgrade their equipment designs by taking advantage of expected near-term GaAs digIC chip evolution.

GaAs DSP

High-performance digital signal processing (DSP) applications such as transform-based algorithms are taking advantage of the superior system speed offered by GaAs ICs. General Electric and McDonnell Douglas reported GaAs DSP evaluation results at the 1987 GOMAC. Ford Microelectronics is producing a family of GaAs DSP circuits based on its E/D MESFET process. ITT has developed a DRFM (digital RF memory) for use in high-performance military DSP applications. These developments signal a trend to GaAs for high-speed DSP designs.

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Digital GaAs ICs—Applications and User Issues

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APPLICATIONS

Applications of GaAs and related III-V compound semiconductors, particularly ICs, to data processing are primarily found in supercomputers, superminicomputers, and peripherals such as optical storage and high-speed graphics subsystems. Initially, GaAs logic and memory chips are finding use in critical paths such as hardwired multipliers and cache memory. GaAs devices are being used in CPU designs now under way at Cray and several other companies.

Dataquest notes that a large number of persons from Amdahl, Control Data Corporation (CDC), Digital Equipment Corporation, Fujitsu, IBM, Unisys, and several other computer houses attended one or more GaAs IC conferences in every year since 1987. This indicates a further acceleration of GaAs IC usage in high-performance commercial EDP systems. Such acceptance is confirmed by the number of prototype designs under way at TriQuint, Vitesse, and other ASIC suppliers.

Other commercial applications are found in digital communications systems. GaAs is also useful in designing high-performance instrumentation for measurement and monitoring functions. Defense and military applications include all of the above plus digital radar, RF digital memory, and other DSP functions.

Supercomputers

For GaAs to have the broadest impact on supercomputer design, the following two major problems had to be resolved:

- Accomplishment of multiple fanout via one lead from the signal source
- Yield of VLSI complexity chips must be improved at a rate permitting a packaged chip cost differential of less than 2x per function at 2x to 3x improvement in absolute speed

The interim solution to the fanout problem is the use of ECL-compatible interface drivers on-chip. The yield problem has been resolved for many products by TriQuint and other companies through rigorous worst-case design methodology supported by quality improvements by major wafer suppliers.

Companies such as Fujitsu, IBM, and Rockwell have developed captive GaAs capability to address the technical and cost issues that remain to be resolved.

Cray's CRAY-3 supercomputer CPU uses more than 48,000 GaAs gate array chips, of approximately 200- to 400-gate density, and 4,000 GaAs register file chips, each containing a 64x4 SRAM. Address access time for the file register is 1.5ns, and on-chip gate delay of the gate array chips is 150ps. Cray chose this level of density for the IC devices to maintain its very conservative design philosophy; one result of this approach is the prototyping of the system two months ahead of an aggressive schedule.

Early in 1987, Cray temporarily discontinued captive production of GaAs chips and awarded a sole-source contract, which exceeded $5 million for 1987 and $7 million in 1988, to GigaBit Logic. Cray continues its lead in the race to take advantage of GaAs in production of supercomputers. GigaBit's 4-inch fab line was moved to Colorado Springs, Colorado, for use in the production of CRAY-3 computer chips in 1990.

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In mid-1987, IBM and Rockwell announced a joint effort in GaAs technology. IBM is believed to be adding significant GaAs capacity at its East Fishkill, New York, facility. Although no specific applications have been announced, Dataquest believes that IBM initially will apply GaAs (possibly HBT or C-HFET) technology to its larger systems.

Superminicomputers

Cost is more critical in superminicomputer design than it is in supercomputer design because in the former, the performance issue can be approached from more than one point (e.g., greater parallelism using lower-cost ECL or BiCMOS LSI devices). Dataquest believes that superminicomputer applications of GaAs devices will, therefore, lag behind supercomputer usage.

In 1989, GigaBit Logic (now merged with TriQuint) began offering GaAs gate arrays to 15,000-gate density with significant speed-power product improvement over silicon technologies at costs reportedly no more than twice those of ECL custom arrays. Gazelle, Vitesse Semiconductor, and others are diligently pursuing aggressive ASIC development activities that further reduce the application time differential of GaAs digICs.

RISC Architectures

Reduced-instruction-set computing (RISC) architectures heretofore have been dominated by silicon chip sets. This trend will continue where computational speed is less important than system cost. However, GaAs (or GaAs-on-Si) technology offers higher performance at lower power and other attributes that are appropriate to many RISC applications, especially DSP. Thus, there is a trend toward adoption of GaAs digICs for many RISC-type machine designs.

At least five companies have been involved in developing RISC architectures designed to take advantage of one or more properties of GaAs: CDC (teamed with Texas Instruments), McDonnell Douglas, RCA, and Rockwell. The CDC GaAs RISC architecture is believed to incorporate a set of 66 instructions; the others are each less than 64 instructions. CDC's GaAs chip complexity is 10,000 gates each, and the CPU comprises three chips. McDonnell Douglas is using E-JFET processing and device complexity on the order of 12,000 transistors. The RCA microprocessor uses E/D MESFET technology. All three companies' GaAs RISC computers are designed for DSP applications.

After a one-year study phase, four-year fabrication programs were initiated at McDonnell Douglas and Texas Instruments (TI). The first prototype chips were available in 1988, and single-board computers were completed in 1989. The goals are to operate a 32-bit main processor chip and a floating-point coprocessor chip at 200-MHz clock rate, 100-mips sustained throughput rate. Table 1 compares three current RISC designs based on GaAs.

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Table 1

GaAs Microprocessor IC Comparison

Characteristic	McDonnell Douglas	Rockwell	TI/CDC
Function	32-bit RISC µP	150 mops 8-bit ALU (1750 type)	32-bit RISC µP
Architecture	3-stage pipeline, 3 busses	3-bus slice expands to 16 bits	6-stage pipeline
Performance	100 mips	150 mops	200 mips
Operations	ALU includes 32-bit barrel shifter and multiply/ divide support	Add, subtract, mod. Booth multiply and divide, bit operations	4 address modes, 16 ALU and 5 control instructions, 10 memory instructions
Power (Watts)	4.7	Low 4.2, high 9.2	Estimated 20 max.
Die Size (mm^2)	8.2 x 11.2 = 91.8	4.9 x 3.9 = 19.1	11.2 x 10.5 = 117.9; proj. 7.6 x 7.6 = 57.8
Chip Complexity	21,606 transistors	9,400 transistors, 3,000 diodes	12,872 gates (typical gate is 1 transistor and 5 resistors)
I/Os: Signal + Pwr/Gnd	130 + 42	64 + 29	171 + 70
Fabrication Process	Ion-implanted GaAs E-JFET	1.0µ GaAs D-MESFET	2µ GaAs HBT, proj. 1.5u HBT
Logic Form	DCFL	BFL	I^2L (modified RTL)
Cell Speed/Power	Not available	120ps/1.6mW (reg.)	160ps/2mW (gate)
Yield Data (1988)	6 percent	18 percent	Exper. 2 percent, proj. 8 percent

Source: Aztek Associates

Peripherals

High-performance optical storage using laser readout is a potential rapid-growth application for III-V compound devices including GaAs. At the 1985 NCC, Verbatim Corporation demonstrated a 3.5-inch erasable optical disk of 40MB capacity. This and other activities such as work under way at Kodak, 3M, and Sony will soon lead to a quantum jump in cost-effective storage capacity for machines ranging all the way down to personal computers. Reliable erasability and alterability at lower system per-bit cost are key to the displacement of present high-density magnetic media. Future designs are expected to incorporate GaAs digICs for improved cost/performance.

High-speed color graphics displays for workstations and other real-time applications are now using GaAs circuits to resolve speed problems. GigaBit and others have supplied GaAs circuits used in the front-end video section of such graphics systems.

Other peripheral equipment applications include couplers and interruptors for printers and other paper-handling equipment. The replacement of mechanical sensor switches with optoelectronic components such as those manufactured by HP, Optek, and TRW enhances system MTBF. The use of GaAs digIC technology in these applications is expected to enhance the cost/ performance ratio.

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Optical Computing

The ability of GaAs and other III-V compounds to function near the visible spectrum has spurred serious research into optical computing. Since the mid-1970s, interest in this field has fluctuated, and recently it has attracted the attention of the U.S. Department of Defense for potential SDI applications. AT&T is investing R&D effort in a prototype optical computer based on multiple quantum well (MQW) device technology to be constructed in the near future.

Venture capital companies including Venrock Associates have invested in this technology, and start-up teams are presently seeking capital to fund new enterprises in this field. Although many technical problems in optical logic are unsolved, Dataquest believes that this area holds much promise for growth in the 1990s and beyond.

Instrumentation

Instrumentation applications for GaAs and other III-V devices now include the following:

- High-speed oscilloscopes
- Logic analyzers
- Signal generators
- Spectrum analyzers

The recent trend to digitized processing of data in such systems dictates a need in many cases for the superior speed of GaAs digICs.

The same dilemma in testing exists today that existed when ECL was initially developed in silicon technology: What does one use to test the highest-speed components? As of 1990, 80-GHz testing can be accomplished at the wafer level but is limited to one or two signal probes; Cascade Microtech is considered a leader in this area. Demands for high-speed wafer-probe stations with more than three probes and for multi-GHz final test equipment for packaged devices have risen acutely with the introduction of LSI GaAs chips. Both suppliers and users are driving these requirements.

Several recent announcements have been made regarding nonintrusive test techniques and methodology. Stanford University and others are making substantial progress in this area. The basic concept involved is the sensing of radiation from the chip at close proximity to determine on-chip signal characteristics.

Dataquest believes that the instrumentation segment of the electronics industry will increasingly adapt GaAs discretes and ICs to instrumentation circuitry, which will cause a corresponding displacement of some ECL components in this application. We also expect growth in the use of InP and other compound chips to solve some of the highest-speed test problems.

Consumer and Automotive

Consumer demand for increasingly sophisticated electronic products is driving the market for IR LED and laser transmitter and receiver chips, display chips, optical circuitry, and other III-V compound semiconductors. Broad categories of consumer applications include a wide range of

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requirements, displays, toys, and optical storage devices such as audio CD players. These markets and the automotive aftermarket are taking advantage of GaAs digital ICs as they become more cost effective.

Military

Although detailed analysis in this area exceeds the scope of this document, three brief examples of military applications for digital GaAs are discussed in this subsection.

Digital Signal Processing

One type of function useful for DSP is the FIR (finite-duration impulse response) filter. A GaAs MESFET implementation of an FIR filter design has been accomplished by a team from the Computer Systems Laboratory of Tampere University of Technology (Finland) and the Department of Electrical and Computer Engineering of the University of California at Santa Barbara. The circuit consists of approximately 260 BFL gates, dissipates 1.6W, and has ECL-compatible I/Os. The process is depletion mode 1μ n-type MESFET.

TMR Functions

Triple modular redundancy (TMR) is a fault-tolerant technique used extensively in electronic hardware, including military systems, for increased reliability. Because TMR can lengthen system cycle time, GaAs is a more attractive medium than silicon for implementation. A TMR chip designed by Research Triangle Institute has been built and demonstrated. The design was based on TriQuint's 1μ D-MESFET process; TriQuint fabricated the prototypes. Initial tests indicated that the circuit adds less than 3ns overhead to a TMR processor configuration.

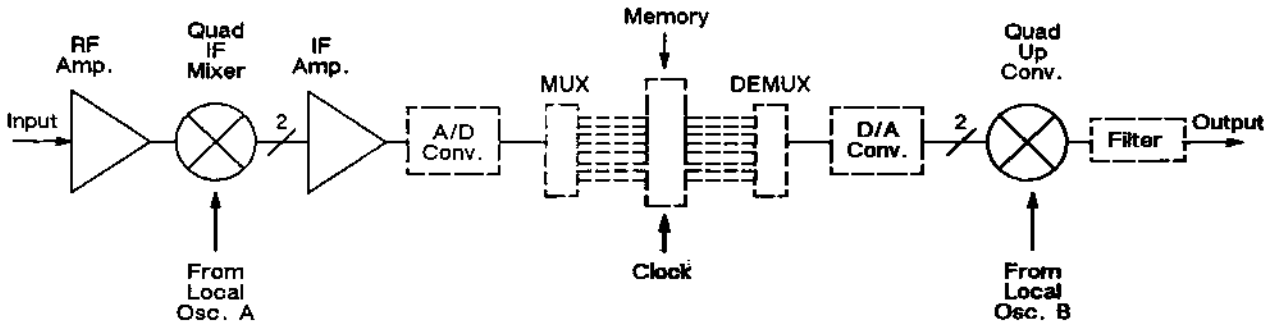
Digital RF Memory

ITT has developed a digital RF memory approach that uses GaAs IC performance for electronic warfare applications. A diagram of such an application is shown in Figure 1. In this type of application, GaAs provides both superior speed and high resistance to radiation compared to silicon.

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Figure 1

DRFM Block Diagram



Source: Dataquest (February 1991)

USER ISSUES

As with any technology, progress in dealing with the issues involved in the application of GaAs digICs requires diligence, patience, and considerable effort. The rewards are substantial; Cray Research has maintained its lead in supercomputers with the application of GaAs to its CRAY-3.

Currently, material defects and process variations cause wafer probe yields below 50 percent for many VLSI-density GaAs devices. Combined with relatively high substrate cost, custom test equipment requirements, and high package costs, the results are functional density and pricing that limit the use of many GaAs digICs to only the highest-performance applications where there is no alternative technology available. However, Gazelle's PLDs and several suppliers' ECL-compatible gate arrays are making inroads into applications previously limited to silicon VLSI.

Decreasing the Risk of System Obsolescence

The advent of cost-effective GaAs digital functions has expanded the users' options to include any desired combination of ECL, TTL, NMOS, CMOS, and GaAs. Thus, the systems house and its competitors have a wider variety of design approaches than ever before, and they must carefully make elaborate tradeoff studies before risking a hardware design to overnight obsolescence by new silicon devices from any of more than 200 suppliers. Unlike baseball, this game can be over before the player ever gets to the field. Astute users will take advantage of the unique properties of GaAs digital ICs in systems approaches that can be made very resistant to obsolescence.

Achieving VLSI

The future growth rate of the digital GaAs IC market is heavily dependent on continuing the timely advance of the VLSI level of integration. The primary pressure toward VLSI is caused by the significant percentage of gate performance loss due to interchip interconnection impedance

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constraints. In addition, high reliability, multichip, controlled impedance packaging is complex and expensive. The largest barrier to be overcome is VLSI yield, which was, until recently, limited by starting-material quality.

Transmission Line Environment Requires In-House Expertise

When choosing a GaAs IC family, the user must determine whether expertise exists in-house or is to be developed if GaAs is to be used to the maximum performance advantage. GaAs ICs allow operation at frequencies requiring terminated-line interconnections. Although this problem can be postponed by using TTL interface levels in the near term, sooner or later it must be confronted by those pursuing the performance market. All of the major computer houses have developed the necessary expertise within their ECL design groups. Other companies that grew up on NMOS or TTL and gravitated toward CMOS will face a design cost barrier at some future time; the height of this barrier increases with time.

Testing

Testing is still a problem area in GaAs digIC production, and suppliers such as GigaBit Logic have been forced to develop in-house test capability. This area represents a market opportunity for the first company to successfully build a multi-GHz LSI/VLSI test system that can be priced within reach of the more than 300 users of GaAs digICs.

International Competition

A major concern among U.S. suppliers of GaAs VLSI and SRAM devices is the relative timing of the Japanese competitors' market entries. Predatory practices such as those experienced in the silicon DRAM and EPROM markets would have a disastrous effect on U.S. SRAM development. This concern has been heightened by the recent entry of Fujitsu into the GaAs gate array market. All of the major Japanese suppliers to the silicon RAM market have GaAs SRAM developments under way, and they are believed to be withholding product introductions until the U.S. GaAs SRAM suppliers develop the market further.

Export Controls

Because of the extensive use of GaAs and other III-V semiconductors in some types of military equipment, export of devices can be a major issue. This is a problem, or a potential problem, for suppliers worldwide, not just for the U.S. suppliers.

Some Japan-based potential supplier companies are believed to be withholding GaAs IC exports until they have met Japan's internal needs for parts for fifth-generation computers and other critical applications. This will strengthen Japan's position in the world computer and communications marketplaces.

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Stability of Sources

The failures of GAIN, MSC, and Tachonics and the merger of GigaBit Logic into TriQuint have generated concern among users about the risk of losing supply sources. This problem is more one of perception than reality. For example, Vitesse has alternate source agreements with Fujitsu and Thomson CSF, and other suppliers of GaAs digICs are eager to establish alternate-source arrangements acceptable to the IC users. Most users resolve this issue by making firm commitments to procure sufficient amounts of products to justify the cost of alternate sourcing. In this regard, GaAs technology is not unlike silicon.

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Digital GaAs ICs—Historical Shipment Data

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Digital GaAs ICs (digICs) grew by approximately 39 percent in 1989, to $163 million worldwide. NRE charges increased nearly 60 percent, to $46 million. The majority of the shipments were made by U.S. companies, with major gains made by the Japanese suppliers. Tables 1 through 5 summarize shipment revenue estimates for GaAs digICs. NRE charges are listed separately.

Table 1

Estimated Worldwide GaAs DigIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	26	51	71	86	117	163
NRE	20	30	36	35	29	46
Standard Logic	1	5	7	11	12	13
RAMs	1	4	5	7	8	10
ASICs	4	12	23	33	68	94

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

Table 2

Estimated U.S. GaAs DigIC Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	24	47	60	69	92	107
NRE	19	29	33	32	26	28
Standard Logic	3	4	5	7	8	6
RAMs	1	4	5	7	7	8
ASICs	1	10	17	23	51	66

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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Table 3

Estimated Western European GaAs DigIC Merchant Shipments by Technology (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	2	3	5	8	11	18
NRE	1	1	2	2	2	8
Standard Logic	0	0	0	1	1	1
RAMs	0	0	0	0	0	0
ASICs	1	2	3	5	8	9

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

Table 4

Estimated Japanese GaAs DigIC Merchant Shipments by Technology (Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	0	1	6	9	14	38
NRE	0	0	1	1	2	10
Standard Logic	0	1	2	3	3	6
RAMs	0	0	0	0	1	3
ASICs	0	0	3	5	9	19

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

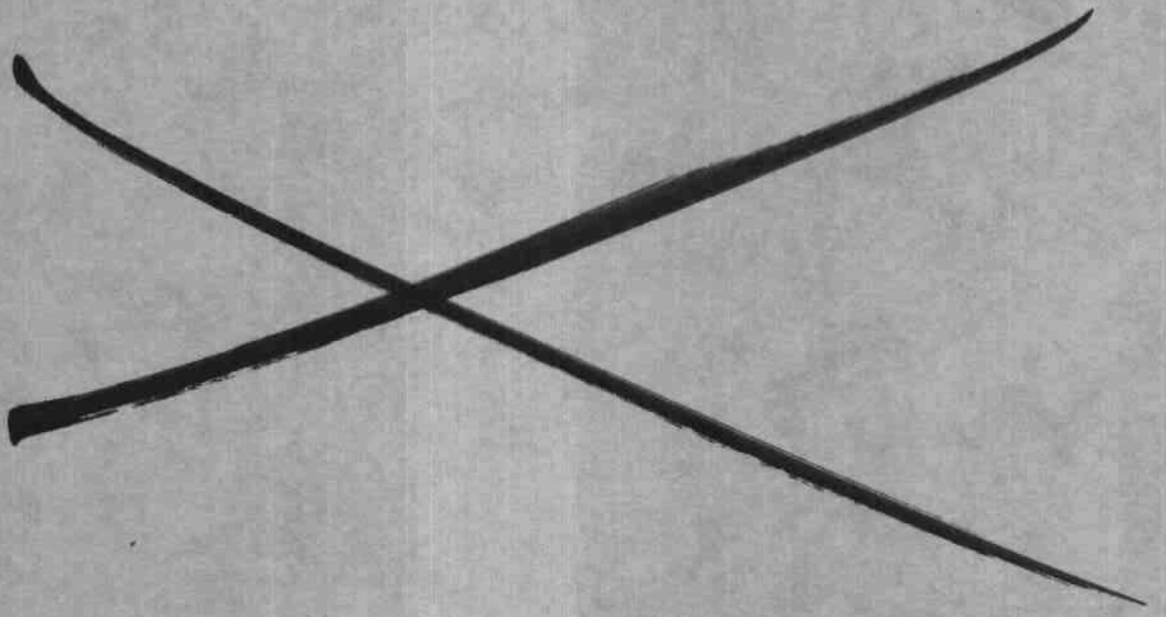
Table 5

Estimated Japanese GaAs DigIC Merchant Shipments by Technology (Billions of Yen)

Category	1985	1986	1987	1988	1989	1990
Digital ICs	0	0.1	0.8	1.1	1.9	5.1
NRE	0	0	0.1	0.1	0.1	1.4
Standard Logic	0	0.1	0.3	0.4	0.4	0.8
RAMs	0	0	0	0	0.1	0.4
ASICs	0	0	0.4	0.6	1.2	2.6

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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GaAs Discretes—Executive Summary

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San Jose, CA 95131-2398
(408) 437-8600

INTRODUCTION

Discrete compound semiconductor devices include transistors, LEDs, lasers and other diodes, and others. The optoelectronics section located elsewhere in this module includes information on several discrete device types, such as LEDs and lasers. This section addresses the "other GaAs discretes" category, which consists primarily of GaAs small-signal and power transistors.

GaAs discrete transistors are available for operation beyond 120 GHz, and research is under way to increase this limit significantly. This section of the GATA module analyzes GaAs discrete transistor products, markets, suppliers, industry structure, competitive behavior, and shipments history. It includes analysis of user issues and a forecast of future markets.

TECHNOLOGY

In the early stages of the development and application of GaAs devices, individual small-signal transistors were used to build hybrid amplifiers and other functions. As integrated circuitry progressed through the development of the integrated inductor, it became possible to replace many hybrid functions with GaAs IC chips, thus slowing the growth of the transistor market. However, some applications still require the use of discrete transistors to accomplish the required tolerance control on such characteristics as low noise and gain-bandwidth. In general, the use of discrete devices may allow tighter control of performance specifications than is achievable with ICs at the same level of production technology. Power GaAs FETs are now available at ratings to 30 watts, and low-noise, small-signal devices are available for 94 GHz and higher-frequency operation.

PRODUCTS

Discrete GaAs devices are broadly categorized as low noise, low power, and high power. The distinction between low- and high-power transistors is usually made at a power level in the range of one-half watt to one watt. Typically, FETs such as HEMTs and E-MESFETs are used in low-noise applications, and FETs HBTs are used where high-power operation is required.

Small-Signal Transistors

GaAs small-signal transistors are usually referred to as low-noise amplifiers (LNAs), although this term has also been used to describe one class of MMIC chips. Small-signal transistors are available for operation to frequencies as high as 120 GHz; NEC's NE04500G is one such device available in chip form. Mitsubishi offers several LNAs for operation at up to 100 GHz. Raytheon and several other companies market devices that operate above 60 GHz.

NEC has applied HFET technology to produce devices with 1dB noise figure and 12dB associated gain at 12 GHz. Fujitsu and others have developed HEMT devices as a means of improving low-noise performance in the microwave frequency range. One example of a supplier serving this market with innovative products is Litton, which has a product line that includes 18-GHz HEMT devices. Other suppliers of LNA products include California Eastern Labs (NEC), Harris, Mitsubishi, Narda, Toshiba, and Varian.

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Power FETs

The replacement of discrete transistors with ICs that has occurred in small-signal GaAs devices has not progressed as rapidly in power FETs, primarily due to the physical constraint of power dissipation. Discrete power FETs still represent a growing niche to the responsive supplier. Thus a market remains for suppliers such as Avantek, Fujitsu, Hughes, M/A-COM, NEC, Philips, Raytheon, and Thomson-CSF, and for several captive sources.

Hall-Effect Devices

Siemens has taken advantage of a developing market for high-temperature Hall-effect devices. GaAs provides a semiconductor capability to operate at temperatures more than 150°C higher than the maximum temperature achievable with silicon. Such products are useful for engine sensors, disk-brake rate-of-rotation sensors, and other very high temperature applications.

OpFETs

Optoelectronic FETs, or OpFETs, are transistors used to convert a photon-induced gate voltage to a corresponding source-drain current flow. Such devices are becoming pratical for communications data processing applications.

MARKETS

Although the military applications represent the primary market for GaAs discretes, the devices are also useful in commercial applications including communications; portable radar such as that used in aircraft, boats, and police speed-detection equipment; test equipment; monitoring and detection equipment; and other environments.

The worldwide market for GaAs discrete devices was $297 million in 1990, with U.S. company shipments accounting for almost 50 percent of the total. The market is expected to grow to $447 million in 1995, representing an estimated 7.4 percent CAGR from 1989 through 1995.

The GaAs power FET market was approximately $188 million in 1990, or 63 percent of the total GaAs discrete market. The low-noise GaAs FET market was approximately $101 million in 1990; GaAs Hall-effect and other devices accounted for the remaining $18 million.

COMPETITORS

Twenty-one companies were supplying GaAs discretes to the U.S. market as of December 1990. Of these, 11 had locations in Silicon Valley, 2 had facilities in Southern California, and 6 had locations in the eastern states. These suppliers are shown in Table 1.

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Table 1

1991 GaAs Discrete Transistor Suppliers

United States	Japan	Western Europe
Avantek	Fujitsu	Philips
California Eastern Labs (NEC)	Matsushita	Plessey
Celeritek	Mitsubishi	Siemens
Harris	NEC	Thomson-CSF
Hughes	Sony	
Litton	Toshiba	
M/A-COM		
Matcom (Toshiba)		
Narda		
Pacific Monolithics		
Raytheon		
TRW		
Varian		

Source: Dataquest (June 1991)

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(408) 437-8600

ISSUES

As in any mature market, GaAs discrete device competitors are facing prospects for slower growth and the need for reassessing product strategy. This is best done with an informed view toward MMIC technology evolution and sustained international competition, especially from Japan.

Another issue is the U.S. defense budget and the extent to which Gramm-Rudman Act pressures will temper demand. While the need for GaAs devices appears critical to certain types of applications, budget pressures could, via the MIMIC initiative, accelerate MMIC technology at the expense of discretes or vice versa.

A major user consideration is the stable supply of specific device types. For example, in 1987, Gould and Harris each sold part of their microwave operations to Litton, and in 1988, Siemens discontinued operation of MSC. As of mid-1990, Varian's GaAs operations are for sale. The user in such situations could face loss of a source of supply should the acquirer decide to exit the market and drop the product line that was designed into the user's system.

Other user issues relate to international competition, export controls, and safety considerations. These are shared with other GaAs product lines, including digital and analog GaAs ICs. Resolution of any of the issues in one product segment is directly applicable to the other product segments.

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GaAs Discretes—Forecast

Table 1 presents Dataquest's forecast of the GaAs microwave and millimeter-wave discrete devices market through 1994. The market is expected to grow at 7.4 percent compound annual growth rate (CAGR) over the 1989 through 1995 time frame.

Table 1

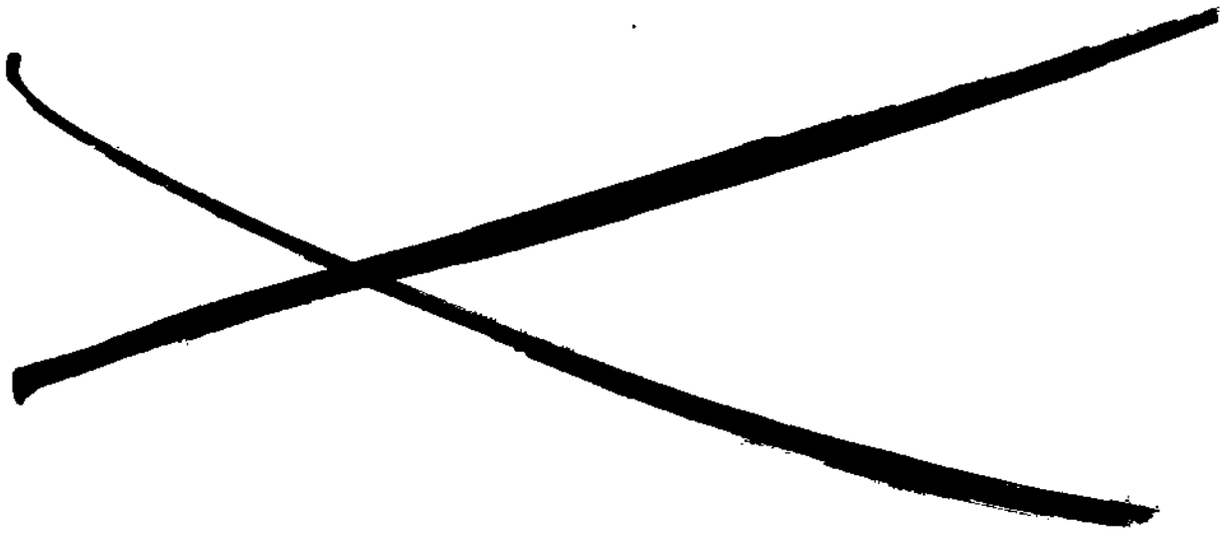
Worldwide GaAs uWave/mmWave Discretes Merchant Consumption Forecast
(Millions of Dollars)

Category	1989	1990	1991	1992	1993	1994	1995	CAGR (%) 1989-1995
GaAs uWave/mmWave Discretes	291	297	318	345	376	410	447	7.4

Source: Dataquest (May 1991)

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GaAs Discretes—Competitive Analysis

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San Jose, CA 95131-2398
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SUMMARY

The GaAs discrete products are relatively mature. The competitors involved have seen severe price pressure, particularly from Japanese suppliers seeking additional market share. As a result, some US competitors have withdrawn products and others have let their discrete product lines stabilize while refocusing on MMICs and other semiconductor product opportunities.

Table 1 shows the major suppliers of discrete GaAs devices as of late 1990. The products available from these companies can be broadly categorized as dual-gate FETs, low-noise FETs, and broadband FET amplifiers. In many applications, MMICs are replacing discrete power amplifiers for reduced cost and improved performance. However, discretes will continue to be used in production systems where the cost of requalification is considered prohibitive; many of these applications are still growing in volume.

Table 1

Examples of GaAs Discrete Transistor Suppliers and Products
1991

Company	U.S. Location	Typical Products
Avantek	Santa Clara, CA	Low-noise (LN) FETs, HEMTs
Calif. Eastern Labs (See NEC)		
Celeritek	San Jose, CA	Broadband amplifiers (amps)
Fujitsu	Santa Clara, CA	LN FETs, HEMTs
Harris	Milpitas, CA	LN FETs, broadband amps
Hughes	Torrance, CA	FETs, amps
Litton	San Jose, CA	LN and dual-gate FETs
M/A-COM	Lowell, MA	LN FETs
Matcom (See Toshiba)		
Mitsubishi	Sunnyvale, CA	LN and dual-gate FETs, HEMTs
Narda	San Jose, CA	LN FETs
NEC	Santa Clara, CA	LN, dual-gate FETs; broadband amps; HEMTs
Pacific Monolithics	Sunnyvale, CA	Broadband amps
Philips	Hicksville, NY	LN FETs, HEMTs
Plessey	Arlington, VA	LN and dual-gate FETs
Raytheon	Northboro, MA	LN and dual-gate FETs
Thomson-CSF	Montgomeryville, PA	FETs
Toshiba	Palo Alto, CA	LN FETs
TRW	Redondo Beach, CA	HBTs
Varian	Santa Clara, CA	FETs, amps

Source: Dataquest (June 1991)

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A few examples of the types of power FETs available today are the matched GaAs power FETs offered by Hughes, as follows:

- Model C2421H-1000, 0.5W, 2-GHz bandwidth, 10-GHz frequency
- Model C2422H-1000, 1.25W, 2-GHz bandwidth, 10-GHz frequency
- Model C2421H-1500, 0.5W, 2-GHz bandwidth, 15-GHz frequency
- Model C2422H-1500, 1.25W, 2-GHz bandwidth, 15-GHz frequency

Hughes patented the first ion-implanted channel FET and was first to apply direct-write e-beam technology to fabricate 0.5u and 0.25u gate-length GaAs FETs.

NEC now offers a family of discrete power GaAs FETs, called the NEZ series, that features linear output power of 37.5 dBm over the range of C through Ku band frequencies. NEC claims the devices are space qualified. NEC also offers 0.3u gate-length HEMTs, such as its NE202 for applications in the 10- to 30-GHz range.

A line of low-noise AlGaAs/GaAs microwave discrete HEMTs available from Sony features a maximum noise figure down to 1.0dB at 12 GHz. The HEMTs are fabricated by MOCVD and are intended for C band through Ka band satellite and other communications applications. Designated 2SK878-1, -2 and -3, initial sample prices were ¥10,000, ¥8,000, and ¥6,000 ($65.79, $52.63, and $39.47), respectively.

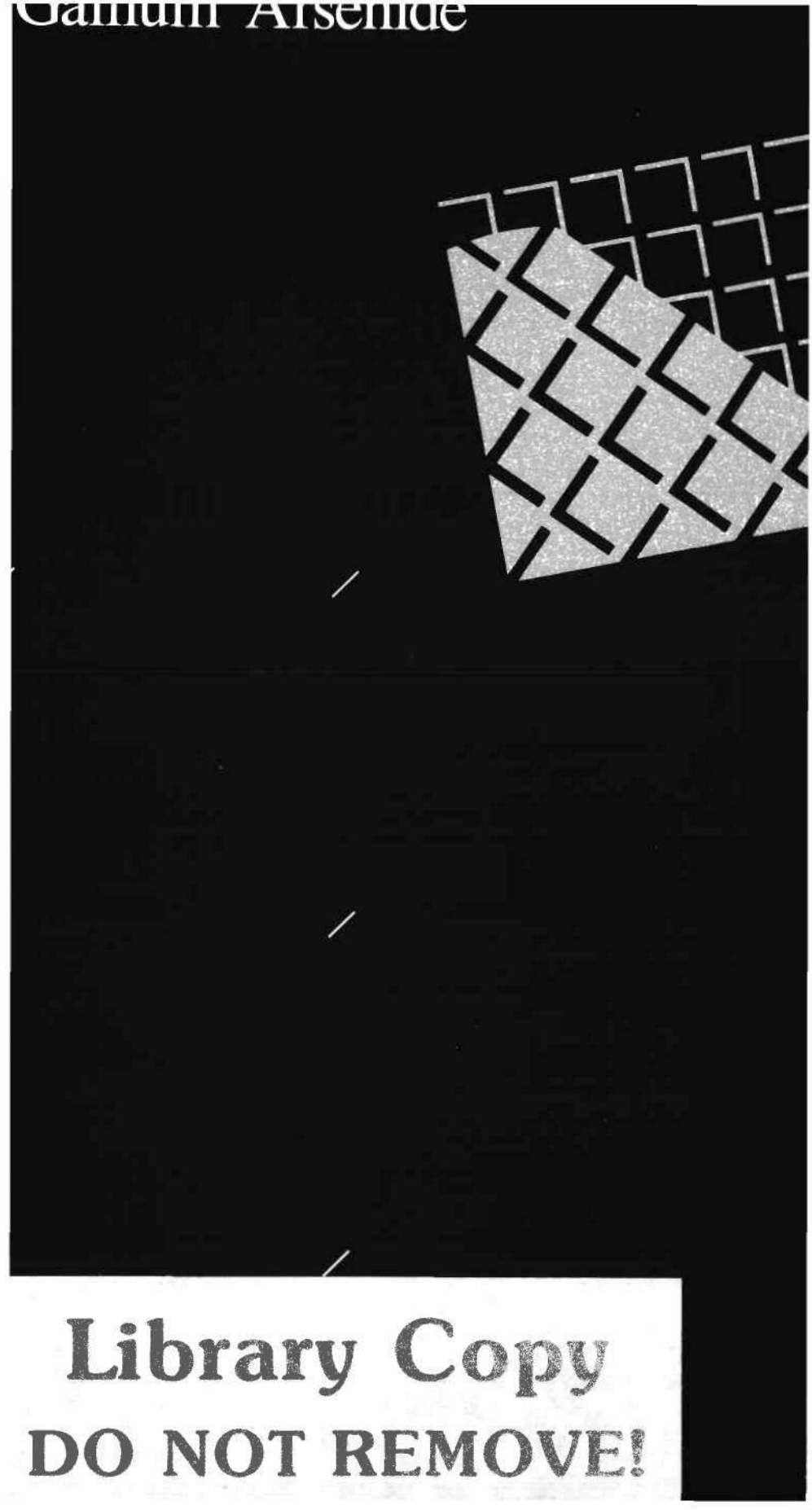
Sony Research Center, Yokohama, Japan, has applied MOCVD technology (previously used for laser fabrication) to the construction of GaAs HEMTs with 0.5u gates. GaAs HBTs were also grown by MOCVD.

Fujitsu has introduced its "FH" family of 0.25u-gate HEMTs for operation to 40 GHz. The company offers space-qualified versions of the devices.

When NHK (the Japan Broadcasting Corporation) began 24-hour DBS service in July 1987, the demand for HEMTs for consumer products increased sharply. Fujitsu implemented a large production boost in late 1987. NEC expanded HEMT production by 500 percent in September 1987, and Sony increased its run rate from 10,000 per month to 100,000 per month.

TRW is now marketing HBT devices. FEI Microwave is TRW's exclusive distributor of GaAs products.

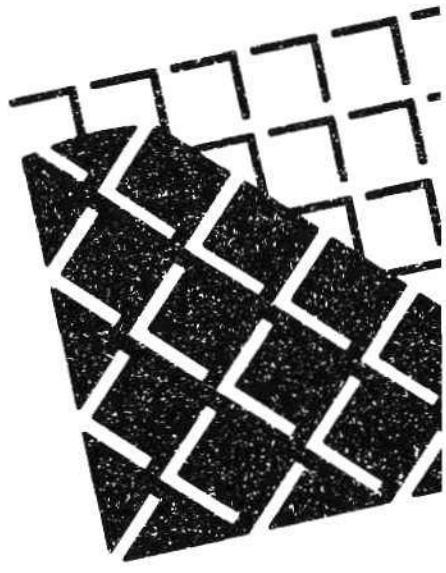
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Who's Who in Gallium Arsenide

November 1990



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A Semiconductor Industry Service Report

Published by Dataquest Incorporated

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ABB HAFO AB

Bruttovagen 1
S-175 26 Jarfalla
Sweden
(0758) 245 00

ESTABLISHED: 1960 (Opto operations) **NO. OF EMPLOYEES: 400**

BACKGROUND

ABB HAFO AB was founded in 1960 as a subsidiary of ASEA in order to participate in the emerging optoelectronic industry. The Company was renamed ABB HAFO as a result of the merger of ASEA and Brown Boveri of Switzerland. HAFO invented the optocoupler in 1968. The Company offers a wide range of semiconductor components for commercial and military markets, including aerospace applications. The products are based on silicon, gallium arsenide (GaAs), and indium phosphide (InP) technologies.

COMPANY EXECUTIVES

Managing Director
Erik Bjorek

Technical Director
Bengt Andersson

Marketing Director
Bengt Lindequist

SERVICES

ABB HAFO AB offers design, production, test, and marketing of optoelectronic semiconductors.

PROCESS TECHNOLOGY

Plasma-etch compound-semiconductor processing (InP and GaAs)
Silicon CMOS VLSI processing
Thick-film hybrid processing and assembly

PRODUCTS

Optocouplers
GaAs lasers—800nm and 900nm wavelengths
InP lasers—1,300nm wavelength
Infrared emitters
AlGaAs and Si photodiodes
Others, including CMOS VLSI

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Alpha Industries, Inc.

20 Sylvan Road
Woburn, MA 01801
617/935-5150

ESTABLISHED: 1962 **NO. OF EMPLOYEES: 1,080**

BACKGROUND

Alpha Industries, Inc., (Alpha) is a major manufacturer of microwave semiconductor devices, components, and subsystems for defense electronics, commercial communications, and other commercial markets. Alpha's GaAs activities originated in 1970. The Company reported sales of $62.2 million and $65.5 million for the fiscal years ending March 31, 1988, and March 31, 1989, respectively.

The Company has seven divisions, including the recently reorganized and expanded Advanced Technology Division. Alpha recently expended $20 million for clean room expansion, including the addition of sub-0.5u e-beam DW lithography. Aerojet-Alpha, a joint venture of Aerojet Electrosystems Co. (California) and Alpha, has developed MMICs for target-activated munitions.

Alpha is teamed with ITT/Martin Marietta on Phase I of the millimeter-wave monolithic IC (MIMIC) initiative, sponsored by the Defense Advance Research Project Agency (DARPA).

COMPANY EXECUTIVES

Chairman and CEO
George S. Kariotis

President and COO
Martin J. Reid

Vice President, R&D (ATD)
Dr. R.E. Goldwasser

Director of Marketing Microwave Sensors
Marc Saucier

Corporate Director of Marketing and Sales
David Barker

STRATEGIC ALLIANCES

Alpha Industries has a joint venture with Aerojet Electrosystems—Aerojet-Alpha—and a joint venture with Martin Marietta—Gamma Monolithics.

PROCESS TECHNOLOGY

Alpha uses sub-0.5u GaAs technology.

PRODUCTS

GaAs discretes
MMICs and mm-wave ICs

FACILITIES

Alpha's Woburn, Massachusetts, facility has 15,000 square feet for GaAs, including 12,000 square feet of clean rooms with Class 10 areas.

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ANADIGICS, Inc.

35 Technology Drive
Box 4915
Warren, NJ 07060
201/668-5000
Telex: 510-600-5741
Fax: 201/668-5068

ESTABLISHED: January 1985 **NO. OF EMPLOYEES: 90**

BACKGROUND

ANADIGICS, Inc., a privately owned company, designs, manufactures, and markets GaAs analog and digital ICs for the telecommunications, military, and instrumentation markets. The Company currently offers RF microwave and signal conditioning amplifiers, A/D converters, dividers, and multiplexers/demultiplexers. In addition, ANADIGICS offers GaAs services and designs both catalog and custom GaAs ICs, as well as custom hybrid assemblies, including fiber-optic data links.

The founders are Ronald Rosenzweig and George Gilbert, who cofounded Microwave Semiconductor Corporation, and Dr. Charles Huang, who was director of GaAs R&D and wafer fabrication services at Avantek.

The Company's strategy is to establish its own niche in producing GaAs ICs for high-frequency analog and digital applications in the defense and communications markets.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
*Ronald Rosenzweig
Microwave Semiconductor Corporation, President

Exec VP/COO
*George Gilbert
Microwave Semiconductor Corporation, Exec VP Opns

VP Engr
*Dr. Charles Huang
Avantek, Dir GaAs R&D

Dir Sales/Mktg
Javed Patel

Dir Finance
John Lyons
General Electric, Dir Finance

*Founder

RECENT HIGHLIGHTS

January 1988
ANADIGICS introduced the ALD30010, a 3-GHz laser driver.

February 1988
ANADIGICS was awarded a $500,000 contract from the navy to develop a chip set for X-band radars.

March 1988
ANADIGICS completed the first stage of a $4 million equity financing. Investors were ABS Ventures, Alan Patricof Associates Inc., Alex Brown Emerging Growth, Canaan Venture Limited Partnership, Century IV Partners, Fairfield Ventures, First Century Partnership III, Investments Orange Nassau, Memorial Drive Trust, Metropolitan Life, and Rothschild Inc.

April 1989
ANADIGICS introduced two new transimpedance amplifiers, the ATA03010 and the ATA30011.

September 1989
Received 1 million-piece MMIC order from Continental Microwave, Luton, Great Britain.

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ANADIGICS, Inc.

June 1990
Shipment rate exceeded 70,000 MMICs per month.

STRATEGIC ALLIANCES

Bendix
June 1987
ANADIGICS was awarded a contract by Bendix Aerospace to develop CAD tools for the Department of Defense's (DOD's) MMIC program. Bendix will adapt the software tools for layout and simulation in the design of GaAs high-frequency broadband amplifiers and mixers.

SERVICES

GaAs IC design
GaAs foundry
Assembly
Test

PROCESS TECHNOLOGY

1.0m and 0.5m GaAs MESFET
Low-power D-MESFET process technologies will be available in the future.

PRODUCTS

Device	Description
AOP1510	Op Amp, 150 MHz
AOP3510	Monolithic Op Amp, 350 MHz
AWA20601	10dB Gain Amplifier, 2 to 6 GHz
ACP10010	Comparator, 1.0ns Typical Delay
ADA25001/25002	25dB Gain Amplifier, 3 GHz
ADV3040	4-to-1 Divider
ALD30010	Laser Driver, 3 GHz
ATA30011	Transimpedance Amplifier, 3 GHz
APS30010	Phase Splitter, 3 GHz
ATA0310	Transimpedance 300-MHz Amplifier
ASW40010	DC—4-GHz Spdt switch
ASW80010	DC—8-GHz Spdt switch fiber optic receiver products
AAR10010	1-GHz, 1,330nm Analog Receiver
AAR10015	1-GHz, 800nm Analog Receiver
AAR10020	1-GHz, High-Output, 1,300nm Analog Receiver
AAR10025	1 GHz, High-Output, 800nm Analog Receiver
ADR16010	1.6-Gb per second (Gbps), 1,300nm Digital Receiver
ADR16015	1.6-Gbps, 800nm Digital Receiver
ADR16020	1.6-Gbps,ECL Output, 1,300nm Digital Receiver
ADR16025	1.6-Gbps, ECL Output, 800nm Digital Receiver
ADR16030	1.6-Gbps, 1,300nm Digital Rcvr/Clock Recovery
ADR16035	1.6-Gbps, 800nm Digital Rcvr/Clock Recovery
ADR12030	1.2-Gbps, 1,300nm Digital Rcvr/Clock Recovery
ADR12035	1.2-Gbps, 800nm Digital Rcvr/Clock Recovery

FACILITIES

Warren, NJ
55,000 sq. ft.
Design, test, manufacturing, administration
10,000 sq. ft.
Clean room

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Avantek, Inc.

3175 Bowers Avenue
Santa Clara, CA 95054
408/727-0700

ESTABLISHED: 1965 NO. OF EMPLOYEES: 2,500

BACKGROUND

Avantek, Inc., is a publicly held vertically integrated company engaged in the design, manufacture, and marketing of solid-state components, subsystems, and systems operating at the frequency range of microwave and below, for the defense, space, communications, test, and instrumentation markets. The Company serves more than 3,000 customers in 35 countries. It manufactures more than 600 proprietary product types, most of which use internally produced semiconductors. Its microwave transistors each sell for approximately $4 to $500.

The Company's "core" strategy is to maximize the competitive advantage provided by vertical integration. The Company's success is keyed to the application of superior microwave semiconductor technology. More than 60 percent of Avantek's 1986 revenue was based on GaAs technology. The Company's sales in 1987 and 1988 were $161.5 million and $123.5 million, respectively. Sales in 1989 were $158.8 million.

COMPANY EXECUTIVES

Chairman
Roy A. Anderson

President/CEO
Dr. E. Oran Brigham

Senior Vice President, Quality, Human Resources, and Administration
Robert W. Busch

Vice President, Finance, CFO, and Secretary
Steven J. Allan

Senior Vice President, Manufacturing
Lionel A. Kirton

Vice President, Sales and Marketing
Peter Manno

Vice President, Products
Ed Winn

SERVICES

Avantek provides custom assemblies based on the largest pretested die bank in the microwave industry.

PROCESS TECHNOLOGY

Submicron GaAs MESFET allowing structures operable above 60 GHz
Microwave silicon processing

PRODUCTS

Silicon and GaAs microwave transistors, MMICs, hybrids
Other microwave subsystems and systems

FACILITIES

Avantek leases 430,000 square feet in Santa Clara and Milpitas, California, and owns 88,000 square feet and 25 acres of land in Folsom, California. The Company also owns nine acres in Newark, California, on which it has built a 150,000-square-foot semiconductor plant that includes 17,000 square feet of Class 10 wafer fab area. The Newark facility started operations in 1987.

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California Eastern Laboratories

3260 Jay Street
Santa Clara, CA 95054
408/988-3500

ESTABLISHED: 1959 NO. OF EMPLOYEES: 113

BACKGROUND

California Eastern Laboratories is a closely held corporation and is the exclusive North American sales agent for NEC's microwave semiconductors. (See "NEC Corporation" company profile for additional data.)

COMPANY EXECUTIVES

President/CEO
Jerry Arden

Executive Vice President
Tom Fuller

Vice President, Marketing and Sales
Leonard Lea

Vice President, Engineering
Mark Burkett

SERVICES

Applications engineering
Design engineering
Testing, including MIL STD 19500 screening

PRODUCTS

GaAs low-noise and power MESFETs and HEMTs
Diodes
MMICs and analog ICs
DigICs including 200-gate and 500-gate BFL arrays and standard logic
Hybrids

FACILITIES

Santa Clara, California
44,000 sq. ft.
Design and test only, no wafer fab facilities (NEC Corporation produces the chips.)

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Celeritek, Inc.

617 River Oaks Parkway
San Jose, CA 95134
408/433-0335
Fax: 408/433-0991

ESTABLISHED: 1984 **NO. OF EMPLOYEES: 160**

BACKGROUND

Celeritek, Inc., designs, manufactures, and markets GaAs FETs, MMICs, and custom subsystems such as up/down converters for military and commercial applications.

The Company has developed a thin-film microwave amplifier technology and manufactures many of its low-noise and medium-power GaAs FETs in-house. All microwave amplifier thin-film circuits use a high-energy sputtering process for reliable and repeatable metal adhesion. The Company can also manufacture silicon MOS capacitors. Celeritek uses a family of standard amplifier modules that can be combined and aligned to achieve customer-specific specifications.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
*Tamer Husseini
Granger Assoc., VP Operations

VP SC Ops
*Ross Anderson
Avantek, Mgr GaAs Dev

VP Finance
*John Beman
ROLM, Controller

VP Marketing/Sales
*Robert Jones
Avantek, Dir Marketing

VP Amp Ops
*Gary Policky
Avantek, Mgr Adv Dev M/W

*Founder

PROCESS TECHNOLOGY

Submicron GaAs MESFET

FACILITIES

San Jose, CA
23,860 sq. ft.
Research and development and manufacturing

1,000 sq. ft.
Class 100 clean room

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Celeritek, Inc.

PRODUCTS

Family	Frequency	Power Output
Low-Noise Amplifiers		
CMA Series	0.5 to 18.0 GHz	+18 dBm
CMT Series	2 to 18 GHz	+18 dBm
CMT Series	18 to 40 GHz	+10 dBm
Medium-Power Amplifiers		
CPA Series	6 to 18 GHz	+27 dBm
CPT Series	6 to 18 GHz	+30 dBm
Microsize Connectorless Amplifiers		
240/400 Series	2 to 18 GHz	
520 Series	0.5 to 4.0 GHz	
MMIC Chips		
CMM-2 Amp	2 to 6 GHz	
CMM-4 Amp	2 to 18 GHz	
CMS-12 Switch	DC to 18 GHz	
GaAs FETs		
CF004-02	2 to 40 GHz	+13 dBm
CF003-01	2 to 20 GHz	+22 dBm
CF010-01	2 to 18 GHz	+28 dBm
Integrated Assemblies		
Frequency Converters		
Switched Amplifiers		
Log Amplifiers		

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COMSAT Laboratories

22300 Comsat Drive
Clarksburg, MD 20871
301/428-4000

ESTABLISHED: 1963 **NO. OF EMPLOYEES: 310**

BACKGROUND

COMSAT Laboratories is the research and development center of the Communication Satellite Corporation. The Company is actively developing MMICs for small signal and power applications. Its products cover the frequency range of one to 94 GHz. COMSAT has provided foundry services to other companies, including Pacific Monolithics.

COMPANY EXECUTIVES

Laboratory Director
Dr. John Evans

Director, GaAs Lab
Dr. Ho Huang

Director, Finance
Rendell Richards

Marketing Director
Fred Gould

SERVICES

COMSAT Labs' capabilities include custom MMIC design, analysis, prototype fabrication, and testing to government and military standards.

PROCESS TECHNOLOGY

GaAs 0.25-micron gate-length MESFETs using vapor phase epitaxy (VPE), metalorganic chemical vapor deposition (MOCVD), and molecular beam epitaxy (MBE) implanted layers, e-beam direct-write equipment, and Ti/Pt/Au metallization

PRODUCTS

GaAs power FETs
GaAs HEMTs
GaAs MMICs

FACILITIES

The Clarksburg, Maryland, facilities include 5,000 square feet of space of Class 100/10 clean rooms.

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EPITAXX, Inc.

3490 U.S. Route One
Princeton, NJ 08540
609/452-1188
Fax: 609/452-0824

ESTABLISHED: 1984 **NO. OF EMPLOYEES: 50**

BACKGROUND

EPITAXX, Inc., produces indium gallium arsenide phosphide (InGaAsP) light-emitting diodes, lasers, and photodetectors for fiber-optic and infrared instrumentation applications. The Company also supplies InGaAsP using a proprietary crystal growth technique, VPE, which allows the elements to be deposited from gases. Custom services include 2,000 and 2,500nm photodiodes, detector arrays, and pulsed laser diodes. EPITAXX sells its components to telecommunications vendors, such as GTE and ITT, and to fiber-optic companies, such as Fibercom and Plantronics Wilcom. The company supports compliance testing to Bellcore specifications.

In order to expand its products, EPITAXX conducts R&D sponsored by industry and the government. The following are some of the Company's development activities:

- Indium gallium arsenide (InGaAs) linear arrays for use in spectroscopy and imaging and airborne communication
- Extended-range sources and detectors for optical sensors and transoceanic communications applications
- InGaAs avalanche photodiodes for optical communications and sensors, range finding, and instrumentation applications
- 5mm InGaAs visible response (500 to 1,700nm) detectors for optical test and calibration and temperature sensors

The Company was founded by Dr. Gregory Olsen and Dr. Vladimir Ban, former research scientists at the RCA David Sarnoff Research Laboratories in Princeton, New Jersey. The founders developed the VPE applications while employed there.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
*Dr. Gregory Olsen
RCA, Scientist

Exec VP
*Dr. Vladimir Ban
RCA, Scientist

Marketing VP
Dr. Yves Dzialowski
General Optronic, Foreign Sales Manager

Finance VP
James Coleman
Lenox China, Account Exec

*Founder

RECENT HIGHLIGHTS

February 1988
EPITAXX announced that the Company was selected by the NASA Goddard Space Flight Center for a Phase-II Small Business Innovative Research (SBIR) contract to develop large-area InGaAs photodetectors for the 500 to 1,700nm spectral range.

March 1988
EPITAXX announced that the Company was awarded a $50,000, Phase-I SBIR contract by NASA's Goddard Space Flight Center to develop a linear array of InGaAs detectors. The array will have a minimum of 32 elements (30 x 30 microns each) and will be installed in a commercial multiplexer readout. EPITAXX plans to apply for a Phase-II program based on linear arrays of InGaAs detectors that are sensitive over the 0.8- through 2.2-micron spectral range.

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EPITAXX, Inc.

April 1988

EPITAXX exhibited the following infrared components at CLEO '88:

- Edge-emitting light–emitting diodes (LEDs) (1,300 and 1,550nm) in a low-cost pigtailed package for local communication and optical instrumentation
- Large-area (0.5 to 3.0mm) InGaAs detectors for gyroscopes, gas sensors, space photography, SWIR detection, and fiber-optic test instrumentation
- High-speed, small-area, planar InGaAs PIN photodiodes for light-wave and range-finding receivers

PROCESS TECHNOLOGY

InGaAs on GaAs wafers
MIL STD 883C processing
Vapor phase epitaxy (VPE)

PRODUCTS

Device	Description
EPITAXX 1300	High-Power LEDs, 1,550 and 1,300nm
ETX60B	PIN InGaAs Photodetector, Low Capacitance and High Speed, 1,300 and 1,550nm
ETX75/100/300	InGaAs PIN Photodetectors, 900 to 1,700nm, with High Responsivity
ETX75F/100F	InGaAs Fibered Photodetectors with Low Dark Current and Capacitance, 1,300 and 1,550nm
ETX500/1000/2000	InGaAs Photodetectors, for Low Noise Measurements of Long Wavelengths (900 to 1,700nm)
ETX3000	Large-Area (3mm) InGaAs Photodetector for Low Noise Detection in the 0.8- to 1.7-Micron Spectral Range
ETX2550	InGaAs 2.5-micron
ETX-Array	256 element InGaAs Detector Array

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Fujitsu, Ltd.

6-1, Marunouchi 1-chome,
Chiyoda-ku
Tokyo 100, Japan
(03)216-3211

ESTABLISHED: 1935 NO. OF EMPLOYEES: Approx. 98,000

BACKGROUND

Fujitsu, Ltd., was founded in 1935 as a spinoff of the parent company, Fuji Electric Co., Ltd. Fujitsu began as a manufacturer of automatic telephone exchanges and related equipment, later adding carrier transmission and radio communications equipment to its line. The Company is considered a world leader in telecommunications; it is also involved in the manufacture and sale of computers and EDP systems, electronic components including semiconductors, and audio products. Fujitsu is one of the top four suppliers to NTT (Nippon Telegraph and Telephone Corp.), along with Hitachi, NEC, and Oki. The three largest shareholders in Fujitsu are Fuji Electric (14.3 percent), Asahi Mutual Life Insurance (6.8 percent), and Dai-Ichi Kangyo Bank (4.7 percent).

Fujitsu established its GaAs FET activity in 1979. The Company has focused its compound semiconductor R&D in several areas, including HEMTs, compact GaAs FET amplifiers, 1K and 4K RAMs using E/D MESFET structures, and a 10ns, 16x16 multiplier. Fujitsu's VLSI GaAs work is paralleling that of NTT, which has also developed 1K and 4K SRAMs.

Fujitsu has developed self-aligned double heterostructure lasers operating at 0.9u to 1.7u wavelength (compatible with fiber-optic cables). In 1985, Fujitsu announced the development of an APD for 1.55u communication applications; the InGaAsP device uses an InP-implanted avalanche effect multiply area to improve the current multiplication ratio by 15 to 20 times that of conventional devices. The Company is equipping a plant in Dallas, Texas, for producing communications equipment.

In mid-1990, Fujitsu and Vitesse entered into a technology exchange agreement on the FURY Series of GaAs VLSI ASICs. Fujitsu is increasing its GaAs capacity to support a 1992 run rate in excess of $200 million per year.

COMPANY EXECUTIVES (GaAs ACTIVITIES)

President
Takuma Yamamoto

Head of Marketing
Masatomi Yasufuku

Managing Director/General Manager, Components Group
Hiroyuki Ino

Executive Vice President/COO, Microelectronics
Taro Okabe

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Fujitsu is part of the DKB Group (Dai-Ichi Kangyo Bank), formed in 1971 through the merger of Dai-Ichi Bank and Nippon Kangyo Bank. DKB is the largest bank in Japan. The DKB Group consists of two subgroups—the Furukawa Group and the Kawasaki Group—that are successors to the former zaibatsu of the same name.

The top five shareholders of Fujitsu are Fuji Electric (15.8 percent), Asahi Mutual Life Insurance (7.3 percent), Dai-Ichi Kangyo Bank (5.7 percent), Industrial Bank of Japan (2.6 percent), and Sega Zurich (2.0 percent). Fujitsu's major financing is via DKB and Mitsubishi Group financial institutions.

PROCESS TECHNOLOGY

Fujitsu uses E/D MESFET technology.

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Fujitsu, Ltd.

PRODUCTS

The Company produces GaAs low-noise and power FETs, HEMTs, APDs, PINs, laser diodes, LEDs, MMICs, detectors, and digICs.

FACILITIES

Aizu plant—includes some GaAs discrete production
Kawasaki plant—67,000 square feet
Yamanashi plant—125,000 square feet; includes 3-inch and 4-inch GaAs wafer fab; produces FETs, other discretes, and optoelectronics

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Gazelle Microcircuits, Inc.

2300 Owen Street
Santa Clara, CA 95054
408/982-0900
Fax: 408/982-0222

ESTABLISHED: June 1986 **NO. OF EMPLOYEES: 60**

BACKGROUND

Gazelle Microcircuits, Inc., was founded to design and market high-performance, digital LSI and VLSI GaAs ICs for high-volume commercial applications such as computation, communication, and military/aerospace. The Company is concentrating on product design and marketing development and does not plan to invest in a wafer fabrication facility.

Gazelle's product strategy is to offer high-yielding, low-cost circuits of large-scale complexity, using existing GaAs fabrication processes. The Company will concentrate on developing unique circuit design approaches to differentiate its performance-oriented devices.

The Company was formed by ex-GigaBit Logic executives Andrew Graham and David MacMillan. In January 1987, Jerry Crowley left Oki Semiconductor, where he was vice chairman and founder, to head Gazelle. In March 1988, Thomas Andrade joined Gazelle as vice president of technology from Pacific Monolithics where he was manager of semiconductor development. Mr. Andrade is responsible for identifying and qualifying the foundries and processes used to fabricate Gazelle's circuits. Before joining Pacific Monolithics, he developed the first of Avantek's microwave IC processes and transferred it into volume manufacturing. He was a member of the research staff at IBM, where he did basic research on GaAs fabrication processes and materials. David MacMillan left Gazelle in mid-1990.

In February 1988, Gazelle moved into its new 22,000-square-foot headquarters in Santa Clara, California. The facility is used for engineering development, circuit design, product evaluation, and marketing operations. Gazelle also has an option on an adjoining 24,000-square-foot space.

Gazelle has signed pacts with several U.S. manufacturers to supply its GaAs wafers to the companies.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
Jerry Crowley
Oki Semiconductor, Vice Chairman

VP Engineering
*Andrew Graham
GigaBit Logic, Dir of Memory Development

VP Technology
Thomas Andrade
Pacific Monolithics, Mgr Semi Dev

VP Sales
Robert Gunn

VP Operations
George Schneer
Intel, VP Operations

*Founder

STRATEGIC ALLIANCES

TriQuint
September 1988
Gazelle Microcircuits announced a two-year, $16.9 million gallium arsenide manufacturing contract with TriQuint Semiconductor, Inc., a subsidiary of Textronix.

PROCESS TECHNOLOGY

E/D GaAs MESFET

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Gazelle Microcircuits, Inc.

PRODUCTS

Part No.	Description
GA22VP10-7 GA22VP10-10	24-Pin PLD Superset with Improved Output Macrocells
GA22V10-7 GA22V10-10	24-Pin PLD Superset with Output Macrocells
GA23SV8-7 GA23SV8-10	20-Pin-Based Sequencer with Output Macrocells and six Buried Registers; a Superset of 32 Silicon PLDs.
GA9011	Transmitter for 40-Pin Data Bus
GA9012	Receiver for 40-Pin Data Bus

FACILITIES

Santa Clara, CA
22,000 sq. ft.
Headquarters, engineering, design

The Company also has an option on an adjoining 24,000 square feet of space.

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General Electric (GaAs Operations)

Electronics Park
EP-3, Box 4840
Syracuse, NY 13221
315/456-0123

ESTABLISHED: 1981 NO. OF EMPLOYEES: NA

BACKGROUND

General Electric Company is an international, vertically integrated manufacturer of electrical and electronic systems and components. In 1986, the Company acquired RCA Corporation; in 1988, it sold part of its semiconductor operations, including Intersil, to Harris Corporation.

GE produces optoelectronic devices and GaAs MMICs. GE invested $3.5 million in advanced equipment for its GaAs R&D facility in 1985 and has made additional investments in the facility since that time.

GE and Hughes Aircraft are one of the four prime contractor teams on DARPA's MIMIC program, Phase I. This team is developing 16 different GaAs IC chip types for radar and other military applications.

COMPANY EXECUTIVES

Manager, Electronics Laboratory
Dr. Walter Butler

Manager, Business Development and Technology Planning
Louis Lego

Manager, GaAs Laboratory
Dr. Alan Swanson

Manager, MMIC Prototype Facility
Dr. Anthony Immorlica

Manager, Finance
Ronald J. Ziomek

STRATEGIC ALLIANCES

GE has a joint venture with Hughes Aircraft on DARPA's MIMIC program.

PROCESS TECHNOLOGY

The Company uses submicron GaAs MESFET technology.

PRODUCTS

Optoelectronic devices
GaAs MMICs

FACILITIES

General Electric's laboratory in Syracuse, New York, has 120,000 square feet. This space is divided into 40 percent for R&D and 60 percent for GaAs products, including an 8,000-square-foot clean room for 3-inch wafer fab.

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GigaBit Logic, Inc.

1908 Oak Terrace Lane
Newbury Park, CA 91320
805/499-0610
Fax: 805/499-2751
Telex: 6711358

ESTABLISHED: August 1981 NO. OF EMPLOYEES: 97

BACKGROUND

GigaBit Logic (GBL) designs, develops, manufactures, and markets GaAs standard and application-specific digital ICs capable of 1-GHz to 5-GHz operation. GBL was founded in 1981 by Fred A. Blum and Richard C. Eden. GBL's goal is to be the leader in the commercial digital GaAs IC market, and the company is targeting product segments in the military, mainframe computers, RF communication and instrumentation, and test equipment markets. GBL's strategy is to penetrate high-performance equipment markets by offering products that are five to ten times faster than silicon for comparable prices.

GBL uses sales representatives, distributors, and a direct sales force to sell its products worldwide. Currently, GBL has sales representatives nationwide and franchised distributors in Japan, West Germany, Italy, France, the United Kingdom, Israel, Canada, Sweden, Denmark, Taiwan, Australia/New Zealand, and South Korea.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
Spencer Brown
GigaBit Logic, Inc., VP Finance

VP R&D
Richard C. Eden
Rockwell, Principal Scientist

VP Prod Dev
Frank S. Lee
Rockwell, Design Engr Mktg

VP Marketing/Sales
Mike Pawlik
Fairchild, Marketing Mgr

VP Mfg
Yieder Shen
GigaBit Logic, Mfg Mgr

RECENT HIGHLIGHTS

January 1988
Cray placed a $6.8 million foundry order with GBL.

September 1988
GBL and NKT (Denmark) initiated a joint venture—named GIGA—to serve the Europe and Israel markets for ICs (see "Strategic Alliances").

November 1988
Cray placed a $29.3 million foundry order with GBL.

December 1988
GBL and SC Hightech Corp.—a division of Sumitomo Group, Tokyo, Japan—signed a marketing and product development agreement. Under the pact, GigaBit Logic will market SC Hightech's GaAs IC products throughout the world, excluding Japan. The agreement also provides the opportunity for codevelopment of future generations of GaAs ICs to the two companies. In addition, SC Hightech may provide foundry services for certain high-volume segments of GigaBit Logic's standard product line.

October 1989
GBL completed its conversion to 100mm wafers.

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GigaBit Logic, Inc.

STRATEGIC ALLIANCES

Kidder, Peabody & Company
December 1983
GBL and Kidder, Peabody & Company formed a research and development partnership to develop four ultrahigh-speed GaAs SRAMs.

Cray Research
April 1987
Cray Research is a contributor in the $14.4 million recapitalization of GigaBit Logic. In return, GBL will provide foundry services for Cray in its development of a GaAs-based parallel processor supercomputer, the CRAY-3.

June 1990
GBL transferred D-MESFET production capability and approximately 25 personnel to Cray's plant in Colorado.

Seattle Silicon, Washington Technology Center
April 1987
GBL, Seattle Silicon, and the Washington Technology Center (WTC) announced that their joint design project had resulted in the fabrication of a functional GaAs IC design based on GBL's cell library; Seattle Silicon's compiler; and WTC's design, engineering support, packaging, and test.

Tachonics
October 1987
GBL and Tachonics agreed mutually to second-source GaAs standard ASIC ICs; GBL to transfer databases, schematics, and test specs of the PicoLogic cell-based families to Tachonics, and the companies to codevelop cell libraries to support future GaAs technologies. (Tachonics ceased operations in 1989.)

NKT (Denmark)
September 1988
GBL and NKT initiated a joint venture (GIGA) to serve the Europe and Israel markets for ICs. GIGA will provide a full-support design center and management for GigaBit's distributor network for standard products in Europe. This alliance makes GBL the first U.S. GaAs company to have full ASIC development capability based in Europe.

SC Hightech Corporation
December 1988
GBL and SC Hightech Corp.—a division of Sumitomo Group, Tokyo, Japan—signed a marketing and product development agreement.

PRODUCTS

PicoLogic Digital and Analog GaAs ICs

Gates
Two and three Input NORs, two Input XOR/XNOR/Line Receivers, Dual AO/AOI

Drivers/Receivers/Comparators
2:1 Multiplexed Fanout Buffer, 1:4 Fanout Buffer Complementary Driver/Comparator

Flip-Flops and Registers
Dual-Precision D Flip-Flop, Quad D Flip-Flops with 2:1 MUXed or XOR Inputs, Octal Register/Shift Register, and PN Code Generator

MUX/DEMUX/Crosspoint
Quad 2:1 MUX, 3:8 or Dual 2:4 Decoder/DEMUX, Quad 4:1 or Dual 8:1 MUX, 8x8x1 Expandable Crosspoint Switch, 16x16x1 Crosspoint Switch

Counters/Prescalers
2- and 7-Stage Ripple Counter/Dividers, 4-Bit Synchronous Programmable Counter, Variable Modulus Divider

Arithmetic Operations
Dual 9-Bit Parity Generator/Checker and 8-Bit Equivalence Checker, High-Speed 4-Bit Adder, Carry Lookahead Generator, 32-Bit DDS Phase Accumulator

Monolithic FET and Diode Arrays
15mA Schottky Diode Array, Single Gate MESFET Array, Dual Gate MESFET Array

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GigaBit Logic, Inc.

Fiber Communications Products
8:1 Time Division MUX, 8:1 Time Division DEMUX, Clock and Data Recovery Circuit, Low Power Clock and Data Recovery, 16G040 Demo Board, Transimpedance Amplifier, Laser Driver, LED Driver, Fiber-Optic Transmitters and Receivers

Analog/ATE/Instrumentation Products
Phase/Frequency Comparator, Dual High-Speed Pin Driver

NANORAM and NANOROM Memory
256x4-Bit Registered, Self-Timed Static RAM, 1,024x4-Bit Latched Self-Timed Static RAM, 1024x4-Bit Replacement for 100474 SRAM, 512x8-Bit and 8192-Bit Mask Programmable ROMs

ASIC Products
SC5000 Standard Cell Library
SC10000 Standard Cell Library
GaAs Foundry Services

Prototyping and Support
Evaluation Boards for Transimpedance Amplifiers, Laser Drivers, and LED Drivers, Universal Prototyping Boards (for 36-, 40-, and 68-pin packages), High-Speed Sockets (for 40- and 68-pin leadless chip carriers)

PROCESS TECHNOLOGY

GaAs D-MESFET
GaAs E/D-MESFET, 0.8-micron gates, three-layer metal

FACILITIES

Newbury Park, CA
20,000 sq. ft.
Headquarters, engineering, design, foundry, manufacturing

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Hamamatsu Corporation

360 Foothill Road
Bridgewater, NJ 08807
201/231-0960

ESTABLISHED: 1957 NO. OF EMPLOYEES: NA

BACKGROUND

Hamamatsu Corporation, a privately held United States-based company, markets semiconductors that are produced by Hamamatsu Photonics K.K. The parent company's Solid-State Division is the largest optoelectronic semiconductor facility in Japan. The Company specializes in photo-electronic semiconductor components and subassemblies.

PROCESS TECHNOLOGY

GaAs and other compound wafer processing by VPE and MOCVD

PRODUCTS

Phototransistors
GaP, GaAsP, and other photodiodes
GaAs, GaAlAs, and other infrared LEDs
Photocouplers and photointerruptors
II-VI and III-V compound detectors
GaAs and other lasers

FACILITIES

The Hamamatsu City (Shizuoka Prefecture) facilities have a wafer start capacity of 15,000 3-inch GaAs and other III-V wafers per month.

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Harris Microwave Semiconductor, Inc.

1530 McCarthy Blvd.
Milpitas, CA 95035
408/433-2222
Fax: 408/432-3268

ESTABLISHED: June 1980 **NO. OF EMPLOYEES: 70**

BACKGROUND

Harris Microwave Semiconductor (HMS), Inc., was formed to develop and manufacture GaAs-based FETs, MMICs, and digital ICs. In addition to offering standard products, the Company offers full and semicustom capabilities and provides foundry services. HMS is a vertically integrated operation of Harris Corporation's Semiconductor Sector. One hundred percent of the Company's funding has been provided by the Harris Corporation.

The Company has capabilities for manufacturing GaAs crystals and wafers as well as ICs, packaged products, and discrete devices. HMS is said to have the world's largest high-purity GaAs ingot-growing capacity, which produces single-crystal GaAs ingots of up to 7 inches in diameter.

COMPANY EXECUTIVES
(Position and Name)

President/Chief Executive Officer
John T. Hartley

Vice President/General Manager
Dr. Joseph Barrera

Marketing and Sales Director
Vic Kovacevic

Marketing Communications
Shelley Hecker

RECENT HIGHLIGHTS

February 1988
HMS introduced the HMM-10620, a 2- to 6-GHz low-current, cascadable, broadband MMIC amplifier designed to meet the electronic warfare systems' low-current requirements.

May 1988
HMS introduced the HMM-11810, a 6- to 18-GHz low-current, cascadable broadband MMIC amplifier designed to meet the low-current requirements of electronic warfare systems.

June 1989
HMS introduced the HMR-1100, a GaAs MMIC Pi Attenuator. The MMIC is a practical solution for slope and gain control in a variety of military components such as amplifiers.

SERVICES

Foundry

PROCESS TECHNOLOGY

1.0- to 0.5-micron GaAs MESFET
2-, 3-, and 4-inch wafers

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Harris Microwave Semiconductor, Inc.

PRODUCTS

Device	Description
FETs (available in chip or packaged form)	
HMF-0300	2-18 GHz, 125mW Power
HMF-03100-100	2-20 GHz, Low Noise, Gain
HMF-03100-200	2-20 GHz, Gain/Drive
HMF-03100-300	2-20 GHz, Drive
HMF-0330	2-20 GHz, Low Noise, Low Current
HMF-0600	2-20 GHz, 250mW Power
HMF-0610	2-20 GHz, Gain
HMF-0620	2-14 GHz, High Transconductance
HMF-12000-100	2-16 GHz, 500mW Power
HMF-12000-200	2-16 GHz, 650mW Power
HMF-1210	2-20 GHz, Gain
HMF-24000-100	2-14 GHz, 800mW Power
HMF-24000-200	2-14 GHz, 1.2W Power
MMICs	
HMR-11000	Pi Attenuator, DC-18 GHz
HMR-10502	Analog Amplifier, 0.5-5.0 GHz
HMR-10503	Analog Amplifier, 1-5 GHz
HMM-10610	Broadband Amplifier, 2-6 GHz
HMM-10620	Broadband Amplifier, 2-6 GHz, Low Current
HMM-11810	Broadband Amplifier, 6-18 GHz
HMM-11820	Broadband Amplifier, 6-18 GHz, Low Current

FACILITIES

Milpitas, CA
37,000 sq. ft. total
15,000 sq. ft. manufacturing space

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Hewlett-Packard Company

3000 Hanover Street
Palo Alto, CA 94304
415/857-1501

ESTABLISHED: 1965 (HP Labs activities) NO. OF EMPLOYEES: NA

BACKGROUND

Hewlett-Packard (HP) is a vertically integrated electronics company that develops and manufactures products for the worldwide marketplace. HP's principal products include integrated instrument and computer systems, test/measurement instruments, computers, peripherals, medical electronics, chemical analysis instrumentation, handheld calculators, and solid-state components.

HP Labs conducts research to extend its technology base. The laboratories originated LED displays, the Schottky-gate GaAs FET X-band amplifier, and GaAs MMICs. HP's Microwave Division (MSD) makes transistors and other microwave components. The Optoelectronics Division (OED) produces LEDs, light bars, and linear arrays. Products of the Optocommunication Division (OCD) include fiber optics and couplers.

HP ships approximately $200 million in merchant and captive optoelectronic components per year. GaAs ICs are now used in many of HP's instrumentation products.

COMPANY EXECUTIVES

Lab Director
Frank Carruba

Executive Vice President, Marketing and International
Dick Alberdin

General Manager, MSD
Paul Sedlewicz

General Manager, OED
Mike Cowley

General Manager, OCD
Rick Kniss

PROCESS TECHNOLOGY

GaAs, GaA1As, and related III-V opto device processes

PRODUCTS

LEDs
Optocouplers
Microwave diodes
Transistors
MMICs

FACILITIES

HP has manufacturing facilities at Santa Rosa and Rohnert Park, California.

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Hitachi, Ltd.

6, Kanda-Surugadai
4-chome, Chiyoda-ku
Tokyo 101-10, Japan
(03) 258-1111

ESTABLISHED: 1910 NO. OF EMPLOYEES: 80,677

BACKGROUND

Hitachi, Ltd., was founded in 1910 by Namihei Odaira, an engineer, to develop domestic manufacturing technology for electric power equipment. After World War II, the Company entered consumer electronics, and in 1950 it entered the field of electronics. Hitachi views electronics and the development of alternative energy sources as its two areas of strategic growth in this decade. Estimated total sales for the Company for its fiscal year ending March 1990 were ¥6.75 million.

Hitachi's compound semiconductor R&D effort has included development of InGaAsP lasers in the visible spectrum (specifically, 752nm to 756nm). Hitachi also has developed buried-layer GaAs FETs with threshold voltage deviations of only 5 percent.

Hitachi participated in the AIST/MITI Japanese national supercomputer project sponsored by NEDO, which resulted in a GaAs-based supercomputer prototype system.

COMPANY EXECUTIVES (GaAs Activities)

President
Katsushige Mita

Head of Marketing
Shuzo Hata

Group Executive, Electronic Devices
Kazuo Kimbara

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Hitachi originated from the pre-World War II Nissan Konzern. The Hitachi Group, formed under Hitachi Ltd., is not one of the six major Japanese industrial groups. The group companies have relations with former Nissan Kozern companies, including Nissan Chemical Industries, through cross-shareholdings and common directors; they also participate in deliberation councils with the DBK, Fuyo, and Sanwa Groups.

The top shareholders of Hitachi include Nippon Life Insurance (4.1 percent), Mitsubishi Trust (3.5 percent), Toyo Trust (3.1 percent), Yasuda Trust (2.8 percent), Dai-Ichi Mutual Life Insurance (2.7 percent), Mitsui Trust (2.5 percent), Sanwa Bank (2.3 percent), and Sumitomo Trust (2.2 percent). Approximately 14 percent of Hitachi's stock is foreign-owned; the ceiling for foreign ownership is set at 30 percent.

Hitachi has technology-sharing and/or licensing agreements with Asahi Chemical, Fairchild (bought by National Semiconductor), Fujitsu, General Motors (owner of Hughes Aircraft), Hewlett-Packard, Monsanto, Motorola, NTT, Signetics (a subsidiary of Philips), Sperry (now part of Unisys), Thomson-CSF, and others.

Hitachi, Fujitsu, Mitsubishi, NEC, Oki, and Toshiba jointly developed a GaAs-based prototype supercomputer system from 1981 to January 1990.

PROCESS TECHNOLOGY

Hitachi produces for internal use and for the merchant market e-beam masking, wafer inspection, and test equipment for production processes requiring submicron resolution and 0.1-micron accuracy. This equipment is used in its GaAs and other compound semiconductor processes.

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Hitachi, Ltd.

PRODUCTS

LEDs
Lasers
Detectors
Small-signal transistors

FACILITIES

Takasaki plant
Komoro factory—fab, assembly, and test of opto devices and hybrids

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Hittite Microwave Corporation

21 Cabot Road
Woburn, MA 01801
617/933-7267
Fax: 617/932-8903

ESTABLISHED: January 1985 **NO. OF EMPLOYEES: 12**

BACKGROUND

Hittite Microwave was formed to market custom and proprietary GaAs MMICs for military and commercial applications. The Hittite team has been involved in all aspects of design, development, and production of monolithic GaAs components, including participation in several Department of Defense GaAs technology development programs.

Hittite's expertise ranges from designing small, single-chip systems to 500-watt, continuous-wave, multichip components and subsystems. Hittite's facility is equipped to conduct design, layout, verification, packaging, and test of GaAs-based components. Wafer fabrication is conducted by foundries.

Hittite is part of the General Dynamics, Honeywell, TRW consortium that is addressing the critical technology, fabrication, and cost issues of inserting microwave/millimeter wave monolithic IC (MIMIC) technology into advanced tactical weapons systems. The team has targeted three main mission areas for MIMIC insertions—smart weapons, electronic warfare, and communications.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/COO
Dr. Francis Paik
Raytheon, Business Dev Mgr

VP/CEO
*Dr. Yalcin Ayasli
Raytheon Research, Mgr R&D Monolithic ICs

VP Finance/CFO
Ronald Kaplan
Wang, Controller

*Founder

STRATEGIC ALLIANCES

Hittite is part of the General Dynamics, Honeywell, TRW consortium as part of the Department of Defense MIMIC program.

PROCESS TECHNOLOGY

0.5- and 1.0-micron GaAs MESFETs

PRODUCTS

Signal Control Components
Microwave Radar Ranging Systems
Other proprietary products

FACILITIES

Woburn, MA
4,800 sq. ft. total
Offices, R&D, assembly, test

400 sq. ft.
Class 10 clean room

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Hughes Microwave Products Division

P.O. Box 2940
Torrance, CA 90509-2940
213/517-6400

ESTABLISHED: 1977 NO. OF EMPLOYEES: NA

BACKGROUND

Hughes Aircraft Company, now owned by General Motors, began GaAs R&D in the late 1960s. The Microwave Products Division (MPD) in Torrance started operations in 1977. From 1977 to the early 1980s, the division invested about $1 million per year in capital equipment. In 1982, the prototype lab was completed. Another $10 million was invested in the pilot fab line constructed in 1985. As of mid-1985, Hughes was investing $40 million in GaAs ICs; $20 million had been invested prior to that time. In 1987, Hughes MPD tripled its GaAs clean rooms to a total of 44,300 square feet, permitting high-volume production in a facility separate from the prototype fab and diode fab areas.

In 1988, Hughes received a Phase I MIMIC award. Phase I is expected to be completed by mid-1991. Hughes is teamed with AT&T, GE, HMS, and M/A-COM on this DARPA-sponsored program. This team is developing a total of 16 chip types for military radar, communications, and smart weapons applications.

COMPANY EXECUTIVES

MPD Division Manager
Dr. N. Bruce Kramer

MPD Division Marketing/Sales Manager
Sandy Edberg

Assistant Division Manager and MPD Facilities Manager
Kenneth P. Grabowski

Assistant Division Manager and MPD GaAs Operations Manager
H. J. Kuno

MPD Division Sales Manager
Richard A. Johnson

Business Development Manager
Richard Larson

MPD Controller
David McLeod

MPD Quality Assurance Manager
P. J. Nobile

STRATEGIC ALLIANCES

MPD is a division of Hughes Aircraft, which is owned by General Motors. Hughes Aircraft is developing electronics for future automotive applications including collision avoidance and communications systems.

Hughes and McDonnell Douglas are teamed with AT&T Bell Laboratories on a DARPA program to develop SDHT (HEMT) SRAMs and logic circuits.

The Hughes MIMIC (DOD initiative) team includes AT&T, Cascade, GE, HMS (Harris Microwave Semiconductor), and M/A-COM.

SERVICES

The company provides circuit design, CAD support, wafer fab, and chip test and evaluation for internal and selected external use.

PROCESS TECHNOLOGY

GaAs MESFET to 0.25u gates; SDHT (HEMT)
Ion implantation, direct-write e-beam, and second-generation MBE equipment (Hughes patented the ion-implanted channel FET.)

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Hughes Microwave Products Division

PRODUCTS

LNAs
Power FETs including 1-Watt, 15-GHz devices
Matched drivers
MMICs

FACILITIES

MPD's facilities are located in Torrance, California. They include 44,300 square feet of clean rooms with 8,000 square feet for diode fabrication, 6,400 square feet for materials and prototype fabrication, and 29,900 square feet for GaAs production areas.

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Isocom Limited

Prospect Way
Park View Industrial Est.
Brenda Road
Hartlepool, Cleveland, England
(0429) 221431

Isocom, Inc.

256 E. Hamilton Avenue, Suite H
Campbell, CA 95008
408/370-2212

ESTABLISHED: November 1982 **NO. OF EMPLOYEES: 85**

BACKGROUND

Isocom Limited was formed to design, manufacture, and market optocouplers with the goal of becoming a major participant in the $80 million military optocoupler market. Marketing efforts were concentrated in the European commercial and industrial markets for the first two years. In 1986, the Company began offering devices to the military market.

The Company's initial products included a range of optocouplers and interrupter switches in single-, dual-, and quad-package configurations. In 1984 and 1985, the product line expanded to include Hewlett-Packard-compatible, high-speed, high-gain optocouplers. Isocom's products, which currently include transistor-output, Darlington-output, AC-input, photo SCRs, TRIACs, and Schmitt Trigger optocouplers, are used in power supplies, telecommunications, instrumentation, and modems. In the second quarter of 1985, the Company became one of the first to offer a range of surface-mount devices.

Isocom was founded by several former Litronix managers and is headquartered in Hartlepool, England, with a U.S. sales and marketing office in Campbell, California. Design, manufacturing, and test are done at the 25,000-square-foot Hartlepool facility. Some assembly is contracted to companies in the Far East.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
*Colin Rees
Litronix, Mgr Europe Sales

Vice President/General Manager Isocom, Inc.
Stephen Parry
*Founder

PROCESS TECHNOLOGY

Silicon
GaAs
GaAlAs

PRODUCTS

Minicouplers
High-Speed/High-Gain Couplers
High-Isolation Optocouplers
High-Speed Tristate Optocouplers
High-Voltage Photo Transistor Couplers
Switches
Hybrids
Visible Lamps
Visible Displays
Integrated Displays

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Isocom Limited

FACILITIES

Hartlepool, England
25,000 sq. ft.
R&D, design, manufacturing, test

Campbell, CA
2,000 sq. ft.
Marketing and sales

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ITT GaAs Technology Center (GTC)

7670 Enon Drive
Roanoke, VA 24019
703/563-8600

ESTABLISHED: 1983 NO. OF EMPLOYEES: Approx. 100

BACKGROUND

ITT GaAs Technology Center (GTC), a unit of ITT Corporation, was founded to support both internal and merchant market needs for MMICs and high-speed digICs implemented with GaAs technology. The activity was part of ITT's Electro-Optical Division until early 1983. ITT GTC is a key player in the DOD's MIMIC Phase I program and offers foundry services for both military and commercial applications.

By mid-1990, ITT GTC had designed and fabricated more than 200 types of MMICs for applications from DC to 18 GHz.

COMPANY EXECUTIVES

Director
Dr. Dennis G. Fisher

Director, Engineering/Operations
Dr. Edward Griffin

Senior Manager, Technical Services
Ed Donoho

Manager, Business Development
Joseph A. Grzyb

SERVICES

ITT GTC operates a GaAs microwave and digIC foundry including design, fab, assembly, and test. The Company has significantly expanded its module test and assembly capabilities to accommodate volume production of c-band T/R modules.

PROCESS TECHNOLOGY

The Company uses GaAs multifunctional self-aligned gate (MSAG) processing on 3-inch wafers. This process allows the manufacture of low-noise, power, and E/D MESFET digital circuits on a single chip.

PRODUCTS

MMICs:
- Low noise, 2 to 18 GHz
- Power, 2 to 12 GHz to 12W output to 70 percent efficiency

DigICs—DCFL standard cells, complexities to 5,000 gates

FACILITIES

ITT GTC has a 27,000-square-foot 3-inch wafer fab facility plus a 12,000-square-foot design/test/packaging area; the Company added a 2,000-square-foot packaging area in late 1987. Equipment includes ion implantation, SEM, and very high temperature burn-in capacity. The facilities have a throughput capacity that exceeds 100 wafer starts per week.

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Kyoto Semiconductor Corporation

418-3, Yodosaime-cho
Fushimi-ku Kyoto 613, Japan
075-631-8823
Fax: 075-631-8291

ESTABLISHED: April 1980 **NO. OF EMPLOYEES: 20**

BACKGROUND

Kyoto Semiconductor offers GaAs LEDs, phototransistors, photosensors, and LED displays. The diodes offer twice the efficiency of available units. The heterostructured diodes feature a 23.6 percent light-emitting efficiency at peak wavelengths of 190nm. Four selections of wavelengths are available: 660, 750, 830, and 890.

Kyoto Semiconductor's major customers are Mitsubishi Electric and General Instrument. The Company contracts assembly to companies in Taiwan.

COMPANY EXECUTIVES

(Position, Name, and Prior Company)

President
Jousuke Nakata
Mitsubishi

PRODUCTS

High Bright LEDs
Infrared LEDs
Photo TRs
Photosensors
LED Displays

FACILITIES

Kyoto, Japan
Production

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Laser Diode Incorporated

1130 Somerset Street
New Brunswick, NJ 08901
201/249-7000

ESTABLISHED: 1971 NO. OF EMPLOYEES: Approx. 220

BACKGROUND

Laser Diode Incorporated originated as a division of M/A-COM. In 1986, the Company was sold by M/A-COM to The Morgan Crucible Company plc (Windsor, England). Laser Diode develops, produces, and markets optical components for commercial and military markets.

COMPANY EXECUTIVES

President and CEO
Robert B. Gill

Controller
Fanny Blumenthal

Laboratory Director
U. V. Choudary

Marketing Director
Michael Robertson

SERVICES

MIL Q 9858A processing
III-V epitaxy

PROCESS TECHNOLOGY

Submicron GaAs VPE and MOCVD processings; A1GaAs and other compound epitaxy

PRODUCTS

Continuous wave (CW) lasers (820, 1,300, and 1,550nm wavelengths)
Pulsed laser diodes and arrays (880 to 1,550nm wavelengths)
LEDs (820, 1,300, and 1,550nm wavelengths)
Fiber-optic data links and other subsystems
III-V epitaxial materials

FACILITIES

The Company's four facilities include 1,200 square feet of manufacturing space.

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Lasertron, Inc.

37 North Avenue
Burlington, MA 01803
617/272-6462

ESTABLISHED: 1980 NO. OF EMPLOYEES: NA

BACKGROUND

Lasertron, Inc., a privately held company, was formed in Burlington, Massachusetts, in 1980 by Dr. Kenneth W. Nill and Dr. James J. Hsieh. The Company is believed to be the largest independent OEM supplier of 1,300nm and 1,550nm fiber-optic components. In 1980, Lasertron introduced the first commercial 1300nm lasers and LED sources, followed with transimpedance pinFET receivers in 1981, 565-Mbps laser sources in 1983, and several other leadership product introductions. In 1987, the company demonstrated 50 years MTTF for all of its products. In 1988, Lasertron introduced 10-GHz fiber-optic microwave transmitters and receivers and completed a USAF contract for 20-GHz diode laser prototypes. Lasertron has sales offices in Burlington, Massachusetts; Harpenden, Herts, United Kingdom; Munich, Germany; and Seoul, Korea.

COMPANY EXECUTIVES

President and CEO
Dr. James J. Hsieh

Executive Vice President
Dr. Kenneth W. Nill

Vice President of Manufacturing
Robert Barboza

Vice President of Sales
David Hardwick

Vice President, Product Assurance and Device Operations
Charles E. Hurwitz

Director of Engineering
Dr. Alex Rosiewicz

STRATEGIC ALLIANCES

Lasertron is licensed by AT&T to use the AT&T-designed Astrotec laser package.

SERVICES

Lasertron offers military contracting services.

PROCESS TECHNOLOGY

Buried heterostructure GaInAsP and GaAs MESFET processes

PRODUCTS

QLM series 1,300 and 1,550nm single-mode and multimode lasers
QLD series LEDs
QDF, QDFM, and QDFT series pinFETs
QDE and QDEP series pin detectors

FACILITIES

Burlington, MA
70,000 sq. ft.
R&D, product design, test, final processing, marketing, and administrative facilities

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Litton Electron Devices Division

2285C Martin Avenue
Santa Clara, CA 95050
408/727-9801 (Fab Facility)
408/433-0933 (Marketing)

ESTABLISHED: 1975 NO. OF EMPLOYEES: 140

BACKGROUND

Litton Electron Devices Division was the Dexcel Division of Gould until July 1987, at which time it was acquired by Litton Industries. Litton Industries is an integrated worldwide electronics company. It develops, manufactures, and markets electronics-based systems, products, and components for key high-growth worldwide markets: information systems, industrial automation, instrumentation, defense systems, and other electronic components and materials.

Litton Industries acquired the amplifier operations of Harris Microwave Semiconductor, Inc., of Milpitas, California in mid-1988.

COMPANY EXECUTIVES

General Manager
Michael Suman

Vice President, Finance, Controller
Robert Clarke

Director, Long-Range Planning
Michael Morris

Marketing Director
David Boyd

STRATEGIC ALLIANCES

Litton Electron Devices is a division of Litton Industries, Inc.

SERVICES

Packaging
High-reliability screening

PROCESS TECHNOLOGY

Recessed-gate submicron GaAs MESFET; HEMT
VPE, ion implantation, air-bridge interconnections

PRODUCTS

GaAs MESFETs—dual gate, low noise, power
HEMTs
Military amplifiers and other subassemblies

FACILITIES

Milpitas, CA
Approximately 37,000 sq. ft.
Administration, assembly, and manufacturing

Santa Clara, CA
Square footage not available
R&D, design, fabrication, and support

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Loral Microwave—Narda West

214 Devcon Drive
San Jose, CA 95112
408/436-4400

ESTABLISHED: 1975 NO. OF EMPLOYEES: 266

BACKGROUND

Narda West is a subsidiary of Loral Corporation. Loral Corporation's operations include design, manufacture, and sale of defense systems, communications systems, transceivers, and navigation equipment. Loral has an advanced development activity at Lanham, Maryland, that is engaged in microwave IC R&D. Narda West develops, produces, and markets active and passive microwave components including signal sources, semiconductor devices, control devices, and integrated assemblies.

COMPANY EXECUTIVES

President
D. Bruce Swartz

Corporate Group Vice President, Microwave
Harry Emerzian

Vice President, Operations
John Daws

Vice President, Finance
Gary D. Darst

Director, Marketing
Leon Becker

SERVICES

Narda West provides manufacturing, assembly, and test services.

PROCESS TECHNOLOGY

The Company uses GaAs MESFET technology.

PRODUCTS

Signal sources
Semiconductor devices (GaAs FETs, MMIC amps, IC assemblies)
Control devices
Subassemblies

FACILITIES

San Jose, CA
Approximately 20,000 sq. ft.
Clean rooms, including Class 100/10 areas

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Lytel Incorporated

61 Chubb Way
P.O. Box 1300
Somerville, NJ 08876
201/685-2000
Fax: 201/685-1282

ESTABLISHED: October 1984 **NO. OF EMPLOYEES: 130**

BACKGROUND

Lytel Incorporated (Lytel) was formed to design, develop, and manufacture InGaAsP technology-based electro-optic components for the telecommunications, data communications, and military markets. Products include semiconductor lasers, LEDs, and photodetectors using an indium phosphide materials technology.

Lytel's first products, introduced in January 1986, were InGaAsP high-power lasers for fiber-optic applications. The Company is focusing on quality, reliability, delivery, and performance.

Lytel's shipments first exceeded $1 million per month in 1989.

COMPANY EXECUTIVES
(Position and Name)

GM
Gerald Leehan

VP Engineering & Development
*Ron Nelson

Controller
Tim Bock

*Founder

PROCESS TECHNOLOGY

InGaAsP, using LPE and MOCVD
1.3-micron opto components

PRODUCTS

InGaAsP High-Power Lasers
LEDs
Optical Data Links

FACILITIES

Somerville, NJ
57,000 sq. ft. total facilities

6,000 sq. ft.
Class 1,000 clean room

8,000 sq. ft.
Class 10,000 packaging and test

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M/A-COM Advanced Semiconductor Operations

100 Chelmsford Street
Lowell, MA 01851
508/453-3100

ESTABLISHED: 1984 *NO. OF EMPLOYEES: 170*

BACKGROUND

M/A-COM Advanced Semiconductor Operations (ASO) was set up to supply GaAs wafers, FETs, standard MMICs, custom MMICs, and foundry services for both internal and external requirements. Except for GaAs wafers, the market segment targeted is essentially microwave and defense related. M/A-COM is heavily involved in the DARPA-funded MIMIC program and is a member of the Hughes/GE team on Phase I.

M/A-COM ASO relies on M/A-COM Inc.'s worldwide network of field sales offices and representatives to market its products.

In mid-1989, M/A-COM acquired Adams Russell Inc., which includes the Adams-Russell Semiconductor Center. Consolidation of the two operations was completed early in 1990.

In 1990, M/A-COM and AT&T began jointly offering foundry services and MMIC products. AT&T's Reading, Pennsylvania, facility performs MBE processing, in-process testing, and reliability validation services.

COMPANY EXECUTIVES

Group Vice President, Semiconductors
Dennis Revelotis (formerly VP/GM of SPD)

Vice President, Advanced Semiconductor Division
Douglas Maki

Vice President, Manufacturing
Peter Ledger (formerly VP of Semiconductor Products, M/A-COM)

Vice President, Sales and Marketing
Larry Ward (formerly of M/A-COM OmniSpectra)

SERVICES

Design
CAD
Foundry-0.8u, 0.5u, and 0.25u D-MESFETs
Assembly
Test
Packaging

PROCESS TECHNOLOGY

0.8u, 0.5u, and 0.25u GaAs D-MESFETs
0.8u GaAs E-MESFETs
0.5u optical lithography, 0.25u e-beam lithography

PRODUCTS

2-inch, 3-inch, and 4-inch semi-insulating GaAs wafers
0.8u FETs: 8W to S-band, 4W to C-band, 1W to Ku-band
0.25u FETs: Low noise up to K-band
MMICs: DC-18-GHz switches, DC-20-GHz attenuators, custom L- to X-band phase shifters
Broad- and narrow-band power and low-noise amplifiers

FACILITIES

M/A-COM's GaAs product manufacturing and support facilities total more than 183,000 square feet. Included are 58,000 square feet of Class 10 clean room facilities. The ASD facilities are in Lowell and Burlington, Massachusetts. MBE processing and related support functions are provided by AT&T's Reading, Pennsylvania, GaAs facility.

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Matsushita Electric Industrial Co., Ltd.

1006 Kadoma, Kadoma City
Osaka 571, Japan
(06) 908-1121

Matsushita Electronics Corporation

1-1 Saiwai-cho, Takatsui City
Osaka 569, Japan
(0726) 82-5521

ESTABLISHED: 1935 **NO. OF EMPLOYEES: 43,001**

BACKGROUND

Matsushita was founded in 1918 by Konosuke Matsushita. The company established Matsushita Electric Industrial Co., Ltd., in 1935. It has become the largest consumer electronics company in Japan, the ninth largest worldwide semiconductor manufacturer, and one of the world's 50 largest industrial corporations. The Company's semiconductors are produced by a subsidiary, Matsushita Electronics Corporation (MEC), 65 percent owned by Matsushita and 35 percent owned by N.V. Philips (of the Netherlands).

The top five shareholders in Matsushita are Sumitomo Bank (4.4 percent), Sumitomo Life Insurance (4.2 percent), Nippon Life Insurance (3.9 percent), Matsushita Investment and Development (2.9 percent), and Mitsubishi Trust (2.3 percent). Konosuke Matsushita, founder, owns 2.6 percent of the company.

Matsushita started its GaAs activity in 1971. In 1982, Matsushita developed GaAlAs LEDs and announced a GaAs FET frequency divider (masterslave flip-flop) with a toggle rate of 2.5 GHz and P_d of 25mW. Matsushita also has developed a three-stage GaAs FET amplifier with a small-signal gain of 25dB and an operating range of 30 MHz to 1.7 GHz. The Company is a large-volume producer of lasers for CD players.

Matsushita and TRW are jointly developing 0.8-micron A1GaAs lasers for space communications.

COMPANY EXECUTIVES (GaAs OPERATIONS)

Chairman
Masaharu Matsushita

President
Akio Tanii

Head of Marketing
Kazuo Fujimoto

President, Matsushita Electronics Corporation
Fumio Kanazawa

STRATEGIC ALLIANCES

The company has major licensing and second-sourcing agreements with Hewlett-Packard, IBM, 3M Company, Mitsubishi, NTT, Philips, Sanyo, Sharp, and TRW.

PROCESS TECHNOLOGY

GaAs MESFET
GaP

PRODUCTS

GaAs analog ICs
GaAs digICs
GaAs MMIC amps and other microwave ICs
Standard logic
Optoelectronic devices
LEDs
GaAs and A1GaAs lasers
Detectors
Small-signal and power GaAs transistors

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Matsushita Electric Industrial Co., Ltd.

FACILITIES

Kagoshima plant—includes opto production
Takatsuki plant
Okayama plant—includes transistor production
Nagaoka plant—includes opto and discrete production
Moriguchi City plant—GaAs discrete, GaAs IC, and opto R&D

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Microwave Monolithics

465 East Easy Street
Simi Valley, CA 93065
805/584-6642

ESTABLISHED: April 1982 **NO. OF EMPLOYEES: 25**

BACKGROUND

Microwave Monolithics specializes in GaAs MMICs for Department of Defense microwave specialty circuits as well as custom GaAs circuits.

The Company is privately held by five partners and completed first-round financing in 1983 through private sources.

Microwave Monolithics did custom GaAs circuit design research and development work for government agencies and OEMs until financing was secured. The Company began producing GaAs MMICs by year-end 1984.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
*Daniel Ch'en
Rockwell, Mgr M/W Rsch

*Founder

PROCESS TECHNOLOGY

0.5-micron GaAs fine-line capability

PRODUCTS

MMICs

FACILITIES

Simi Valley, CA
8,000 sq. ft.
Two Class 100 clean rooms

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MicroWave Technology, Inc.

4268 Solar Way
Fremont, CA 94538
415/651-6700
Fax: 415/651-2208

ESTABLISHED: May 1982 **NO. OF EMPLOYEES: 148**

BACKGROUND

MicroWave Technology, Inc., (MWT) is a vertically integrated manufacturer of GaAs-based microwave components and subassemblies. MWT designs, manufactures, and markets GaAs epitaxial materials, GaAs FET devices, MMICs, hybrid MICs, and microwave components and subassemblies. The Company's products are designed for defense-related applications.

MWT produces both ultralow-noise and medium-power GaAs FETs and AlGaAs HEMT devices for applications ranging from 0.5 GHz to 40.0 GHz. The devices are produced with gate lengths from 0.1 to 0.25 micron. The Company is developing a family of high-performance MMIC products and has completed a series of 2- to 6-GHz MMIC amplifiers. Products in the 2- to 18-GHz and 6- to 16-GHz ranges are in development.

The Company also offers GaAs FET amplifiers from 0.5 to 26.5 GHz that use MMIC and hybrid MIC modules.

In 1987, MWT acquired Monolithic Microsystems, Inc., of Santa Cruz, California. Monolithic Microsystems makes detector log video amplifiers (DLVAs), log video amplifiers (LVAs), and threshold detectors based on proprietary monolithic LVA ICs. Products are used in various EW systems and other defense electronic applications. Monolithic Microsystems will operate as a wholly owned subsidiary of MWT and will continue manufacturing in its 8,200-square-foot Santa Cruz facility.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
Joseph Lee
Litton, President

VP Finance and Administration/CFO
James M. Geyton
Avantek, Div Controller

VP Materials Development
Arthur Herbig
Avantek, Tech Staff

VP Engineering/R&D
Dr. Masa Omori
Avantek, Eng Mgr

Directory, Sales
Aytch Roberts

VP Operations
John Sorci
Watkins-Johnson, Subsystems Div Mgr

PROCESS TECHNOLOGY

GaAs MESFET
AlGaAs HEMT
0.25μ gate lengths
Thin-film hybrid VPE on GaAs wafers

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MicroWave Technology, Inc.

PRODUCTS

GaAs Epitaxial Materials
GaAs FET Amplifiers, 0.5 to 26.5 GHz
GaAs MMIC Amplifiers, 2 to 6 GHz
GaAs MIC Microwave Products
Thin-Film Hybrids
Log Amplifiers
Detector Log Video Amplifiers

FACILITIES

Fremont, CA
50,000 sq. ft.
Design, manufacturing
6,000 sq. ft.
Class 1,000 clean room

Santa Cruz, CA
8,200 sq. ft.
Manufacturing

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Mitsubishi Electric Corporation

Mitsubishi Denki Bldg., 2-3, Marunouchi 2-chome
Chiyoda-ku, Tokyo 100, Japan
(03)218-2111

ESTABLISHED: 1898 **NO. OF EMPLOYEES: 48,050**

BACKGROUND

Mitsubishi Corporation was founded in 1898 as a heavy electrical equipment plant in Nagasaki. Its main areas of business are heavy machinery, electronic products and systems, industrial products, and consumer products. It was the first commercial Japanese electronics company to develop an integrated circuit, and in 1987 began R&D on 4Mb and larger DRAMs. Mitsubishi is Japan's third largest electronics company, and Japan's top defense electronics supplier. In 1986, the Company began marketing a sequential inference machine developed as part of MITI's Fifth-Generation Computer Project.

GaAs activity at Mitsubishi was initiated in 1963. Mitsubishi operated its first pulse-mode AlGaAs 780nm laser at room temperature in 1967. The company began marketing low-noise 12-GHz to 18-GHz GaAs FETs in mid-1980. In late 1982, Mitsubishi started constructing a prototype production line for GaAs LSI. Mitsubishi has a joint venture with Monsanto that produces and markets GaAs substrates.

In mid-1984, Mitsubishi announced that it had developed the technology required for mass production of GaAs solar cells for such applications as communications satellites. The cells have conversion efficiencies that range up to 19 percent. The cells are used in the CS-3 communication satellite launched in 1987. This development work was accomplished under the sponsorship of the National Space Development Agency of Japan.

A low-voltage 4Kx4 GaAs SRAM was developed by Mitsubishi's LSI R&D Laboratory, Itami, Hyogo, Japan, under the MITI Scientific Computing Systems Program (sponsored by Japan's NEDO). Test devices, using a 1.0u E/D DCFL SAG MESFET process and dual-layer metal, were operated at 1.0V power supply voltage, t_{aa} of 11ns max and P_d of 1.0W. The 5.79mm x 4.73mm^2 die incorporates four blocks of 128x32 memory cells, each 31.5um x 24.0um^2.

COMPANY EXECUTIVES (GaAs ACTIVITIES)

Chairman
Nihachiro Katayama

President
Moriya Shiki

Head of Marketing
Shinichi Yufu

Senior Executive Vice President/GM Semiconductor Div.
Yuichi Okutomo

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Mitsubishi is a member of the Mitsubishi group, a continuation of the Mitsubishi Zaibatsu. Although the zaibatsu were dissolved following World War II, the Mitsubishi Zaibatsu companies reorganized into one of the most powerful industrial groups in Japan.

The top five shareholders in Mitsubishi are Mitsubishi Trust and Banking Corporation (5.0 percent), Mitsui Trust and Banking Corporation (4.1 percent), Meiji Mutual Life Insurance Company (4.0 percent), Nippon Life Insurance Company (3.6 percent), and Mitsubishi Bank Ltd. (3.1 percent). The Mitsubishi Electric Group Employee Shareholders Union owns 2.1 percent; another 4.3 percent is foreign-owned.

Mitsubishi has technology-sharing and licensing agreements with Dai Nippon Printing Co., GE, Hoya Corporation, Intel, Materials Research Corp., Matsushita, Nihon MRC Co., Sanyo, Sharp,

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Mitsubishi Electric Corporation

Texas Instruments (TI), Ulvac Coating Co., Westinghouse, and others. Recent agreements include photonic integration (NTT and Batelle) and silicon semiconductor alliances with National and TI.

From 1981 to January 1990, Mitsubishi, Fujitsu, Hitachi, NEC, Oki, and Toshiba jointly developed a GaAs-based prototype supercomputer system.

PRODUCTS

MMICs and digICs
LEDs
Lasers
Detectors
Small-signal and power GaAs FETs

PROCESS TECHNOLOGY

1.0-micron E/D DCFL self-aligned gate GaAs MESFET
Submicron GaAs MESFET

FACILITIES

Kita-Itami Works
Optoelectronic Device Production

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Motorola, Inc.

1303 E. Algonquin Road
Schaumberg, Il 60196
312/397-5000

ESTABLISHED: 1928 **NO. OF EMPLOYEES: 100,000**

Motorola, Inc., Semiconductor Products Sector

5005 E. McDowell Road
Phoenix, AZ 85008
602/244-6900
602/897-5901 (GaAs Research and Development Labs)
602/244-6786 (Opto)

ESTABLISHED: 1954 **NO. OF EMPLOYEES: 13,500 (GaAs R&D Lab: 65)**

BACKGROUND

Motorola, Inc., is one of the world's leading manufacturers of electronic equipment, systems, and components produced for both U.S. and international markets. Its products include two-way radio and other electronic communications systems, semiconductors, and defense and aerospace electronics. The Opto division, established in 1966, supplies a broad range of IREDs, photodetectors, couplers, isolators, and other GaAs products.

Motorola SRDL is engaged in GaAs R&D and prototype production for captive consumption.

COMPANY EXECUTIVES

GaAs R&D Director
John Escher

Opto Marketing Director
Dean Walters

Opto Operations Manager
David Stevenson

PROCESS TECHNOLOGY

The Company uses Submicron GaAs MESFET and GaAs opto technology.

PRODUCTS

The Company offers infrared (IR) optoelectronics devices including IR emitters, photodetectors, optocouplers, optoisolators, and related products.

FACILITIES

The corporate research center has approximately 65 people assigned to GaAs R&D. Size of the fab space is not available.

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NEC Corporation

33-1, Shiba 5-chome
Minato-ku, Tokyo 108, Japan
(03)454-1111

ESTABLISHED: 1899 NO. OF EMPLOYEES: 39,170

BACKGROUND

NEC was founded in 1899 as a manufacturer of telephone sets and switchboards. Initial capitalization came from what later became Western Electric Company. NEC has nine operating groups that cover its four major areas of business, which are communications, computers and industrial electronic systems, electron devices, and home electronics.

NEC is one of the top five international suppliers of communications and computing equipment and services and is the number one manufacturer of semiconductors in the world. The Company is positioned to pursue the ECL-compatible GaAs digIC merchant market, ahead of most U.S. GaAs suppliers; sample digICs were first offered in February 1986 at a cost of approximately $250 each (about twice that of ECL 100K devices). The first GaAs digICs in large-volume production at NEC were prescalers.

California Eastern Labs (CEL) is the exclusive North American agent for NEC microwave semiconductors. The CEL product offerings include GaAs FETs and HEMTs, diodes, MMICs, digICs, and microwave hybrids.

NEC participated in the AIST/MITI Japanese national supercomputer project sponsored by NEDO, which resulted in a GaAs-based prototype supercomputer system.

COMPANY EXECUTIVES (GaAs ACTIVITIES)

Chairman
Atsuyoshi Ohuchi

President
Tadahiro Sekimoto

Head of Marketing
Kanji Sugihara

STRATEGIC ALLIANCES AND FINANCIAL BACKING

NEC is a member of the Sumitomo Group. This group began as a zaibatsu more than 100 years ago and was the third largest in Japan by 1941. NEC is the only electronics company of the 21 nucleus companies in the White Waters Club (Hakusui-Kai) of the Sumitomo Group.

The major shareholders of NEC are Sumitomo Life Insurance (6.9 percent), Sumitomo Trust and Banking (5.1 percent), Sumitomo Bank (4.6 percent), Nippon Life Insurance (3.6 percent), Dai-Ichi Mutual Life Insurance (3.2 percent), Sumitomo Marine and Fire Insurance (2.6 percent), and Toyo Trust (2.3 percent). Foreign ownership of NEC is 7.4 percent.

NEC has licensing or technology-sharing agreements with Corvus, Digital Research Corporation, Hewlett-Packard, Matra-Harris Semiconducteurs, Oki, Sharp, Sony, Sophia Systems, Standard Microsystems Corporation, Tektronix, Texas Instruments, and others.

From 1981 to January 1990, NEC, Fujitsu, Hitachi, Mitsubishi, Oki, and Toshiba jointly developed a GaAs-based prototype supercomputer system.

PROCESS TECHNOLOGY

Submicron GaAs MESFET and HEMT
InP
Other III-V compound semiconductor processes

PRODUCTS

GaAs, MMICs, digICs, and OEICs
Optocouplers

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NEC Corporation

LEDs
Lasers
Detectors
Small-signal and power transistors—GaAs and silicon

FACILITIES

Tamagawa plant—R&D
Kagoshima plant—optoelectronics, discretes, others
Kyushu Denshi (Kumamoto)—LED fab, others

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N.V. Philips Gloeilampenfabrieken

P.O. Box 218, 5600MD
Eindhoven, Netherlands
(040) 738 749

ESTABLISHED: 1891 **NO. OF EMPLOYEES: NA**

BACKGROUND

N.V. Philips Gloeilampenfabrieken (Philips) was founded by Gerard Philips in 1891 to make carbon-filament lamps. The Company established its Physical Research Laboratory in 1914. Philips performs basic research in many areas including III-V compound semiconductors. The Company supplies internal needs and participates in the merchant market for LEDs, lasers, MICs, MMICs, discrete FETs, and digICs.

The Company has an agreement with Cray Research involving GaAs SRAMs for supercomputer applications. This activity is under way at LEP (France). The effort has resulted in a 1K ECL-compatible design that operates at 2ns cycle time and dissipates 200mW.

Amperex, a wholly owned subsidiary of Philips that markets Philips semiconductors in the United States, changed its name to North American Philips Electronics Corporation in 1989.

STRATEGIC ALLIANCES

Philips owns 35 percent of Matsushita Electronics Corporation; N.A. Philips Trust, which owns Signetics; LEP (France); and North American Philips Electronics Corporation.

PROCESS TECHNOLOGY

GaAs, GaAlAs, and other III-V MESFET and HEMT processes
0.7u DCFL GaAs MESFET

PRODUCTS

Small-signal and power GaAs FETs
LEDs, including IR emitters and detectors
Laser diodes, CW and pulsed
Optocouplers
Opto discretes and OEICs
GaAs ICs

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Oki Electric Industry Co., Ltd.

7-12, Toranomon 1-chome
Minato-ku, Tokyo 105, Japan
(03) 501-3111

ESTABLISHED: 1881 NO. OF EMPLOYEES: 13,827

BACKGROUND

Oki Electric Industry Co., Ltd. (Oki), was founded in 1881 as a telephone manufacturing company by Kibataro, a maker of traditional Japanese swords and armor. In 1916, the Company began quantity production of radio communications equipment. Oki first manufactured semiconductors in the early 1960s; it was the first Japanese company to produce green LEDs. Today, the Company is a leading supplier of telecommunications systems, EDP systems, and electronic devices, including semiconductors.

Oki views GaAs and other new materials as instrumental in achieving major advances in semiconductor technology. One of its overall strategies is to advance ICs based on GaAs technology to mass production. Its R&D effort has included development of an 8x8 GaAs multiplier using W-Al gates for yield enhancement. Oki has done work on HEMTs for operation at liquid nitrogen temperatures with recorded propagation delays of 27ps per gate.

Oki participated in the AIST/MITI Japanese national supercomputer project sponsored by NEDO, which resulted in a GaAs-based prototype supercomputer system.

COMPANY EXECUTIVES (GaAs ACTIVITIES)

Chairman
Namio Hashimoto

President
Nobumitsu Kosugi

Executive Vice President/General Manager, Electronic Devices Group
Masao Nogami

Director/General Manager, Marketing Division
Yoji Tanaka

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Oki is a member of the Fuyo Group, started after World War II and composed of companies having close financial relations with Fuji Bank. The group's policy-making council (Fuyo-Kai) is made up of the presidents of the 29 group companies. Marubeni is the Fuyo Group's central trading company.

Major shareholders of Oki are Yasuda Mutual Life Insurance (7.8 percent), Meiji Mutual Life Insurance (5.8 percent), Dai-Ichi Mutual Life Insurance (5.4 percent), Fuji Bank (4.1 percent), and Yasuda Trust and Banking (4.0 percent). Foreign ownership is 2.1 percent.

Oki has technology-sharing and licensing agreements with AT&T (GaAs ICs), Catalyst Semiconductor, Intel, Silicon Systems, Thomson-CSF, Voest Alpine AG (Austria), and others.

From 1981 to January 1990, Oki, Fujitsu, Hitachi, Mitsubishi, NEC, and Toshiba jointly developed a GaAs-based prototype supercomputer system.

PROCESS TECHNOLOGY

Oki uses III-V compound processing including GaAs, GaAlAs, GaAsP, and others.

PRODUCTS

Optoelectronic devices including LEDs
GaAs ICs including multiplexers and demultiplexers

FACILITIES

Hachioji
GaAs fab, assembly, and test capabilities

Chichibu (Tokyo)
Optoelectronics, other

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Optek Technology, Inc.

1215 West Crosby Road
Carrollton, TX 75006
214/323-2200

ESTABLISHED: 1979 NO. OF EMPLOYEES: 2,100

BACKGROUND

Optek Technology, Inc., was founded by James D. Crownover in 1979 as Crown Semiconductor, Inc., to design, develop, and manufacture optoelectronic products for military and commercial markets. The Company was reincorporated in Delaware in August 1984, at which time it changed its name to Optek Technology, Inc. Optek's sales in 1986 exceeded $11 million. The Company has more than 200 active customers and is now the largest manufacturer of IR optoelectronics products in the world.

Optek became a public company with an initial offering of 900,000 shares offered to the public at $6 per share in July 1987. There were 2.165 million shares of common stock outstanding and held of record by 94 stockholders as of May 1, 1987. The Company's authorized capital stock was 12 million shares of common stock and 1 million shares of preferred stock as of July 23, 1987.

In July 1988, Optek acquired TRW Optoelectronics, which added approximately 1,400 employees and 326,000 square feet of facilities. In 1989, corporate headquarters were relocated to the current address.

COMPANY EXECUTIVES

President and Chairman
James D. Crownover (formerly Cofounder and Senior Vice President, Spectronics)

Executive Vice President, General Manager, and Secretary
Tom L. Barnes (formerly Manager of Inventory Control, TRW/Optron)

Vice President, Finance, and Treasurer
James M. Barry (formerly Vice President and CFO, OptoSwitch, Inc.)

Vice President, Military Division
Robert A. Fletcher (formerly General Manager of TRW/Optron)

Assistant Secretary
Mary Sanderford (formerly of Optek)

Director of Plastic Operations
Hollis G. Cotten (formerly Cofounder and President, C&F Tooling, Inc.)

Director of Commercial Engineering
Richard G. Dahlberg (formerly Director of Engineering, C&F Tooling, Inc.)

Director of Sales, Marketing, and Advanced Engineering
Larry Newman

Director of National Sales
Wayne Davis

Director
Rodes Ennis

Director
Grant Dove

Director
Donald M. Johnston

Director
Michael Cahr

SERVICES

The Company provides custom chip design and fabrication services.

PROCESS TECHNOLOGY

Optek uses GaAs, GaAlAs, and silicon processes.

PRODUCTS

LEDs
Emitters, including visible and IR emitters

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Optek Technology, Inc.

Sensors, including photosensors, reflective sensors, and Photologic and Hallogic sensors (Photologic and Hallogic are trademarks of Optek Technology, Inc.)
Optocouplers and optoisolators
Interrupters (slotted switches)
Hybrids

FACILITIES

Carrollton, Texas
Corporate headquarters and wafer fab, totaling 205,000 square feet

McKinney, Texas
A 20,000-square-foot building on 1.7 acres housing administration, engineering, and fab

Dallas, Texas
Plastics molding shop comprising 10,000 square feet

Mineral Wells, Texas
Military processing and environmental test facility consisting of 50,000 square feet

Juarez, Mexico
Assembly facility (Optek's subsidiary beneficially owns three buildings totaling 75,000 square feet used for assembly, operated as a *Maquiladora*, an official Mexican government term for a foreign-owned company operating under Mexican law.)

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Opto Diode Corp.

750 Mitchell Road
Newbury Park, CA 91320
805/499-0335
Fax: 805/499-8108

ESTABLISHED: 1981 **NO. OF EMPLOYEES: 13**

BACKGROUND

Opto Diode Corp. (ODC) was formed in 1981 by James Kim, formerly with Rockwell's Collins division in Dallas, Texas. ODC offers semicustom high-reliability devices made to customer specifications. The Company is occupying a 15,000-square-foot facility in Newbury Park, California.

ODC had $1 million in sales in 1985 from GaAs infrared LEDs for solid-state relay and optoelectronics markets. Future plans are to penetrate the U.S. military market and European market.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
*James Kim
Rockwell, Sr Research Engr—Science Center

Sales Manager
Russell Dahl

*Founder

PROCESS TECHNOLOGY

AlGaAs on GaAs

PRODUCTS

Gallium Aluminum Infrared LEDs

FACILITIES

Newbury Park, CA
15,000 sq. ft.
Design, manufacturing

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Opto Tech Corp.

32 Industrial East 4th Road
Science-Based Industrial Park
Hsinchu, Taiwan
ROC
(035) 777-481/3
Telex: 31592 OPTO TECH

ESTABLISHED: December 1983 **NO. OF EMPLOYEES: 110**

BACKGROUND

Opto Tech is offering GaAs-based products, silicon wafers, and photoresistor and photodiode semiconductors. The Company plans to offer small-signal and transmitting transistors, junction FETs, microwave transistors, and fast-recovery and Schottky-barrier diodes. Production began in July 1984.

The Company spun off from Fine Microelectronics and is owned by local investors and the Bank of Communications.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President
James Chiu
Petrochemical Industry, President

Business Liaison
S. Shyu

PROCESS TECHNOLOGY

GaAs
Silicon

PRODUCTS

LED
Transistors
Photodiodes
Phototransistors
Infrared Devices

FACILITIES

Hsinchu, Taiwan
9,175 sq. ft.

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OPTOTEK Limited

62 Steacie Drive
Kanata, Ontario, Canada K2K 2A9
613/591-0336

ESTABLISHED: 1977 **NO. OF EMPLOYEES: Approx. 50**

BACKGROUND

OPTOTEK Limited was founded in 1977 to specialize in LEDs and associated electronics for military and commercial applications in North America, Europe, and Japan. In 1981, the Company began developing GaAs MMICs.

COMPANY EXECUTIVES

President
David Kennedy

Vice President of Operations
Gunnar Wareberg

Vice President of Marketing
David Kennedy, Acting

Director of R&D
Randy North

SERVICES

MMIC foundry
Ion implantation and annealing
Thick-film and thin-film hybrid packaging

PROCESS TECHNOLOGY

GaAs MESFET, 0.5-micron, selective ion implantation
HgCdTe processing

PRODUCTS

Infrared LEDs, visible LEDs, and LED arrays
Photovoltaic detectors
Custom MMICs and hybrids
MMIC design software

FACILITIES

The OPTOTEK facilities total 37,000 square feet of space, including Class 1,000/100 clean rooms.

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Ortel Corporation

2015 West Chestnut Street
Alhambra, CA 91803
818/281-3636

ESTABLISHED: 1980 NO. OF EMPLOYEES: 100

BACKGROUND

Ortel Corporation is a privately owned company founded in 1980 by Dr. Israel Ury, Dr. Amnon Yarviv, and Dr. Nadav Bar-Chaim. Prior to 1980, the founders were at the California Institute of Technology. The Company makes a complete line of semiconductor lasers, detectors, and fiber-optic transmitters and receivers.

Ortel also performs government-sponsored R&D in ultrahigh-speed and integrated optoelectronics, high-power lasers and laser arrays, and phase conjugate optics. The Company has conducted R&D under contracts from DARPA, NRL, RADC, MICOM, and others.

COMPANY EXECUTIVES

President/CEO
Wim Selders

Vice President, Manufacturing
Claude Mathews

Vice President/CFO
Stephen Workman

Director of Marketing
Larry Stark

Chief Technology Officer
Israel Ury

Vice President/Sales
Bill Moore

Vice President/QA
Bob Mielke

SERVICES

R&D
Design
Manufacturing
Test

PROCESS TECHNOLOGY

The Company uses GaAs buried heterostructure technology.

PRODUCTS

GaAs lasers
Detectors
Fiber-optic transmitters and receivers at 840nm and 1,300nm with bandwidths to 12 GHz

FACILITIES

Alhambra, California
Corporate headquarters, R&D, and manufacturing facilities totaling 24,000 square feet, of which approximately 8,000 square feet are clean rooms (Class 100)

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Pacific Monolithics, Inc.

245 Santa Ana Court
Sunnyvale, CA 94086
408/732-8000
Fax: 408/732-3413

ESTABLISHED: March 1984 **NO. OF EMPLOYEES: 120**

BACKGROUND

Pacific Monolithics, Inc., designs and manufactures MMICs based on GaAs, as well as microwave subsystems based on its GaAs MMICs. The Company offers more than 200 microwave macrocells (PM Cells) for semicustom IC design for consumer, communications, and defense applications. Company strengths include yield-tolerant design techniques, advanced packaging technology, a proprietary CAD/CAE system, and foundry services.

The Company participated as a team member on several contracts for the Department of Defense, including Phase 0 and Phase 1 of the MIMIC program. The contracts were in the areas of communication, radar, electronic warfare, and smart weapons for the army, navy, and air force.

Pacific Monolithics has developed a set of monolithic GaAs subsystem building blocks for microwave signal processing. The Company's ASIC cell library includes amplifiers, mixers, oscillators, couplers, combiners, switches, attenuators, phase shifters, modulators, and demodulators. By mid-1990, the Company had developed more than 1,500 MMIC device types for its customers.

In March 1986, the Company relocated from a 10,000-square-foot facility to a 22,000-square-foot facility that can be expanded by an additional 13,000 square feet. Currently, Pacific Monolithics uses several foundry services, including TriQuint and COMSAT.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
Donald A. Bond
Sanders, VP/GM Microwave

Senior VP & Director
Allen Podell
A.F. Podell Assoc., President of Technology

VP, Controller
Joel Keissig

VP Sales
Frank Russell
Avantek, Sales Mgr

VP Engineering
Pang Ho
Geotech, President

Manager, Special Projects
*Doug Lockie
Strategic Technology, Consultant

*Founder

PROCESS TECHNOLOGY

GaAs D-MESFET, E/D-MESFET, and HBT processes
0.2-micron and smaller gate lengths

PRODUCTS

Channelized Up/Down Converters
Converters
Amplifiers
Oscillators
Attenuators
Active Isolators
Phase Shifters
Switches
Synthesizers
TR Modules
Single-Chip Radars
Microwave Sensors
Expendable Countermeasure Subassemblies

FACILITIES

Sunnyvale, CA
35,000 sq. ft.
Lab, manufacturing, administration

6,000 sq. ft.
Class 100 clean room

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PCO, Inc.

20200 Sunburst Street
Chatsworth, CA 91311
818/700-1233

ESTABLISHED: 1984 NO. OF EMPLOYEES: 145

BACKGROUND

PCO, Inc., started as a joint venture of Plessey and Corning Glass Works, called PlessCor, Inc., with shares owned by the two companies and by the founders. Recently, Corning became the parent company, and the company was renamed PCO, Inc. In 1983, the company started marketing products developed by Plessey (United Kingdom) as well as its own designs. PCO has developed a silicon bipolar chip set for use in 200Mb fiber-optic links and is developing InP devices for higher links.

COMPANY EXECUTIVES

President/CEO
Sanford Kane

Vice President, Marketing and Sales
Robert King

Senior Vice President and General Manager, Technology
Bor U. Chen

Vice President, Special Programs
James E. Goell

Vice President, Quality
David Law

Vice President, Controller, Secretary, and Treasurer
James J. Hetherman

Director, Sales
Norman Weinberg

FINANCIAL BACKING

Corning Glass Works is the parent financial backing company and retains 65 percent ownership in PCO. IBM owns a 25 percent stake; the remaining 10 percent is held by PCO employees and other private investors.

In January 1989, Plessey sold its 25 percent stake in PCO to IBM. Corning retained its 65 percent share; the founders and other private investors hold the remaining share.

PROCESS TECHNOLOGY

InP, GaAs, InGaAs, and related III-V processes

PRODUCTS

PLD series laser diodes modules
ELD series fiber-optic transmitters and receivers including Synchronous Optical Network (SONET) modules for operation to and above video frequencies
InGaAs PIN photodiodes
Laser diodes
ELEDs
Digital interface modules
LANs—token-ring and Ethernet
Long-haul communications links
Factory automation
TV systems

FACILITIES

The Company's operations are accomplished in three buildings located in Chatsworth, California, at the above address.

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Photonic Integration Research, Inc.

1357 Perry Street
Columbus, OH 43201
614/424-3313
Fax: 614/424-3320

ESTABLISHED: July 1987 NO. OF EMPLOYEES: 12

BACKGROUND

Photonic Integration Research, Inc., (PIRI) was formed to develop basic optical IC technology for commercial applications. The Company is the result of a joint venture between Nippon Telegraph and Telecommunications (NTT), Mitsubishi Electric Corporation of Japan, and the Batelle Memorial Institute. NTT owns 49 percent of the Company; Mitsubishi owns 41 percent; and Batelle owns 10 percent.

PIRI president, Dr. Tadashi Miyashita, was formerly head of the Optoelectronic Materials Section of the Electronics Materials Department at NTT's Ibaraki Electrical Communications Laboratories. Shigeki Sakaguchi and Shin Sumida also were previously at NTT's Ibaraki Telecommunications Laboratories, where the optical IC technology was invented.

In addition to developing commercial applications for optical waveguide technology, PIRI also develops applied components that are made available to equipment manufacturers for use in such end products as optical communications equipment, optical measuring equipment, automobiles, and airplanes. The Company expects advancement in the technology to lead to greater miniaturization and increased utilization of fiber optics.

PIRI is located in the Batelle Memorial Institute's Columbus, Ohio, facilities.

COMPANY EXECUTIVES

(Position, Name, and Prior Company)

President
Dr. Tadashi Miyashita
NTT

General Manager
Shigeki Sakaguchi
NTT

Chief Supervisor
Shin Sumida
NTT

PRODUCTS

Optoelectronic Devices
Custom-Design Optical Devices

FACILITIES

2,000 square feet of administration and R&D
1,000 square feet of Class 100 manufacturing

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Plessey Research Caswell, Ltd.

Caswell, Towcester, Northants, NN12 8EQ
United Kingdom
(0327) 51871

ESTABLISHED: 1985 NO. OF EMPLOYEES: 400

BACKGROUND

Plessey Research Caswell, Ltd., acquired by GEC-Marconi, was formerly the Plessey Three-Five Group. Until mid-1990, the Plessey Three-Five Group was a group within Plessey Opto Microwave Ltd., a subsidiary of Plessey plc. The first GaAs FET production at Plessey plc occurred in 1965.

In 1989, Plessey Opto Microwave Ltd. was restructured into three groups. Plessey Microwave Group focuses on hybrids and modules. Plessey Opto Group is involved in lasers, PIN diodes, receivers, and other opto components. Plessey Three-Five Group has responsibility for chip manufacturing, MMICs, discrete FETs, ICs, and the Caswell R&D Center. A foundry service for GaAs ICs is available, offering D-MESFETs with 0.9u nominal gate lengths integrated with ion-implanted diodes and resistors, metal-insulator-metal (MIM) and interdigitated capacitors, and spiral dielectrically isolated (DI) bridge inductors.

In 1990, Plessey Research Caswell, Ltd., assumed responsibility for all GaAs operations, including R&D work previously accomplished at the GEC Hirst Research Center.

COMPANY EXECUTIVES

Managing Director
John Brian

Marketing Executive
Peter Bradshaw

Sales Executive
Pim Meaning

Director of R&D
Fred Myers

International Sales Manager
Ray Evans

SERVICES

The Company provides a full-service GaAs MMIC foundry.

PROCESS TECHNOLOGY

The Company uses submicron GaAs MESFET technology.

PRODUCTS

GaAs ICs
Fiber-optic devices
Low-noise and power MESFETs

FACILITIES

The 40,000-square-foot facilities employ approximately 400 people in GaAs processes. Plessey invested £50 million between 1985 and 1989 to upgrade its facilities.

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Quality Technologies Corporation

Optoelectronics Division
670 North Mary Avenue
Sunnyvale, CA 94086
415/493-0400

ESTABLISHED: 1979 **NO. OF EMPLOYEES: 1,740**

BACKGROUND

This division of Quality Technologies was previously a division of General Instruments (GI). In September 1987, GI sold its Optoelectronics Division to Quality Technologies Corp., a Palo Alto, California-based holding company, reportedly for $25 million.

The division's semiconductor products consist of discrete and opto devices, ICs including VLSI devices, and hybrids.

COMPANY EXECUTIVES

Chairman
Robert L. Parker

President and CEO
Ralph Simon

Vice President of Special Projects
Walter P. Steward

Vice Chairman and General Counsel
Donald L. Coomber

Vice President, Finance & Administration
Edward M. Miller

Vice President, Marketing/Sales
Charles Bates

Managing Director
G.T. Tuan (Kuala Lumpur)

PROCESS TECHNOLOGY

The Company uses GaAs and related III-V optoelectronic device processes.

PRODUCTS

Opto isolators
LEDs—discrete and arrays
Optoswitches
III-V materials

FACILITIES

Quality Technologies Corporation's Sunnyvale, California, facility has 12,000 square feet. Additional assembly facilities are located in Malaysia.

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RAMAX Limited

Monash Business Park
Level 1, Building 11
Business Park Drive
Notting Hill VIC 3168
Australia
(03) 558 9900
Fax: (03) 558 9123

ESTABLISHED: 1987 NO. OF EMPLOYEES: NA

BACKGROUND

RAMAX Limited was formed in 1987 to commercialize and produce integrated circuits for global markets based on new nonvolatile memory (NVM) technology. Funding for the Company was provided solely by the Victoria State Government in the form of equity subscription. This funding has allowed RAMAX to acquire rights to this new technology and commence the pursuit of the business opportunities it has identified.

The Company recognizes that the demand for integrated circuits with higher density and higher speed is driving the semiconductor industry toward the use of optical techniques. These techniques are based primarily on active thin-film technologies, and RAMAX has chosen to specialize in this rapidly growing market area.

To realize its market opportunity, RAMAX will develop and commercialize a range of differentiated products based on active thin-film technologies; these products are thin-film ferroelectrics and compound semiconductor epi layers. RAMAX's long-term emphasis will be on compound semiconductor-based (specifically GaAs) integrated circuits—electronic and optoelectronic—that combine the advantages of both the GaAs and thin-film ferroelectric materials. However, market opportunities in silicon NVMs also will be pursued, particularly the replacement of current EEPROMs with ferroelectric versions that offer superior performance characteristics.

The Company formed a joint venture with Epi Materials Ltd. (EML) of the United Kingdom to enter the epi-treated wafer market in Asia. The product initially will be sourced from EML and primarily will be GaAs-based epi layers that use an enhanced, high-quality, high-yield MOCVD process developed by EML. Once sufficient sales volume has been generated, the product will be manufactured in Australia.

The silicon NVM market will be approached in two phases. In the first, RAMAX proposes to market the product from an existing European or North American manufacturer into Asia to build marketing capability and understand customer needs before entering the market with its own products. The second phase will be the launch of a new NVM product that offers significantly improved user benefits utilizing thin-film ferroelectrics. A foundry manufacturing strategy will be employed for production.

Initial entry to the GaAs market will be via an agency for products from an existing manufacturer. As with silicon NVMs, this method of entry will allow a marketing capability to be established and the building of customer relationships. The Company then proposes to establish a design facility for standard GaAs products and ultimately design GaAs NVM products utilizing the thin-film ferroelectric technology.

The Company's long-term entry to the optoelectronic IC market will result from the integration of the active thin-film technologies that will allow a new generation of OEICs to be developed.

COMPANY EXECUTIVES

(Position and Name)

Chief Executive Officer
Allan G. Tapley

Admin. Manager & Company Secretary
William D. Gleeson

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RAMAX Limited

Technology Manager
R. Bruce Godfrey

STRATEGIC ALLIANCES

Ramtron Corp.
June 1987
RAMAX licensed Ramtron's thin-film ferroelectric NVM technology. RAMAX has worldwide nonexclusive rights with sublicensing on silicon and worldwide exclusive rights with sublicensing on GaAs.

Epi Materials Ltd.
October 1989
An Australian joint venture was formed to market EML's epi-treated wafers into Asia and ultimately to manufacture epi-treated wafers in Australia.

SERVICES

Marketing
Manufacturing

PRODUCTS

MOCVD epi-treated wafers
Silicon- and GaAs-based NVM and standard products to be announced

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Rockwell Microelectronics Research and Development Center (MRDC)

3370 Miraloma Avenue
Anaheim, CA 92803
714/762-4074
805/375-1295 (Newbury Park facility)

ESTABLISHED: 1975 NO. OF EMPLOYEES: 150

BACKGROUND

Rockwell International is a multi-industry corporation engaged in R&D and the manufacture and sale of products for government and commercial markets. It was the prime contractor for the B1 bomber. Its principal space activity is the space shuttle program for NASA.

Rockwell developed the first DOD-sponsored GaAs foundry capability via DARPA and other funding. The cost of the facility was $16 million. Its production schedule was 100 3-inch wafers per shift per week in 1989 with a total planned capacity of 250 wafers per shift per week. The plant includes LEC crystal production, wafer preparation, device R&D, CAD systems, and complete fab capabilities.

COMPANY EXECUTIVES

Vice President/Center Director
Dr. Eugene E. Pentecost

GaAs Facility Director
Jai Haku (Newbury Park)

GaAs Programs Manager
Art Cappon

STRATEGIC ALLIANCES

IBM and Rockwell have a GaAs technology exchange agreement.

SERVICES

The Company operates a full-service GaAs foundry.

PROCESS TECHNOLOGY

The Company uses GaAs MESFET and HBT technology.

PRODUCTS

MMICs
DigICs, including 16K SRAMs
6,000-gate arrays for operational use by DARPA
Optoelectronic devices

FACILITIES

Rockwell MRDC's Thousand Oaks, California, facilities have more than 40,700 square feet, including 12,200 square feet of controlled environment.

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Sharp Corporation

22-22 Nagaike-cho
Abeno-ku, Oaska 545, Japan
(06)621-1221

ESTABLISHED: 1912 NO. OF EMPLOYEES: 24,079

BACKGROUND

Sharp Corporation was founded in 1912 by Tokuji Hayakawa. The Company is named after its first product, the Ever-Sharp pencil, invented by the founder. The Company's business operations cover development, production, and marketing of products including consumer appliances, office equipment, industrial equipment, and electronic components. Sharp is a leader in electronic calculators, including solar-powered models.

Sharp claims that it developed the first GaAs visible LED (in 1964). In 1985, Sharp developed a GaAs laser for continuous operation at 680nm at room temperature. The laser has a threshold current of 100mA and an optical power output of 5mW. Laser development is continuing at Sharp.

The Company entered the GaAs FET market in March 1986 with its LT300, a 1-GHz small-signal amplifier.

COMPANY EXECUTIVES

President/CEO
Haruo Tsuji

Head of Marketing
Kosaku Okano

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Sharp Corporation is a member of the Sanwa Group. Sharp's president is on the Sanwa Group's 42-company policy-making council called Sansui-Kai (Third Wednesday Conference).

The Company's eight major shareholders are Nippon Life Insurance Company (5.3 percent), Fuji Bank (4.4 percent), Daiwa Bank (4.2 percent), Sanwa Bank (4.0 percent), Yasuda Mutual Life Insurance Company (3.9 percent), Dai-Ichi Mutual Life Insurance Company (3.8 percent), Sumitomo Life Insurance Company (3.5 percent), and Taisho Marine and Fire Insurance (2.8 percent). Foreign stock ownership is 4.2 percent.

Sharp has technology-sharing or licensing agreements with NEC, RCA, Rockwell, Samsung (South Korea), WaferScale Integration, Zilog, and others.

PROCESS TECHNOLOGY

AlGaAs and other III-V VPE and MOCVD on GaAs wafers
GaAs MESFET: submicron

PRODUCTS

The Company produces GaAs FETs and optoelectronic devices including photocouplers, interruptors, photo relays, LEDs, LED arrays, and lasers.

FACILITIES

Nara factory (established 1964)
Discrete and opto fab, assembly, and test

Shinjo factory (established 1981)
Opto fab and test

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Siemens GmbH

Munich, Germany

ESTABLISHED: 1847 NO. OF EMPLOYEES: 363,000

Siemens Components, Inc.

186 Wood Avenue South
Iselin, NJ 08830

ESTABLISHED: 1982 NO. OF EMPLOYEES: 20

Siemens Optoelectronics Division

19000 Homestead Road
Cupertino, CA 95014
408/257-7910

ESTABLISHED: 1977 NO. OF EMPLOYEES: 190

BACKGROUND

Siemens is a leading international manufacturer of electric and electronic products and systems; its annual sales exceed $17 billion. More than 50 percent of its equipment and systems sales are derived from developments completed within the last five years. Siemens maintains facilities in 128 countries and employs more than 320,000 persons.

The Company's subsidiary, Siemens Components, Inc., has four U.S. subsidiaries, including the Optoelectronics Division (formerly Litronix). Siemens Components has an advanced circuit research lab in Princeton, New Jersey. Siecor, Siemens' joint venture with Corning, is second only to AT&T in terms of kilometers of optical cable in service. Siemens owned and operated MSC (Microwave Semiconductor Corporation) until late 1988, at which time it discontinued MSC's GaAs operations and sold the silicon discrete operations.

The Optoelectronics Division was acquired by Siemens in 1978. The division designs, manufactures, and markets a wide range of opto components including LEDs, LED displays, more than 50 types of optocouplers, and more than 100 different IR devices. Its line of displays is self-contained, using LED and CMOS chip technology and requiring no external logic.

COMPANY EXECUTIVES (OPTOELECTRONICS DIVISION)

Senior Vice President/General Manager
Peter Albus

Vice President, Engineering
Ed Insel

Director of Marketing
Chuck Berghoff

PROCESS TECHNOLOGY

Siemens GmbH uses GaAs and other LED-related III-V processes.

PRODUCTS

The Company's optoelectronic products include LEDs and displays and IR devices.

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Siemens GmbH

FACILITIES

Munich, Germany
830,000 square feet
Primarily silicon wafer fab and test; includes R&D labs and some GaAs production

Regensburg, Germany
250,000 square feet
Opto device production

Cupertino, CA
55,000 square feet
Opto device production

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Solid State Optronics Inc.

1440 Koll Circle, Suite 107
San Jose, CA 95112-4609
408/436-1390
Fax: 408/436-1392

ESTABLISHED: June 1982 **NO. OF EMPLOYEES: 6**

BACKGROUND

Solid State Optronics, Inc., designs and manufactures solid-state relays, photoresistors, and thyristors. The Company was founded by Zag Kadah in 1982. Prior to founding the Company, Mr. Kadah was employed at Electro-Trol, Inc., as vice president in charge of the optoelectronics division. In 1979, Mr. Kadah founded Power Interface, a company that pioneered the development of an IC to drive back SCRs in solid-state relays.

The Company subcontracts manufacturing to a company in Asia; assembly is done in the Philippines.

COMPANY EXECUTIVES
(Position, Name, and Prior Company)

President
*Zag Kadah
Elec-Trol, Inc.

Marketing
Sid Kadah
UC Berkeley

Financial Officer
Fay Kadah
Magnex

*Founder

PROCESS TECHNOLOGY

Bipolar
Dielectric isolation
DMOS
GaAs and GaAlAs

PRODUCTS

Input/Output Modules
Interrupters
Photodiodes
Photo Arrays
Silicon Photo Detectors
Solid-State Relays
Hybrid Optoelectronic Modules

FACILITIES

San Jose, CA
1,200 sq. ft.
R&D, design, engineering, and assembly

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Sony Corporation

7-35 Kitashinagawa 6-chome
Shinagawa-ku, Tokyo 141, Japan
(03)448-2111

ESTABLISHED: 1946 NO. OF EMPLOYEES: 60,500

BACKGROUND

Sony was founded in 1946 by Masaru Ibuka and Akio Morita. The name Sony was adopted in 1958. Sony has many marketing firsts including: the first all-transistor radio in Japan (1955), the first transistor television (1960), the first VTR (1963), the first IC radio (1966), Walkman (1979), and Discman (1985). As a result of the negative impact of sluggish consumer sales, the Company plans to reduce its dependence on consumer electronics from 50 percent in 1986 to 20 percent by the end of 1990. Akio Morita remains chairman of Sony.

Sony entered the merchant semiconductor market in 1983. Also in 1983, the Company reported results of R&D and successful testing of a GaAs JFET chip containing 511 DCFL gates organized as a 4x4 multiplier, 10b accumulator, and 8b shift register.

Sony is constructing a 1.7-million-square-foot GaAs manufacturing facility in Miyagi Prefecture. The $51 million investment includes assembly and provision for adding a GaAs wafer fab by 1994.

COMPANY EXECUTIVES (GaAs ACTIVITY)

President/CEO
Norio Oga

Managing Director/Senior General Manager, Semiconductor Group
Masahiro Takahashi

Head of Marketing
Fumio Kono

STRATEGIC ALLIANCES

In December 1984, Sony licensed MLEC crystal growth to Monsanto.

In February 1986, Sony and AMD announced a joint technology development program that includes development of common process technology and marketing of each other's products under their own company names.

Sony and TriQuint (Tektronix) entered into a technology agreement on GaAs ICs in 1988.

PROCESS TECHNOLOGY

GaAs JFET
MESFET
VPE and MOCVD epi processes

PRODUCTS

Optoelectronic devices including LEDs and lasers
Analog ICs
MMICs

FACILITIES

Atsugi factory
GaAs, R&D, laser fabrication, other

Kawasaki plant

Miyagi plant
1.7 million sq. ft.
GaAs assembly operations by 1992 and future GaAs wafer fab

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Spectra Diode Labs

80 Rose Orchard Way
San Jose, CA 95134
408/943-9411

ESTABLISHED: 1983 **NO. OF EMPLOYEES: NA**

BACKGROUND

Spectra Diode Labs (SDL) originated as a joint venture of Spectra-Physics Inc. and Xerox Corporation. The Company has pioneered development of high-powered laser diodes. Research at Xerox PARC, begun in 1971, let to such developments as MOCVD, the first cw phased array laser diodes, and efficient MQW structures. In 1988, Ciba-Geigy purchased the Spectra-Physics share of SDL. Future product focus will be in high-power and high-brightness cw and pulsed GaAlAs lasers.

In October 1990, SDL retained Saloman Brothers to investigate the sale of the Ciba-Geigy share, the Xerox share, or both shares of the company.

COMPANY EXECUTIVES

President/CEO
Don Scifres

Director, Advanced Research
Dave Welch

Director, Marketing
David Evans

STRATEGIC ALLIANCES

Spectra-Physics Inc.
Xerox Corporation

SERVICES

Custom design, development, and production—commercial and military
R&D contracts—government and commercial

PROCESS TECHNOLOGY

GaA1As MQW and SQW
MOCVD

PRODUCTS

SDL produces a family of more than 110 types of GaA1As high-power laser diodes up to 10 watts cw and 1.5KW pulsed.

FACILITIES

SDL has a 42,000-square-foot facility located in San Jose, California.

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Stanley Electric

Tokyo, Japan
(03)710-2222

ESTABLISHED: 1933 NO. OF EMPLOYEES: 3,760

BACKGROUND

Stanley Electric is the leading supplier of electrical equipment for automobiles in Japan. The Company is considered the leader in the high-brightness segment of the LED market. The Company began marketing super-bright LEDs (300 to 1,200 millicandela) in 1982.

COMPANY EXECUTIVES

Chairman
Takaoki Kitano

President/CEO
Tooru Teshima

Head of Marketing
Shuji Kobayashi

FINANCIAL BACKING

The major shareholders in Stanley Electric include Nippon Life Trust (5.6 percent), Mitsui Trust (4.7 percent), Honda (4.6 percent), Mitsui Bank (4.4 percent), and others.

PROCESS TECHNOLOGY

The Company uses GaAs and related III-V processes.

PRODUCTS

The Company produces LEDs and other opto devices.

FACILITIES

Stanley Electric's plant is in Hatano.

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Telcom Devices Corporation

914 Tourmaline Drive
Newbury Park, CA 91320
805/499-0611
Fax: 805/499-8018

ESTABLISHED: 1986 NO. OF EMPLOYEES: 6

BACKGROUND

Telcom Devices Corporation was formed in early 1986 to offer InGaAs photodiodes and indium gallium phosphide (InGaP) LEDs.

Founders James Kim, Ock-Ky Kim, and Larry Perillo are former Rockwell engineers. Telcom Devices is a subsidiary of Opto Diode Corp. (ODC) and is operating from ODC's facilities in Newbury Park, California. Both companies share clean room and manufacturing space.

Telcom Devices began volume production of its first products in May 1986. The products were InGaAs PIN photodiodes for fiber-optic applications and included the Planar 13PD100 and Planar 15PD100.

COMPANY EXECUTIVES
(Position, Name, and Prior Company)

Chairman/CEO
*James Kim
Rockwell

President
Doug Holmes
Rockwell

VP Engr
*Ock-Ky Kim
Rockwell

*Founder

PRODUCTS

InGaAs Photodiodes
Long-Wavelength LEDs

FACILITIES

Newbury Park, CA
10,000 sq. ft.
Administration, manufacturing

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Teledyne Monolithic Microwave

1274 Terra Bella Avenue
Mountain View, CA 94043
415/966-8632

ESTABLISHED: 1984 NO. OF EMPLOYEES: 22

BACKGROUND

Teledyne Monolithic Microwave (TMMIC) was founded by Teledyne MEC, a subsidiary of Teledyne, Inc. Teledyne MEC manufactures microwave devices for use in electronic countermeasures. Teledyne, Inc., is a vertically integrated corporation involved in four major areas of work: aviation and electronics; machines and metals; engines, energy, and power; and commercial and consumer.

Teledyne MEC is supporting TMMIC in establishing a technical and business base, in preparation for TMMIC to spin off as an independent company. TMMIC introduced its first product, a 2- to 18-GHz MMIC amplifier, in the first half of 1986.

Teledyne is a member of the Raytheon/Texas Instruments team, which received a Phase I award under the DARPA-sponsored MIMIC program.

COMPANY EXECUTIVES

Executive Director
Dr. James Ewan

Director, Technology
Dr. Steven Ludvik

Director, Applications
Dr. Robert Mandel

SERVICES

Design
Manufacturing

PROCESS TECHNOLOGY

The Company uses GaAs MESFET technology.

PRODUCTS

The Company produces MMIC subsystems utilizing GaAs MESFET technology that operate at microwave and/or millimeter-wave frequencies.

FACILITIES

The Teledyne Monolithic Microwave plant is approximately 15,000 square feet, including a 4,000-square-foot design center and a 6,000-square-foot clean room in Mountain View, California. No wafer fab is included at this facility.

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Telefunken Electronic GmbH

P.O.B. 1109 D-7100 Heilbronn
Germany
(07131)67-0

ESTABLISHED: 1982 **NO. OF EMPLOYEES: NA**

BACKGROUND

Telefunken Electronic GmbH began as an alliance of United Technologies Corporation (Hartford, Connecticut) and AEG-Telefunken (Heilbronn, Germany). AEG-Telefunken was founded in 1893; in 1979, it faced bankruptcy after it lost a nuclear power contract. Subsequently, it was rescued by a group of West German banks. In 1988, AEG-Telefunken repurchased its stake; that was sold to UTC in 1982 for an undisclosed sum.

Total worldwide sales of semiconductors by Telefunken Electronic GmbH exceed $275 million annually, of which approximately 40 percent are optoelectronic and other compound semiconductor sales.

PROCESS TECHNOLOGY

GaAs and AlGaAs VPE on GaAs, GaP, and other compound wafers

PRODUCTS

Opto devices including lasers, detectors, optocouplers, and visible and IR LEDs
GaAs MESFETs
GaAs microwave ICs
Fiber-optic transmitters and receivers
Solar cells and solar panels

FACILITIES

Heilbronn, Germany
Braunau, Austria
Vocklabruch, Austria

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Texas Instruments, Inc.

13500 N. Central Expressway
Dallas, TX 75265
214/995-2011 (Headquarters)
214/997-3300 (Opto Marketing)
214/995-3043 (Foundry)

ESTABLISHED: 1960 (GaAs materials work)
1973 (GaAs FETs)

NO. OF EMPLOYEES: 74,000

BACKGROUND

Texas Instruments (TI) is a vertically integrated producer of semiconductor materials, devices, and circuits; electronics; and other hardware including instrumentation, calculators, radar systems, ordnance, computers, and terminals. TI's Central Research Lab (CRL) has done work in GaAs technology for more than 25 years. By 1975, TI had demonstrated 8- to 10-GHz FETs. In 1982, the Company's Defense Systems and Electronics Group (DSEG) established a pilot production capability for MMICs and discrete power devices capable of operation to 18 GHz. CRL has pushed analog GaAs circuit operating frequency to more than 100 GHz and is developing a 4K ECL-compatible SRAM. CRL demonstrated a 1K SRAM with the smallest cell reported as of November 1985.

TI established its MMIC foundry in 1986 and has invested more than $50 million in GaAs design and production facilities. One of its products, the TGA8014, is claimed to be the first true power amplifier available as a GaAs MMIC, delivering 400mW from 6 to 18 GHz. In 1987, TI reported performance and yield data on its single-chip X-band radar transceiver, which contains a four-bit phase shifter, three-stage LNA, and four-stage power amp.

The TI/Raytheon joint venture is developing 14 GaAs ICs under the Phase I MIMIC initiative; six are for EW applications, four are for use at 20 to 50 GHz, and four are for radar applications.

COMPANY EXECUTIVES

Laboratory Director
Dr. Dean Collins (Central Research Laboratories)

Associate Laboratory Director
Dr. William R. Wisseman (Central Research Laboratories)

Optoelectronics Marketing Director
Milt Hogan

Foundry Operations Manager
Ray Toole

MMIC Marketing Manager
Paul Schurr

STRATEGIC ALLIANCES

TI and Raytheon have a joint venture in GaAs technology; the joint venture was awarded Phase 0 and Phase I contracts under the U.S. DOD MIMIC initiative.

SERVICES

TI provides a full-service GaAs MMIC foundry.

PROCESS TECHNOLOGY

0.5u GaAs MESFET on ion-implanted 3-inch wafers (foundry)
Three doping profiles: power, low-noise, and intermediate

PRODUCTS

Opto devices including LEDs, displays, and optocouplers

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Texas Instruments, Inc.

LNAs and power FETs:
- TGA monolithic amplifier series
- TGF GaAs FET series

Single-chip radar transceivers
Custom digICs including RISC microprocessors
MMICs

FACILITIES

In Dallas, Texas, TI has a 9,000-square-foot clean room at DSEG with capacity for more than 100 3-inch GaAs wafer starts per week.

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Thomson-CSF GaAs Department

Route Departmentale 128
BP48
91401 Orsay Cedex
France
(1)6019 7000

Thomson Composants Microondes
Grenoble, France

ESTABLISHED: 1968 **NO. OF EMPLOYEES: 270**

BACKGROUND

Thomson-CSF is a vertically integrated high-technology company dedicated to R&D of advanced manufacturing technology and to the manufacture of electronic equipment and systems. The Mitterand government has taken a significant interest in Thomson-CSF as part of the government's restructuring of French industry.

Thomson produces its own GaAs crystals, wafers, and discrete and IC semiconductors. It has about 250 employees involved in GaAs device development and production. Thomson has used 2-inch wafers since 1983 and 3-inch wafers since 1986. In 1988, the Company added a fab line with capacity for 50 2-inch wafers per week. Thomson's GaAs facilities supply 80 percent of the Company's internal needs for military and communications end-equipment usage of compound semiconductors.

Thomson-CSF is a stakeholder in ANADIGICS (Warren, New Jersey) and in Vitesse Semiconductor Corporation (Camarillo, California). Both are U.S.-based GaAs IC companies.

COMPANY EXECUTIVES

Director
John Magarshack

Manager, Hybrid Strategy
Francois Bizec

STRATEGIC ALLIANCES

Thomson-CSF Ventures invested $3 million in ANADIGICS in mid-1988 and another $3 million in 1989. It also invested an unspecified amount in Vitesse Semiconductor Corporation in October 1990.

SERVICES

GaAs MMIC and digIC foundry
Training in custom GaAs IC design
VPE and MOCVD epitaxial services
Wafer testing
JANTX-V equivalent military screening

PROCESS TECHNOLOGIES

1μ D-MESFET
0.5μ, 20-GHz MESFET
0.3μ MESFET and HEMT
Ion implantation
Air-bridge interconnects

PRODUCTS

GaAs and InP diodes—power generator, receiver, and control
GUNN diodes to 100 GHz
GaAs FETs—power and low noise
Low-noise HEMTs to 40 GHz
MMICs
Linear GaAs ICs
BFL logic devices
Second source of all Vitesse GaAs ICs

FACILITIES

Thomson-CSF has 13,000 square meters including 2,000 square meters of Class 100 clean rooms.

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Three-Five Systems, Inc.

10230 S. 50th Place
Phoenix, AZ 85044
602/496-0035
Fax: 602/496-0168

ESTABLISHED: April 1985 **NO. OF EMPLOYEES:** 235

BACKGROUND

Historically, Three-Five Systems, Inc., produced and marketed custom and semicustom products that combine silicon and GaAs technologies for the consumer, industrial, telecommunications, and computer markets. The Company's main product thrust now is custom user interface modules utilizing LED, LCD, and keyboard components.

The Company is headquartered in a 40,000-square-foot facility in Phoenix, Arizona. The facility houses all corporate functions as well as a quick-turn prototype manufacturing area. In 1987, Three-Five consolidated its domestic operations in Phoenix, Arizona, and eliminated a facility in Troy, New York.

The Company was formed via a leveraged buyout of National Semiconductor's Optoelectronics business unit and was named Three-Five Semiconductor. The Company's founders are Frank Shroff, John Gragg, Dennis Riccio, Joe Riccio, and Brent Fox. Three-Five received acquisition funding, which was completed in December 1985, from Continental Illinois Venture Corporation (Chicago, Illinois) and OptoVen of Phoenix, an investment company formed specifically to invest in Three-Five.

In 1987, the Company changed its name from Three-Five Semiconductor Corporation to Three-Five Systems to reflect a shift from a front-end semiconductor emphasis to a broader systems approach. The Company has reorganized into two groups. The optoelectronics group supplies all existing and future standard products, and the display group is responsible for Application-Specific Integrated Displays (ASIDs) as well as other technologies that may be added. In September 1987, Three-Five raised $5.5 million in second-round financing, which was used to expand its technical staff and facilities to support the Company's thrust into new opto product areas. In March 1988, Three-Five initiated a further round of financing to support the Company's thrust into LCDs.

Currently, 400 products that were developed by the Company while it was a division of National are offered by Three-Five and include infrared and custom devices. New products include custom LCDs. In the long term, the Company will focus on PLCDs and GaAs-based products, optoelectronics (standard and custom), and integrated optoelectronic ICs. The Company will also focus on display systems, such as LED and LCD, with a higher degree of electronic control.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
David R. Buchanan
Talos Systems (now Calcomp Digitizer Division), Founder/Chairman/CEO

VP Finance/CFO
Kenneth M. Julien
CerProbe, VP/CFO

VP Quality
*Joseph Riccio
Motorola, Area Sales Mgr

Dir Mktg/Sales
Norman E. Clarke
MCI Telecommunications, National Account Manager

Dir European Ops
Martin Woolfenden
National Semiconductor, Marketing Manager

Dir Manufacturing
Dr. Carl Derrington
Motorola, Prod Mgr, Sensors

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Three-Five Systems, Inc.

Dir Materials and Process Technology
Dr. Joseph Morrissy
Alcatel Information Systems, Manufacturing Manager

Dir Engineering
Mike Petera
Alphasil, Elec Design Mgr

*Founder

PROCESS TECHNOLOGY

Liquid Crystal, including PLCD
GaAs

PRODUCTS

Application-Specific Integrated Displays(ASIDs)
Custom User Interface Modules (Displays and Keyboards)
LCD Modules—Standard and Custom
Integrated Displays
Integrated LED Bar Graphs
Infrared Emitters
LED Dot Matrix Displays
Visible Lamps and LED Digits
Multidigit LED Displays
Keyboards

FACILITIES

Phoenix, AZ
40,000 sq. ft.
Prototype laboratories, corporate headquarters

Manila, Philippines
Manufacturing, inventory

Swindon, United Kingdom
European headquarters

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Toshiba Corporation

1-1 Shibaura 1-chome
Minato-ku, Tokyo 105, Japan
(03)457-4511

ESTABLISHED: 1875 **NO. OF EMPLOYEES: 70,870**

BACKGROUND

Toshiba Corporation was founded in 1875 as Tanaka Seizo-sho. The Company merged with Tokyo Electric Company in 1939 and changed its English name to Toshiba Corporation in 1978. The Company is one of the two leaders of the Toshiba-IHI Group. Toshiba is focused in electronics and energy; it is targeting AI, next-generation computers, and software as high-growth areas. It is the second-largest semiconductor supplier in the world.

Toshiba's GaAs activities began in 1974. GaAs developments by Toshiba include GaAs Schottky FETs for use in TV tuners, 4x4 parallel multipliers with multiply time of 6ns and P_d of 39mW, GaAs MMIC operating at 12 GHz, Pt-gate GaAs FETs with transconductance of 1.8 milliSiemens, and a 1K gate array with 75ps gate delay.

In mid-1983, Toshiba reported developing a twin-mesa substrate laser and a methodology for forming a number of such lasers on the same substrate for use in multiplexing light sources. In late 1983, Toshiba began sampling a GaAlAs/GaAs laser used in optical disks for audio systems at a sample price of $44.00. By 1984, the device was in mass production at an ASP of $13.00, and by 1989, the price had fallen to less than $2.50.

A 6,000-gate GaAs gate array was developed by Toshiba's VLSI Research Center at Saiwai-ku, Kawasaki, Japan, as a part of the MITI Scientific Computing Systems Program. The array used a conventional SCFL structure to implement 232 rows by 26 columns of cells. A test structure, with serial-parallel-serial registers occupying 80 percent of the die, consumed 952mW when operated at an 850-MHz rate. Die size is 8mm x 8mm^2.

Toshiba participated in the AIST/MITI Japanese national supercomputer project sponsored by NEDO, which resulted in a GaAs-based prototype supercomputer system.

COMPANY EXECUTIVES

President and CEO
Joichi Aoi

Senior Manager, Worldwide Business Planning
Takeshi Nakagawa

STRATEGIC ALLIANCES AND FINANCIAL BACKING

Toshiba has electronics technology exchange agreements with Brooktree, GE, Hewlett-Packard, Intel, Korea Electronics Company, Laser Path, LSI Logic, Motorola, Olivetti, Pohang (South Korea), SGS, Siemens, Sun Microsystems, Tokuda Works, Zilog, Zoran, and others.

From 1981 to January 1990, Toshiba, Fujitsu, Hitachi, Mitsubishi and NEC jointly developed a GaAs-based prototype supercomputer system.

Major shareholders in Toshiba Corporation include Dai-Ichi Life Insurance (4.2 percent), Nippon Life Insurance (3.6 percent), Mitsubishi Trust (3.5 percent), Mitsui Trust (3.4 percent), and Mitsui Bank (2.9 percent). Foreign owners hold 3.4 percent.

PROCESS TECHNOLOGY

Toshiba uses GaAs and other III-V compound semiconductor processes.

PRODUCTS

LEDs, lasers, and other opto devices
Analog ICs
MMICs
Discretes

FACILITIES

Kitayushu plant
Tamagawa plant
Korea Electronics
Optoelectronics and discrete production

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TriQuint Semiconductor, Inc.

Group 700
P.O. Box 4935
Beaverton, OR 97076
503/644-3535
Fax: 503/644-3198

ESTABLISHED: January 1984 NO. OF EMPLOYEES: 180

BACKGROUND

TriQuint designs, develops, manufactures, and markets microwave, linear, and GHz digital GaAs IC components. TriQuint also offers a broad range of foundry services. The Company's products are used in high-performance applications such as fiber-optic telephone communication, high-speed computer interfaces, instruments, and military systems.

The Company evolved from research on GaAs ICs that began in Tektronix Laboratories in 1978. Several of TriQuint's founders were leaders on the Tektronix research team. In 1984, TriQuint was formally established as a majority-owned subsidiary with the entrepreneurial freedom to establish a broad portfolio of long-term manufacturing contracts. In mid-1990, TriQuint had sales revenue of approximately $25 million.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
Alan D. Patz
Tektronix, GM GaAs ICs

Dir Mktg/Sales
Dennis C. Powers
Tektronix, Sales Manager

QA/Materials Manager
Richard Allen
Tektronix, Div Mfg Mgr

VP R&D
Dr. Richard Koyama
Tektronix, Technical Manager

Dir Finance/Admin
Richard Sasaki
Tektronix, Financial Manager

VP Mfg
Dr. Gordon Roper
Tektronix, Principal Engr

VP Microwave Products
Philip Snow

RECENT HIGHLIGHTS

February 1988
TriQuint announced a radio-frequency/large-scale integration (RF/LSI) GaAs IC foundry service named the QED/A process.

March 1988
TriQuint introduced the QLSI cell-based library, a GHz LSI cell-based library that supports LSI applications of up to 6,000 equivalent gates and toggle rates of up to 2 GHz.

May 1988
TriQuint is the first GaAs foundry to manufacture microwave and digital ICs on 4-inch wafers.

May 1988
TriQuint announced an optimized 0.5-micron microwave foundry process.

July 1989
TriQuint announced the shipment of wafers and die screened to U.S. DOD Class 5 requirements, the first commercial IC manufacturer to announce availability of this level of screening—permitting satellite systems applications.

STRATEGIC ALLIANCES

Tektronix
January 1984
Tektronix spun off TriQuint, remaining the parent company and completing a sales agreement with the new subsidiary.

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TriQuint Semiconductor, Inc.

EEsof
May 1986
EEsof and TriQuint teamed up to incorporate TriQuint's GaAs custom MMIC foundry models into Touchstone, EEsof's minicomputer- and workstation-based MMIC CAD program. Jointly, they developed a GaAs MMIC element library that allows users to simulate microwave ICs, using MMIC components that model components available from TriQuint's custom MMIC foundry facility.

TRW
June 1987
TRW Components and TriQuint agreed jointly to develop and supply class-S level GaAs devices for space applications. TriQuint will provide microwave and digital GaAs technology in addition to foundry services.

MSC
March 1988
Microwave Semiconductor Corporation and TriQuint agreed to provide customers with GDS-II tape interchangeability and equivalent performance for GaAs analog and digital ICs and MMICs.

Hewlett-Packard
May 1988
TriQuint's MMIC Library of foundry design models are incorporated into Hewlett-Packard Company's microwave CAE design system.

Gazelle Microcircuits
May 1988
Gazelle Microcircuits signed a foundry contract with TriQuint for 4-inch digital wafer production.

Pacific Semiconductor Pty (Sydney, Australia)
May 1990
TriQuint and Pacific jointly acquired all patents formerly held by Gain Electronics Company.

PROCESS TECHNOLOGY

1.0- and 0.5-micron gate length depletion mode MESFET processes capable of fabricating D-MESFETs VIAs
1.0- and 0.5-micron gate length enhancement/depletion mode MESFET processes capable of fabricating E- and D-MESFETs
3-inch wafers
4-inch wafers

PRODUCTS

Foundry Process	Description
1A/1D Process	1.0-Micron Gate Length Depletion Mode MESFET for D-MESFET, Schottky Diodes, Implanted Resistors, MIM Capacitors, and Airbridge Inductors
HA Process	0.5-Micron Gate Length Depletion Mode MESFET Process for Both 0.5- and 1.0-Micron D-MESFETs, Schottky Diodes, Implanted Resistors, Precision Nichrome Resistors, MIM Capacitors, and Airbridge Inductors
QED Process	1.0-Micron Gate Length Enhancement/Depletion Mode MESFET for E- and D-MESFETs, Schottky Diodes, Implanted Resistors, and Airbridge Inductors
QED/A Process	An Enhanced Version of the QED Process that Allows the Mixing of Low-Power Digital LSI Circuits and Precision Analog Circuits on a Single Die
3A Process	Optimized 0.5-micron Microwave Process

Gate Arrays

Family	Linewidth	Delay	Gates
QLSI	1.0	0.15	2,000; 3,000; 4,000

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TriQuint Semiconductor, Inc.

Cell-Based Library

Family	Cells
Q-Logic	1,000 Gates, Data Encoders/Decoders, MUX/DEMUX, Counters, Dividers, Prescalers
QLSI	8,000 Gates, ZFL Cells, SCFL Cell Family

MMICs (Die and Components)

TQ9111	1- to 8-GHz Amplifier
TQ9141	1- to 10-GHz Power Divider
TQ9152	1- to 10-GHz SPDT Switch
TQ9161	1- to 10-GHz Variable Attenuator
TQ9121	0.5- to 20.0-GHz 10w Noise Amplifier
TQ9131	0.5- to 20.0-GHz Active Combiner

Digital Products

TQ1131	Pgm 8:1, 16:1 MUX
TQ1132	Pgm 1:8, 1:16 DEMUX
TQ1133	4:1 MUX
TQ1134	1:4 DEMUX
TQ1135	12:1 MUX
TQ1136	12:1 DEMUX

Linear ICs

TQ6330	Pin Driver
TQ6331	Line Receiver
TQ6111-D	8-Bit DAC, 600 Ms/S, Die Form
TQ6111-M	8-Bit DAC, 600 Ms/S, Ceramic Package
TQ6111-BI	8-Bit DAC, 600 Ms/S, Board Module, Instrumentation Version
TQ6111-BV	8-Bit DAC, 600 Ms/S, Board Module, Video Version
TQ6112-D	8-Bit DAC, 1,000 Ms/S, Die Form
TQ6112-M	8-Bit DAC, 1,000 Ms/S, Ceramic Package
TQ6112-BI	8-Bit DAC, 1,000 Ms/S, Board Module, Instrumentation Version
TQ6112-BV	8-Bit DAC, 600 Ms/S, Board Module, Video Version
EK-TQ6101	GIGADAC Evaluation Kit

FACILITIES

Beaverton, OR
35,000 sq. ft.
Administration, engineering, manufacturing

15,000 sq. ft.
Class 100 clean room

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Varian Solid-State Microwave Division

3251 Olcott Street
Santa Clara, CA 95054
408/988-1331
408/562-2650 (Marketing)
408/562-2834 (MMIC Foundry)

ESTABLISHED: 1965 **NO. OF EMPLOYEES: 230**

BACKGROUND

Varian Solid-State Microwave is a division of Varian Associates, Inc. Varian produces GaAs devices for both the merchant market and internal consumption. The Company is a leader in InP technology, presently supplying mm-wave oscillators, reflection amplifiers, Gunn diodes, and other InP devices to the marketplace. Varian discontinued its merchant line of GaAs varactors, LNAs, and power FETs in early 1985, reportedly due to heavy Japanese competition. Varian is one of very few companies that produces chips capable of 100-GHz operation. Its foundry services include a design training course.

COMPANY EXECUTIVES

Division General Manager and Vice President, Operations
Dr. Frank Olson

Director of Marketing
Dean Merkley

Director of Foundry Sales
Mike Kopec

PROCESS TECHNOLOGY

The Company's GaAs and InP wafer processing is based on MBE active layers, proton isolation, 0.50-micron contact lithography and 0.25-micron e-beam lithography, PECVD passivation, and reactive ion etching.

PRODUCTS

GaAs—IMPATT diodes, Gunn diodes, MESFETs, MODFETs, and MMICs
InP—MMIC oscillators, amps, Gunn diodes, VCOs
Full foundry services for custom MMICs
2-inch and 3-inch MBE GaAs and InP wafers
100-GHz amplifiers

FACILITIES

The Company's Santa Clara, California, facility has 20,000 square feet, including a 6,000-square-foot clean room. The facilities provide for three levels of screening: standard level (C), high reliability (R), and space qualified (S).

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Vitesse Semiconductor Corporation

741 Calle Plano
Camarillo, CA 93010
805/388-3700
Fax: 408/433-0331

ESTABLISHED: July 1984 NO. OF EMPLOYEES: 188

BACKGROUND

Vitesse Semiconductor Corporation designs, manufactures, and markets cost-effective digital GaAs large-scale ICs for the high-performance marketplace and offers foundry services on a contract basis. Products are manufactured using enhancement/depletion mode transistors and self-aligned gate technology according to silicon manufacturing techniques. The Company's first products were commercial versions of a family of GaAs ICs, including gate arrays, RAMs, and logic products.

Initially, the Company was funded by Norton Company and organized into two divisions—the Integrated Circuits Division, which was responsible for GaAs IC designs, and the Digital Products Division, which was developing a minisupercomputer product. Early in 1987, the Integrated Circuits Division raised $10 million, establishing an independent company, and was renamed Vitesse Semiconductor Corporation. Dr. Louis Tomasetta, formerly president of the IC Division, is president and CEO of the new company. Dr. Tomasetta was director and program manager of the $40 million DARPA GaAs pilot program at Rockwell International.

Vitesse remains in the existing 45,000-square-foot facility and will use the additional funding raised in 1987 to develop additional products and expand into higher-volume production. The building is designed specifically for the production of LSI-level digital ICs in GaAs. Approximately 12,000 square feet have been designated as clean room area, and half of that area is a Class 10 clean room.

In March 1987, Pierre R. Lamond was elected chairman of the board. Mr. Lamond organized the $10 million financing of Vitesse Semiconductor and also serves on the boards of Convex Computer, Cypress Semiconductor, and several other private companies. In October 1987, Dr. T.J. Rodgers, president and CEO of Cypress Semiconductor Corporation, joined the board of Vitesse Semiconductor.

Vitesse has established a nationwide network of manufacturers' representatives to sell its foundry services and products. In June 1987, Vitesse signed Zeus as its first distributor to sell its 29G00 family of products.

Vitesse announced $250,000 in profit on $3.5 million in sales in first quarter 1990 and $500,000 in profit on $4.5 million in sales in second quarter 1990.

COMPANY EXECUTIVES

(Position, Name, Prior Company, and Prior Position)

President/CEO
*Dr. Louis R. Tomasetta
Rockwell, Dir R&D Center

Executive VP
*Patrick L. Hoffpauir
VLSI Technology, GM ASIC Ops

VP Finance and Administration
Michael A. Russell
Avicon International, CEO

VP Marketing/Sales
David Mooring
Intel, Mktg Mgr

VP Sales
Neil Rappaport
AMCC, Ntl Sales Mgr

VP Engineering
*Ira Deyhimy
Rockwell, Mgr IC Engr

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Vitesse Semiconductor Corporation

VP Operations
James Mikkelson
Hewlett-Packard, Mgr Process Dev

VP Finance/CFO
Michael A. Russell
Avicon Intl, VP Finance/CFO

*Founder

RECENT HIGHLIGHTS

January 1988
Vitesse introduced the VS8001, a 1.25-GHz 12-to-1 multiplexer, and the VS8002 1-to-12 demultiplexer with ECL-compatible parallel I/O. The devices offer 12-bit parallel-to-serial and serial-to-parallel data conversion for communications applications. A unique feature is a self-test path designed to allow the devices to test each other.

March 1988
Vitesse announced that it has developed the VS8010, a MUX/DEMUX with control logic that meets the SONET standard at the 1.2-Gbps communications rate.

November 1988
Vitesse announced the world's first GaAs VLSI product, a 10,000-gate array, the VSC 10000.

January 1989
Vitesse announced a GaAs 22,000-gate array using standard cells.

August 1989
Vitesse announced shipment of its VSC10K GaAs gate array to E-Systems for that company's high-performance digital signal processor series.

October 1990
Vitesse announced the VSC864, 64x64 crosspoint switch.

STRATEGIC ALLIANCES

Norton
July 1984
The initial investment of $30 million in Vitesse was provided by the Norton Company, a $1.3 billion company located in Worcester, Massachusetts.

Advanced Micro Devices
November 1985
Vitesse and AMD agreed to develop and manufacture AMD's AM2900 family of MPUs in gallium arsenide.

TRW
December 1986
Vitesse signed a sales and marketing agreement with TRW Components International Inc. (TRWCI) covering logic, memory, and ASIC products. Vitesse will supply high-performance wafers, die, and packaged devices to TRWCI, which will assemble, test, qualify, and sell to the space-quality, Class-S-level market. The companies also will cooperate to solve the radiation problems found in logic and memory products.

E-Systems
August 1987
Vitesse signed an agreement allowing E-Systems to use Vitesse's proprietary GaAs technology in its current and future programs. E-Systems also has an option to purchase design, packaging, and test technologies. The agreement allows Vitesse to participate in the EW systems market through E-Systems' military programs.

VLSI Technology
September 1987
Vitesse will develop a GaAs cell library for VLSI's design tools. VLSI will provide technical information and assist in the porting effort. When the library is completed, both companies will market the tools, which Vitesse will use internally. VLSI will extend the tools to its silicon compiler library; Vitesse will own the library and provide fabrication.

Ford Microelectronics
October 1987
Vitesse and Ford Microelectronics agreed to second-source each others' IC foundry services. The companies will develop common design rules.

Fujitsu
November 1989
Vitesse and Fujitsu Ltd. announced an alternate-source agreement with regard to Vitesse's FURY GaAs VLSI gate array family.

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Vitesse Semiconductor Corporation

October 1990
Thomson CSF's subsidiary, Thomson Composants Microondes (TCM), will second-source the FURY Series.

PROCESS TECHNOLOGY

GaAs E/D MESFET
0.6-1.25 microns
3-inch wafers

FACILITIES

Camarillo, CA
45,000 sq. ft.
Total space

10,000 sq. ft.
Class 10 clean room

PRODUCTS

Foundry

LSI Enhancement/Depletion Mode Process, 0.8-Micron Feature Size, Sub-100ps Gate Delays, 3-layer metal

	Device	Description
Gate Arrays	VSC1500	Structured Cell Array
	VSC4500	Gate Array
	VSC10K	Gate Array
	VSC15K	Gate Array
	VSC30K	Gate Array
	VSC100K	Gate Array
	VCB50K	Standard Cell
SRAMs	VS12G422E	256x4 SRAM, 3, 4, 5ns
	VS12G422T	256x4 SRAM, 4, 6, 8ns, TTL I/O
	VS126476	4Kx1 SRAM 2.5ns Self-Timed
Microcomponents	VS29G01	4-Bit Slice Processor
	VS29G02	Look-Ahead Carry Generator
	VS29G10	Microcontroller
Standard Products	VS8001	12:1 MUX at 1.2 GHz
	VS8002	1:12 DEMUX at 1.2 GHz
	VS8010	SONET MUX/DEMUX
	VS8004	4:1 MUX at 2.5 Gbps
	VS8005	1:4 DEMUX at 2.5 Gbps
	VSC864	64x64 Crosspoint Switch

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Watkins-Johnson Defense Division

3333 Hillview Avenue
Palo Alto, CA 94304-1204
415/493-4141

ESTABLISHED: 1957 NO. OF EMPLOYEES: 375

BACKGROUND

Watkins-Johnson Company is engaged in the design, development, manufacturing, and marketing of solid-state amplifiers, receivers, microwave receiving systems, and equipment for surveillance, direction finding, and countermeasures. The Company comprises four divisions and five subsidiaries worldwide. Watkins-Johnson is a member of the ITT/Martin Marietta MIMIC team.

COMPANY EXECUTIVES

Vice President of Defense Group
Keith D. Gilbert

Vice President, Manager of Subsystems Division
Paul Y. Lin

Vice President of Components Division
James L. Schram

Marketing Director
Mal Carabello

PROCESS TECHNOLOGY

The Company uses submicron GaAs MESFET technology.

PRODUCTS

VHF and microwave amps
Oscillators
Mixers
Synthesizers
Subsystems

FACILITIES

The Company's Palo Alto, California, facility has 180,000 square feet, including an 8,000-square-foot clean room. The Scotts Valley, California, facility has approximately 120,000 square feet.

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Safety Issues

Microwave amplifiers may represent sources of dangerous radiation, depending on frequency of operation. Whereas the cancer-causing and other hazardous effects of X-rays have long been known, the real and potential adverse effects of microwave and near-visible radiation are less understood. However, there is evidence that long-term exposure to UV radiation is carcinogenic. Organizations such as the University of Washington School of Medicine are studying the effects of pulsed microwaves on human tissue such as heart muscle.

The problems are complex; for example, the most radiation-resistant microwave-protective suits in a test at 2.5 GHz proved to be less flame-retardant than were other suits having higher resistance to radiation at this frequency. All of the suits tested appeared to provide reasonably good protection above 700 MHz but were not satisfactory at VHF frequencies, which are used for commercial and civil television and communications bands.

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GaAs Discretes—Emerging Technology and Trends

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EMERGING TECHNOLOGY

The new discrete compound semiconductor devices emerging from the Free World's laboratories exhibit record performance. Scaling is progressing below 0.35u gate lengths, resulting in major increases in cutoff frequency. HEMTs are today's high-performance workhorse, but they will soon be replaced with HBT structures where acceptable.

For example, Matsushita's Wireless Research Laboratory has investigated a multiple self-aligned process for AlGaAs/GaAs heterojunction bipolar transistors (HBTs). The process uses one mask for emitters, emitter contacts, emitter contact leads, buried collectors, base contacts, and base contact leads. HBTs with 1 x 20 um^2 emitters, base islands of 4 x 20 um2, base contacts of 1.5 x 20 um2, and O ± implanted buried collectors demonstrated f_T of 54 GHz and fmax of 42 GHz. Base contact-to-emitter spacing was 0.25u. Process refinements are expected to increase the maximum gain available cutoff frequency to a value greater than 100 GHz.

Heterostructure FETs (HFETs) have been built using gate lengths less than 0.25u. Such devices have cutoff frequencies near 170 GHz and maximum oscillation frequencies near 350 GHz.

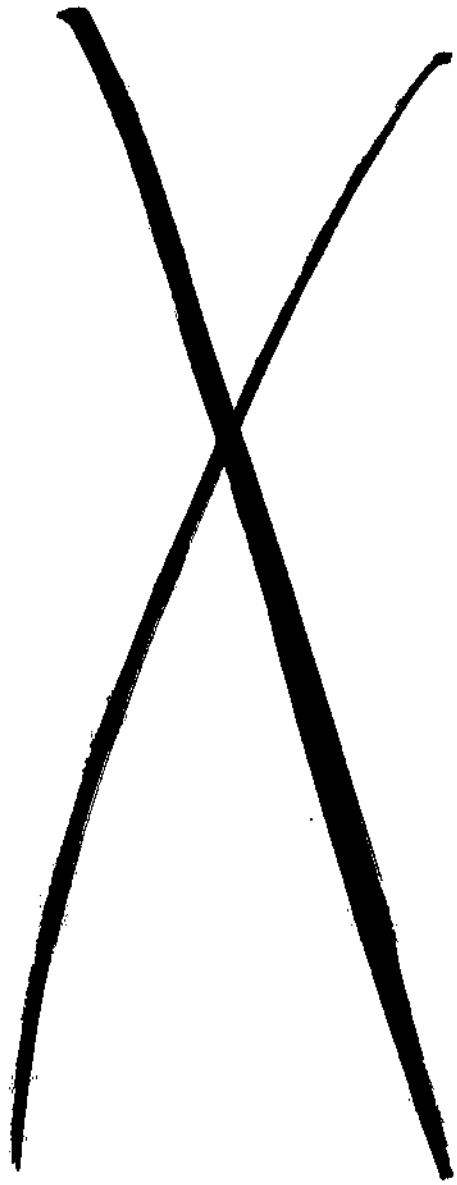
TRENDS

The market for discrete GaAs transistors will continue to evolve, with a steadily widening range of applications as the device costs decline. Present cost structures allow use of GaAs discretes in cellular telephones and other portable consumer-type equipment, and the emergence of millimeter-wave discretes will spur more new applications.

Dataquest believes that the process technology has created a temporary applications gap, which was exacerbated by the temporary halt of GPS satellite launches caused by the Challenger disaster. Recent resumption of GPS satellite launches has spurred development of low-cost equipment for navigation, surveying, and other applications in the frequency bands above 1 GHz. The announcement of Motorola's Iridium system, which will include a constellation of 77 satellites, has created a new market for GaAs discretes for communications. Such applications will benefit from the recent breakthroughs in HEMTs, HBTs, and other discrete GaAs devices.

The size of discrete GaAs transistors limits the available performance. Available lithography technology currently dictates feature sizes greater than 0.1 micron. The present trend is toward increasing performance by refining device structures based on improved materials and epitaxial layering technology. The recent development of HBTs incorporating resonant tunneling devices exemplifies this trend. Another example is the adoption of multiple gate structures in GaAs FETs to improve frequency response.

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GaAs Discretes—Applications and User Issues

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APPLICATIONS

In a typical application, power and small-signal transistors tend to interact as follows:

- As the sensitivity of a small-signal (receiver) device improves, the power (transmitter) device can remain relatively constant.
- As the power increases, the sensitivity can remain unchanged for a given system specification.

Traditionally, microwave discrete devices have been used in hybrid assemblies to implement radar, communications, electronic warfare, and other commercial and military/government hardware. These applications are growing at a rate that allows a phaseover to MMICs for many new designs, while still supporting a growing market for discretes in older designs. However, hybrid is not dying because in some applications, it provides the ultimate customized solution for a given level of technology.

One application of GaAs technology to automotive equipment is for rotation sensing. One such device is the GaAs Hall-effect sensor developed by Siemens. These GaAs and other devices can be designed to function at temperatures well above the physical limits of silicon, allowing use in the engine compartment for such tasks as measuring crankshaft rotation.

Some automakers such as Mercedes-Benz are using Hall sensors on disk brake assemblies to facilitate microprocessor-controlled antiskid braking systems. Others such as Volvo are exploring the use of Hall sensors in active suspension systems.

The present automotive aftermarket consumes millions of GaAs chips annually for radar detectors, which are becoming obsolete as radar makes a transition to lidar for police use in monitoring traffic. New GaAs devices will be required for future detection equipment. Future automotive applications will include GaAs devices for global positioning satellite (GPS) location sensing, collision avoidance, and proximity detection.

USER ISSUES

Some of the user issues involved in the application of GaAs discrete technology to analog/linear functions are similar to those encountered in digital and optoelectronic applications. These issues are discussed in this section.

To Integrate or Not to Integrate?

The issue of choosing a monolithic versus a hybrid approach can be very involved. At microwave frequencies, all passive and active components exhibit some time-variant combination of resistance, inductance, and capacitance. This aggravates the usual chip layout and packaging problems and eliminates many of the options that are otherwise available at lower frequencies.

The degree of integration achievable above 18 GHz is not obvious to most designers, so a key design concept is to proceed with caution and test the assumptions. Often, a hybrid approach is the only achievable solution to a system problem with time constraints. Companies such as Avantek are focusing on this specific area with a tremendous inventory of fully characterized dice and sufficient staffing to provide quick response when faced with short lead-time constraints.

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Decreasing the Risk of System Obsolescence

The advent of cost-effective GaAs analog/linear and digital functions has expanded the users' options to include any desired combination of silicon analog/linear, ECL, TTL, NMOS, BiCMOS, CMOS, and GaAs. Thus the systems house (and each of its competitors) has a wider variety of design approaches than ever before.

The user must carefully make elaborate trade-off studies rather than risk a hardware design to overnight obsolescence by new silicon devices marketed by any one of dozens of suppliers. The astute user will take advantage of the unique properties of GaAs devices in systems approaches that can be made very resistant to obsolescence. Avantek and other suppliers offer both monolithic and hybrid capabilities to support a broad range of design possibilities for the systems houses.

Testing

Parametric testing at speed remains a problem area in GaAs applications, and suppliers have been forced to develop in-house test capability. This area represents a market opportunity for the first company that successfully builds a 90+ GHz test system priced within reach of the hundreds of GaAs users.

International Competition

A major concern among U.S. suppliers of GaAs discrete components is the relative timing of Japanese competitors' market entries. Predatory practices such as those experienced in the silicon DRAM and EPROM markets would have a disastrous effect on U.S. GaAs discrete suppliers. All of the major Japanese suppliers to the communications market have GaAs advanced product developments under way, and the consumer analog/linear device suppliers are not far behind. Japanese suppliers have already attacked some segments of the discrete market and could become very aggressive across the board.

Export Controls

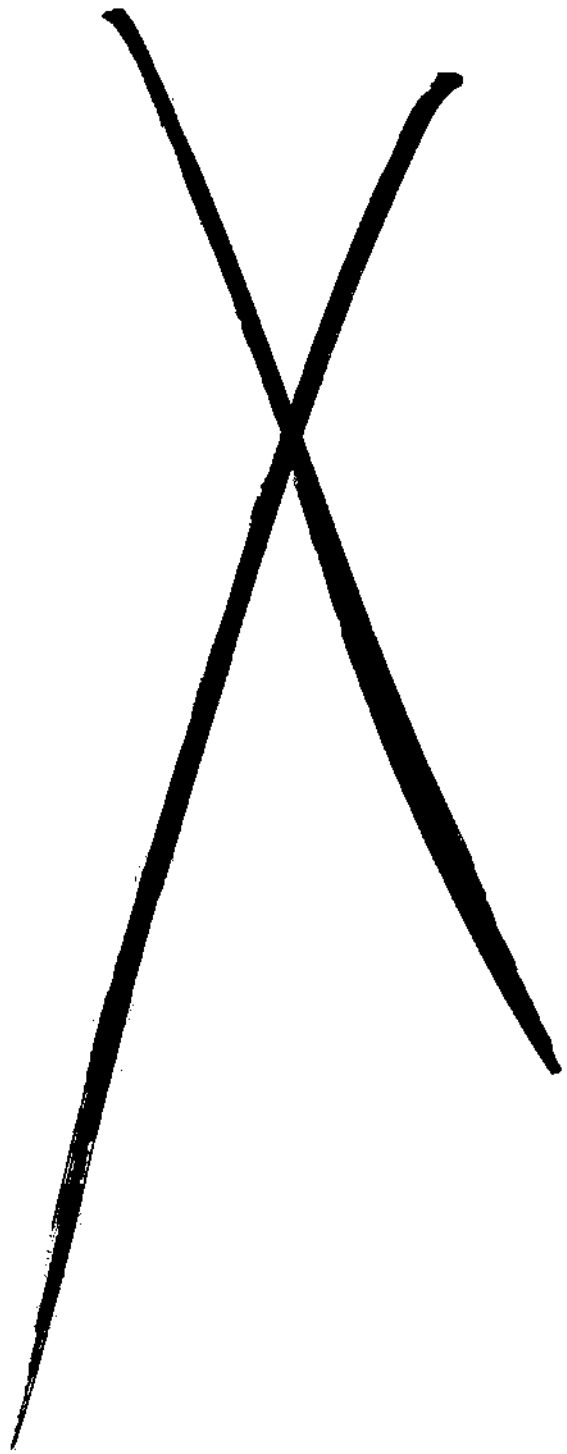
Because of the extensive use of GaAs and other III-V semiconductors in some types of military equipment, export of devices can be a major issue. This is a problem or potential problem for suppliers in any country, not just for the U.S. suppliers.

Some Japan-based potential supplier companies are believed to be withholding GaAs HEMT and HBT merchant market entry until they have met their internal needs for parts for communications equipment and other critical applications. Entering the GaAs HEMT and HBT merchant markets has strengthened Japan's position in the world GaAs discrete marketplace.

Product Availability

The rapidly changing GaAs analog/linear technology has caused rapid obsolescence of many existing device designs. This is causing some suppliers to reevaluate their product portfolios and others to reassess their positions in the microwave and emerging millimeter-wave device marketplaces. Thus the user may face the loss of one or more supply sources and may have to qualify new suppliers as the industry completes its readjustment to the realities of the 1990s.

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GaAs Discretes—Historical Shipment Data

Tables 1 through 5 summarize shipment revenue estimates for GaAs uWave/mmWave discretes by geographic region.

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Table 1

Estimated Worldwide GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	178	228	222	243	291	305
SS Transistors	109	141	135	150	181	188
Power Transistors	59	73	72	77	92	98
Hall Elements, Others	10	14	15	16	18	19

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

Table 2

Estimated U.S. GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	87	112	118	117	131	136
SS Transistors	35	54	61	58	59	60
Power Transistors	51	56	55	57	69	73
Hall Elements, Others	1	2	2	2	3	3

Source: Dataquest (April 1991)

Table 3

Estimated Western European GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	11	14	16	19	22	22
SS Transistors	6	7	8	10	11	11
Power Transistors	4	5	6	7	8	8
Hall Elements, Others	1	2	2	2	3	3

Source: Dataquest (April 1991)

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Table 4

Estimated Japanese GaAs uWave/mmWave Discretes Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	80	102	88	107	138	147
SS Transistors	68	80	66	82	111	117
Power Transistors	4	12	11	13	15	17
Hall Elements, Others	8	10	11	12	12	13

Source: Dataquest (April 1991)

Table 5

Estimated Japanese GaAs uWave/mmWave Discretes Merchant Shipments
(Billions of Yen)

Category	1985	1986	1987	1988	1989	1990
Other Discretes	20.0	17.0	12.7	13.9	19.0	19.8
SS Transistors	17.0	13.4	9.5	10.7	15.3	15.8
Power Transistors	1.0	2.0	1.6	1.7	2.1	2.3
Hall Elements, Others	2.0	1.7	1.6	1.5	1.7	1.8

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (April 1991)

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III-V Optoelectronics—Executive Summary

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INTRODUCTION

Optoelectronics is the science and technology of hardware in which photons cause electron flow or vice versa. Optoelectronic chips contain transducers used between photonic circuit media (such as fiber cable or free space) and electronic media (such as copper wiring or plated circuits); they may also contain amplifiers, logic, and/or other photonic or electronic functions.

Although often treated as if it were a recently created concept, the principles of optoelectronics were demonstrated in 1878 by Alexander Graham Bell in his photophone, which he considered his greatest invention. Two years later, Bell transmitted and received a message over a distance exceeding 200 meters, using a sound-modulated mirror that reflected sunlight onto a selenium photodetector that drove a telephone receiver. There were two main obstacles to early exploitation of the technology: light interference and inadequate transmission media. These difficulties were resolved in principle with the invention of lasers and fiber optics in the 1960s.

This section of the GATA module analyzes optoelectronics products, markets, suppliers, industry structure, competitive behavior, and shipments history. It includes analyses of user issues and a forecast of future markets.

TECHNOLOGY

Optoelectronic ("opto") semiconductors consist of a variety of devices, ranging from single-element discrete light-emitting diode (LED) lamps and sensors to optoelectronic integrated circuits (OEICs) containing thousands of circuit elements. Some CCDs comprise more than 1 million transistors per chip. All such devices are used to convert electronic energy to photonic energy or vice versa. Although some photonic/electronic devices have been developed using silicon as the raw material, the need to integrate a variety of electronic and photonic devices monolithically is the primary reason for using GaAs or some other compound semiconductor material for OEIC implementation. As a result of recent breakthroughs in materials processing and device manufacturing techniques, compound semiconductor opto devices increasingly are impacting the evolution of high-technology products and systems.

Although the vast majority of opto products are fabricated on GaAs or other compound substrates, some sensors and a relatively small percentage of transmitters (e.g., some IR LEDs) are built using silicon wafers. This usage is driven by manufacturing cost considerations. Discrete opto device technology is relatively mature and tends to follow the growth rate of the overall market for semiconductors. This is also true of hybrid opto devices such as optocouplers and interruptors because they are usually built from two discrete devices (an emitter and a sensor). However, the field of OEICs is relatively new, and, recently, its growth rate has accelerated as a result of improved circuit yields and corresponding cost reductions.

PRODUCTS

Dataquest has identified the following categories of compound semiconductor optoelectronic products:

- Discrete LED lamps or single-diode visible indicators
- LED displays consisting of an array or matrix of LEDs

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- LED transmitters that generate visible light or near-visible radiation perpendicular to the plane of the substrate
- LED lasers that generate collimated visible or near-visible radiation parallel to the plane of the substrate
- Sensors or detectors that detect photons and generate electrons proportionally
- Optocouplers or isolators, which are hybrid assemblies used to separate two electrical or electronic circuit paths and provide a high degree of isolation between them
- Interruptors, which are hybrid assemblies used to detect the motion of an object in a medium (e.g., paper moving through a printer)
- Photovoltaic cells, large-area sensors used for energy conversion in power supplies, battery chargers, and similar applications
- OEICs, which contain one or more laser drivers and/or sensors together with electrical analog and/or digital electronic circuits integrated into a single substrate

MARKETS

The worldwide market for discrete optoelectronic devices was $2.6 billion in 1990 and is expected to exceed $4.1 billion in 1995. This market is growing at a long-term rate of approximately 9.2 percent per year and is considered relatively mature.

The integrated optoelectronics device market was $72 million in 1990 and is forecast to grow at 19 percent CAGR through 1995 to more than $170 million. This represents a growth opportunity to companies such as Epitaxx, Lytel, and Optek.

As the market for discrete opto semiconductor functions has matured, price pressure has become more intense, with frequent negotiations and loss of profit margins. The maturation of discrete opto technology caused suppliers such as TRW and General Instrument to reassess their positions in this marketplace. National Semiconductor and TRW optoelectronic product divisions changed ownership during 1986-1987, and others will follow as the industry completes its readjustment to the realities of the 1990s.

A major potential market exists in the applications of GaAs technology to CCD and CMD image sensing. To date, these applications are almost exclusively silicon based.

COMPETITORS

There are approximately 26 North American, 20 Asian, and 9 European suppliers of optoelectronic semiconductors in today's merchant marketplace. Table 1 shows the industry suppliers in mid-1991 by geographic region. (Note: Philips dropped the name "Amprex" in early 1990.)

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Table 1

III-V Optoelectronic Device Suppliers

North America	Japan	Western Europe	ROW
AT&T	Anritsu	ASEA-HAFO	Korean Electronics Corp. (KEC)
BT&D Technologies	Fuji Electric	CIT-Alcatel	OptoTech Corp.
Epitaxx	Fujitsu	Ericsson	
General Electric	Hamamatsu	Philips	
General Optronics	Hitachi	Plessey	
Hewlett-Packard	Kyoto Semiconductor Corp.	Siemens	
Honeywell	Matsushita	Stantel	
ITT	Mitsubishi	Telefunken	
Laser Diode Inc.	NEC	Thomson-CSF	
Lasertron	New JRC		
Lytel	Oki		
M/A COM	Rohm		
Monsanto	Sanken		
Motorola	Sanyo		
Optek Technology	Sharp		
Opto. Diode Corp.	Sony		
OptoTek Ltd.	Stanley		
Ortel	Toshiba		
PCO			
Photonic Integration Research Inc.			
Quality Technologies Corp. (formerly General Instrument)			
Spectra Diode Labs			
Telcom Devices Corp.			
Texas Instruments			
Three-Five Systems Inc. (formerly owned by NSC)			

Source: Dataquest (July 1991)

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ISSUES

Need for OEIC Standards

The designs of specific OEICs may be directly influenced by industry standards in much the same way as electronic ICs were impacted by the evolution of RS-232-C and IEEE-488. Both the suppliers and the users need to keep abreast of evolving standards by participating in standards committee activities as much as possible to avoid surprises necessitating redesigns.

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Maturation of Discrete Optoelectronic Devices

As discrete opto technology matured, it caused suppliers such as TRW and General Instrument to rethink their positions in this marketplace. As the industry matures further, consolidation of suppliers may occur and lead to possible supply problems. The resultant instability concerns opto device customers who may face loss of primary or secondary sources and may incur costs of qualifying alternate vendors.

Product Evolution

Although relatively mature, LEDs and other discretes are undergoing evolution and innovation. Suppliers need to stay abreast of competitive behavior. A recent example is the focus on ZnSe for blue LEDs. Such innovative products offer new opportunities to materials and device suppliers as well as to systems applications.

Interference

The opportunity for electronic and photonic product interaction is increasingly complex. In the past, the FCC in the United States and similar agencies in other countries have set standards to minimize product interactions. For example, the limitation on transmitter power minimizes the chance of a garage door opener or portable telephone inducing errors in commercial aircraft navigation radio equipment, which could cause disastrous results. Adding photonic emitters to household appliances could cause undesirable interactions, and the responsible regulating agency might become backlogged for years before developing an adequate standard to correct the situation. Thus, the need for adequate product testing by the opto device user is becoming more important than ever.

Safety

The human eye is extremely susceptible to damage by lasers, including semiconductor lasers. Lasers can damage other human tissue as well. The damage results from rapid heating caused by the high concentration of energy. The damaging radiation may not be visible.

There is evidence that long-term exposure to UV radiation is carcinogenic. Other evidence raises questions about other possible adverse effects of microwave-frequency radiation. Also, arsenic and some of the other elements and compounds used in opto material and device fabrication are known hazards. Suppliers and users alike should perform sufficient investigations of these areas to avoid any likelihood of personal injuries and to be able to deal with liability claims.

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III-V Optoelectronics—Forecast

Dataquest identifies the value of the optoelectronic market at nearly $2.7 billion in 1990. The market is expected to have a 9.2 percent compound annual growth rate (CAGR) from 1990 through 1995, as shown in Table 1. Growth is fastest in the optoelectronic IC market, at approximately 19 percent over the same time period. Laser devices comprised more than $270 million in 1990, up from $230 million in 1989, and are expected to grow to more than $370 million by 1995.

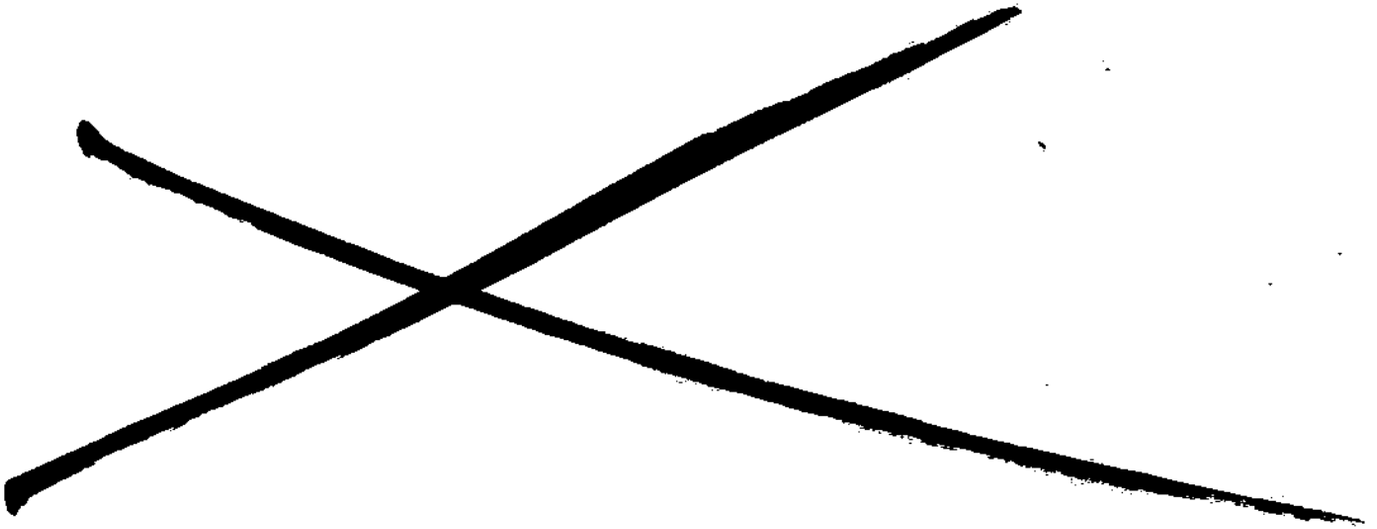
Table 1
Worldwide III-V Optoelectronics Merchant Consumption Forecast
(Millions of Dollars)

Category	1989	1990	1991	1992	1993	1994	1995	CAGR (%) 1990-1995
Total Optoelectronics	2,627	2,687	3,008	3,254	3,560	3,949	4,178	9.2
Discretes and CCDs	2,560	2,615	2,925	3,157	3,445	3,801	4,008	8.9
OEICs	67	72	83	97	125	148	170	18.7

Source: Dataquest (May 1991)

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III-V Optoelectronics—Product Analysis

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LIGHT-EMITTING DIODES

A light-emitting diode (LED) is a p-n heterostructure that emits visible light when electrons or holes injected through the junction collide and reform. They are used in a wide range of electronic products such as indicators, and as emitters in audio and computer CDs, videodisc players, and "laser gun" toys.

LEDs incorporating GaAlAs substrates have the highest visible luminance. Red LEDs are usually made of GaAlAs, GaAsP/GaAs, and GaP. Yellow LEDs are made of InGaP grown epitaxially on GaP or GaAsP substrates. Orange LEDs are made of nitrogen-doped GaAsP/GaP, and the color can be varied from near red to near yellow during manufacture by changing the ratio of arsenic to phosphorous.

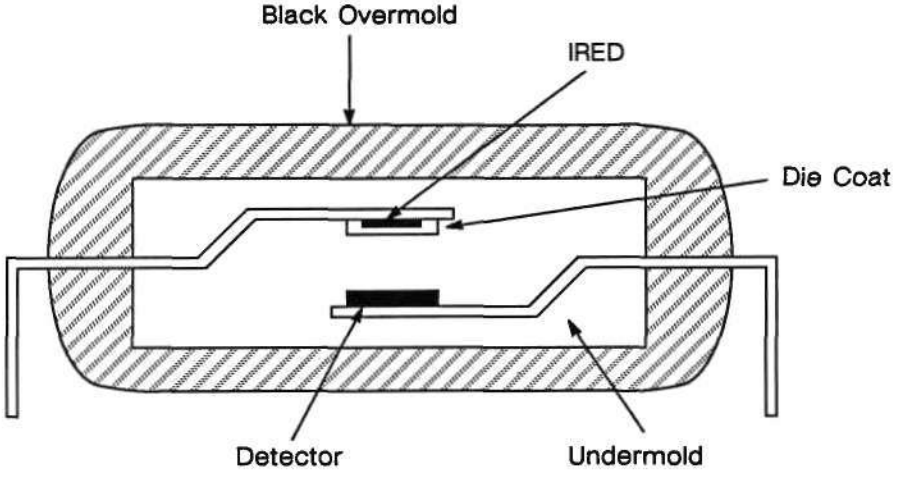
OPTOCOUPLERS

The term "optocoupler" refers to devices that allow one electrical circuit to be isolated from another through an optically transparent medium. This offers the advantage of reduced coupling of electrical noise from one circuit to another, and is sometimes used to reduce electrical hazards such as shock potential. LED laser suppliers usually offer optocouplers in addition to their other products.

Figure 1 shows a cross section of an optocoupler produced by Motorola. The device consists of a GaAs infrared-emitting diode (IRED) and a silicon transistor photodetector separated by an epoxy undermold, located in a black (opaque) package.

Figure 1

Cross Section of an Optocoupler



Source: Dataquest (July 1991)

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OPTICAL COMMUNICATIONS

One of the major driving forces in the evolution of the field of optoelectronics has been the promise of greatly enhanced communications. Research into optocommunication began in 1960 with the availability of laser sources.

Optical communications consist of line-of-sight links and fiber-optic links. Line-of-sight links represent the earliest application of optical communications. As explained later in this section, much development activity transpired before low-loss fibers became practical.

Line-of-Sight Links

Because the early semiconductor lasers were only modestly coherent and fiber optics were relatively inefficient, the first applications of optical techniques to communications were in line-of-sight links. Such links were particularly suitable to space applications over short distances.

Fiber-Optic Links

About ten years of R&D were required after the invention of the laser before optocommunication became practical. The main limitation was lack of availability of low-cost, relatively low-loss fiber for transmission lines. Since then, much progress has been made, and today optical fibers with absorption coefficients near 0.5dB/km can be economically manufactured.

Corning Inc. is the dominant supplier of glass fiber for fiber-optic links in the merchant market. Corning has joint ventures with other major participants in the optoelectronic field, including Plessey and Siemens (i.e., PCO and Siecor).

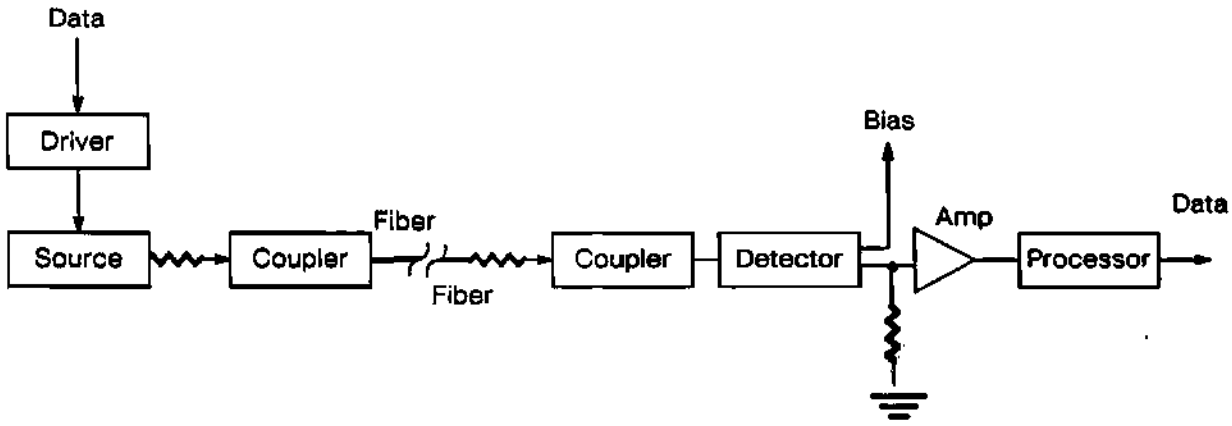
A typical fiber-optic transmission link is shown in Figure 2. GaAs devices are used at the transmit and receive ends of the link. Typically, an LED laser serves as the transmitter and an APD performs the receiver light-to-electrical signal conversion function. Multiplexing and demultiplexing of two or more signals on the same channel may also be accomplished with GaAs devices such as those now available from GigaBit Logic and other suppliers.

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Figure 2

Typical Fiber-Optic Transmission Link



Source: Dataquest (July 1991)

Direct Detection

In a fiber-optic communication link involving direct detecting, the photodetector converts the optical pulses representing digital data directly into an electrical signal. This method of optocommunications offered the highest possible performance until 1985. The longest link employing direct detection without a repeater is approximately 204km.

Coherent Detection

Coherent detection promises communications over single fibers at multi-GHz rates and channel densities of 1,000 times those possible using direct detection. Although coherent detection (in the form of heterodyning) has been used in radio communications since the 1930s, it did not become feasible in optical communications until highly coherent semiconductor lasers and low-loss fiber cable were developed and used together in a system.

Starting in 1985, experimental coherent detection fiber-optic communication systems have exceeded the performance of direct detection systems. AT&T has achieved 2-GHz transmission and reception over a 150km unamplified link. This is the highest rate and rate-distance product yet reported. NEC holds the distance record of 290km, at a much lower frequency of 400 MHz and a lower rate-distance product of 116 (versus AT&T's 300).

Several groups are actively engaged in development of coherent optical communications, and the number is expected to increase rapidly. Table 1 summarizes progress in coherent optolink experiments.

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Table 1

Coherent Detection Tests

Company	Modulation Method*	Rate (Gbps)	Distance (km)	Rate x Distance
British Tel.	FSK	0.140	200	28
NEC	FSK	0.280	204	57
AT&T	PSK	0.400	257	103
NEC	FSK	0.400	290	116
Bellcore	FSK	0.560	38	21
AT&T	PSK	1.0	200	200
Bellcore	FSK	1.0	100	100
AT&T	FSK	2.0	150	300

*FSK = Frequency shift keying
PSK = Phase shift keying
Source: AT&T

Much research is needed before this technology will be ready for the commercial market. A key element is the tunable laser, which is essential for practical heterodyning. Progress in III-V lasers has been made by AT&T Bell Labs and NEC; both have demonstrated InGaAsP lasers tunable over more than 5nm for a bandwidth in excess of 700 GHz. Additional work is also needed in coding schemes and in automatic adjustment of fiber polarization.

OPTOCOMMUNICATION SEMICONDUCTOR DEVICES

Semiconductors used in optical communications include LED lasers, photodetectors, repeaters, and optoelectronic ICs. LED lasers are used as transmitters and as receiver local oscillators in coherent links, photodetectors are used as receivers; repeaters allow extending link lengths; and OEICs are used to enhance performance and reduce cost.

LED Lasers

The most commonly used signal source for optical transmission is an LED laser. GaAs, AlGaAs, InGaAsP, and other III-V compounds are used in manufacturing LED lasers, depending on the desired electrical and optical characteristics. In mid-1983, NEC reported testing a 1.3u InGaAsP/InP LED capable of transmitting data 2.7km in optical fiber at 500Mbps using a driving current of 100mA.

LED laser suppliers include CIT-Alcatel, Hamamatsu, Lytel, PCO, RCA, Siemens, Sony, Thomson-CSF, and the companies listed in Table 2. The table exemplifies typical characteristics of several suppliers' products. Figure 3 shows an example of a III-V compound laser diode structure.

The most efficient means of optical coupling is to connect the glass fiber directly to the LED light source. An example of this is shown in Figure 4.

Siemens has reported results of its development work in the area of monolithic phase-locked GaAlAs laser arrays. Power conversion efficiency of 36 percent was reported for a high-powered array grown by MOVPE. Siemens has also developed an LCW laser for reduction of "chirp" (linewidth broadening at 1.55u wavelength).

By December 1990, at least one company was actively developing laser chips that are expected to sell for less than ten cents in volume in the early 1990s.

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Table 2

Representative Communications LED Laser Suppliers and Products

Company	Compound	Wavelength (nm)	Type CW, P[1]	Mode S, M[2]
Anritsu	InGaAsP	1,300	CW	M
Fujitsu	InGaAsP	1,300	CW	M
General Optronics	GaAlAs	800-850	CW	M
	InGaAsP	1,300	CW	S, M
Lasertron	InGaAsP	1,200, 1,300, 1,530	CW, P	S, M
M/A-COM				
	GaAs	850, 1,300	CW, P	S, M
Mitsubishi	GaAlAs	780, 815, 850	CW	S, M
	InGaAsP	1,300	CW	S, M
NEC	GaAlAs	780, 850	CW	S, M
	InGaAsP	1,200, 1,300	CW	S, M
Opto-Electronics	GaAs	904	P	M
	GaAlAs	850	P	M
	InGaAsP	1,300, 1,500	P	M
Ortel	GaAlAs	820-860	CW	S, M
Philips	InGaAsP	1,300	CW	M
	GaAlAs	850	CW	M
Spectra Diode Labs	GaAlAs	780-870	CW, P	S, M
Stantel	GaAlAs	850	CW	M
	InGaAsP	1,300	CW	S, M
Telefunken	GaAlAs	790-850	CW	M

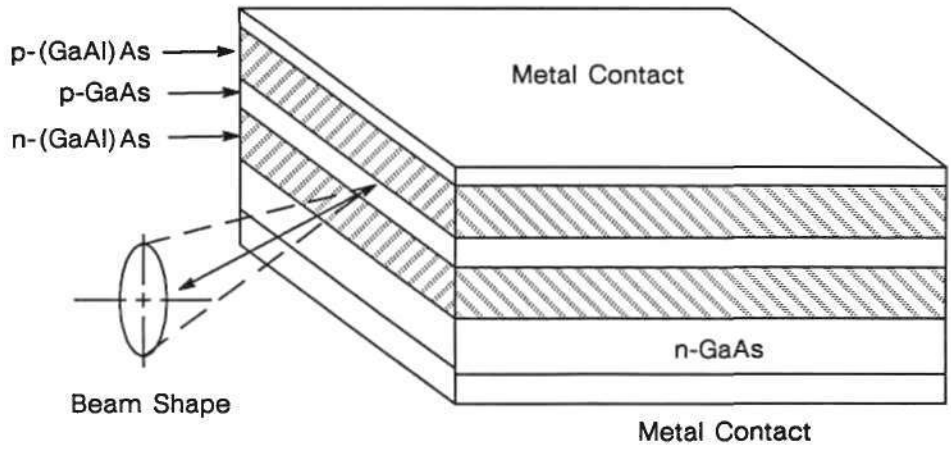
[1] CW = continuous wave, P = pulsed types
[2] S = single-mode, M = multimode operation
Source: Dataquest (July 1991)

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Figure 3

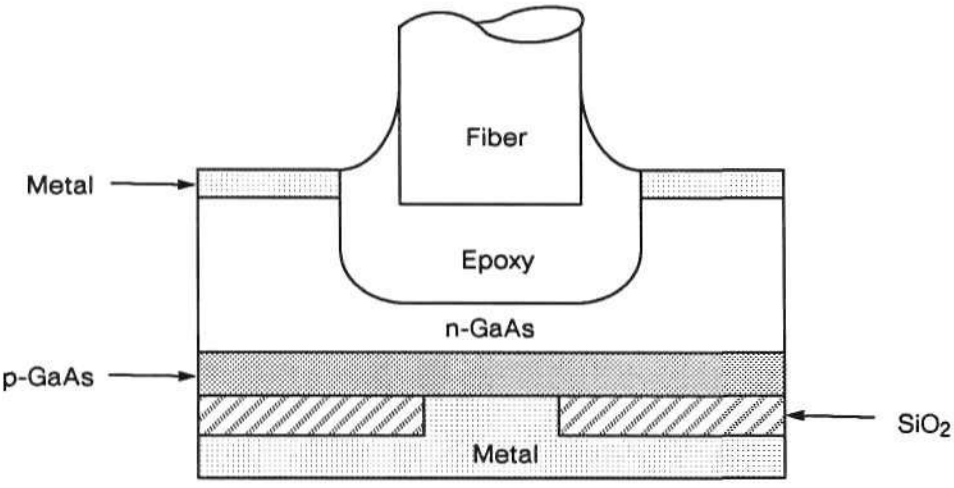
Diagram of Laser Diode



Source: Dataquest (July 1991)

Figure 4

LED to Fiber-Optic Coupling



Source: Dataquest (July 1991)

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Photodetectors (Optical Sensors)

Photodetectors are devices that convert optical signals into equivalent electrical waveforms. At frequencies above 1 GHz, avalanche photodiodes (APDs) are usually used for this purpose, having a regeneration time ranging near 10^{-10} seconds (100ps). Suppliers of GaAs detectors include GE/RCA, M/A COM, Motorola, PCO, and III-V Semiconductors Inc. Figure 5 shows a cross section of an InGaAs/InP photodetector.

Repeaters

Optical repeaters are used on transmission lines exceeding the length allowable for a given transmitter power. The insertion of repeaters allows regeneration of the transmitted signal to maintain communications integrity over any required distance. A typical repeater consists of a receiver containing a detector, an amplifier, resynchronization circuitry if required, and a transmitter. Two repeaters are required at each regeneration point for bidirectional communications.

Optoelectronic ICs (OEICs)

Because optical components can be manufactured on GaAs substrates, it is possible to build integrated optoelectronic chips that cannot be constructed in silicon. This creates new opportunities for semiconductors in a rapidly growing end market. IBM has done work in this area that is expected to lead to systems having optical interconnection of chips, including optical power distribution.

AT&T remains the leader in OEIC development ad production. Other OEIC suppliers include BT&D, Fujitsu, NEC, and Rockwell as well as several other companies.

In 1990, Boeing Aerospace developed and demonstrated integrated HFETs and MSM photodetectors on InP substrates. The 1.0u gate-length HFETs had cutoff frequency of 30GHz. Boeing expects to extend the technology above 100 GHz.

PHOTOVOLTAIC CELLS

The various space programs have accelerated III-V solar cell technology. The advantages of GaAs solar cells over silicon in a space environment include the following:

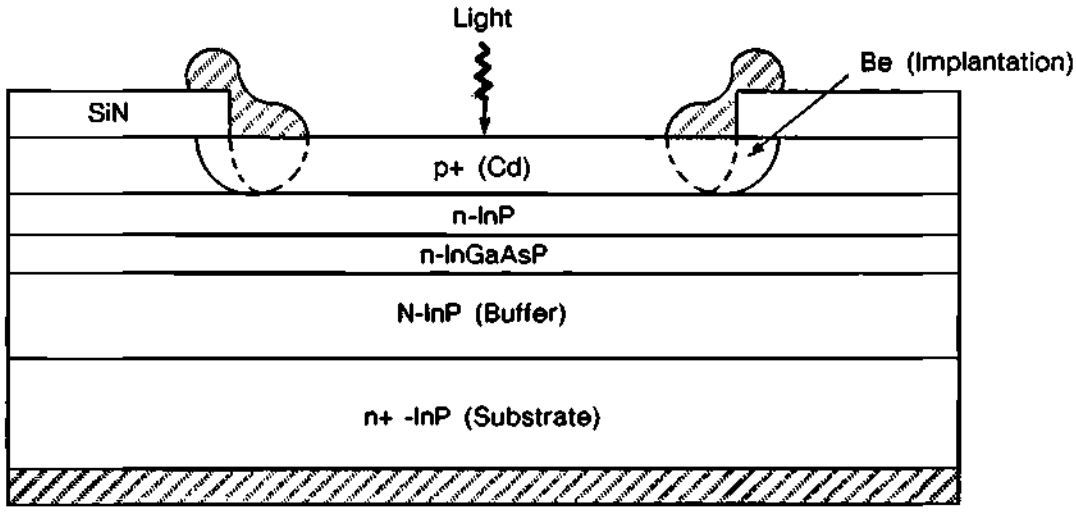
- Superior resistance to heat
- Higher tolerance to radiation
- Increased per-cell power output
- Smaller, lighter cells

Varian has developed a 2 x 2cm solar cell with 21 percent efficiency attainable in a space environment. This approaches the theoretical limit attainable with GaAs and compares favorably with the maximum possible of 14.5 percent for silicon. At 60 to 80°C, the efficiency of the GaAs device is still 19 percent, compared with 9 percent for silicon under similar conditions.

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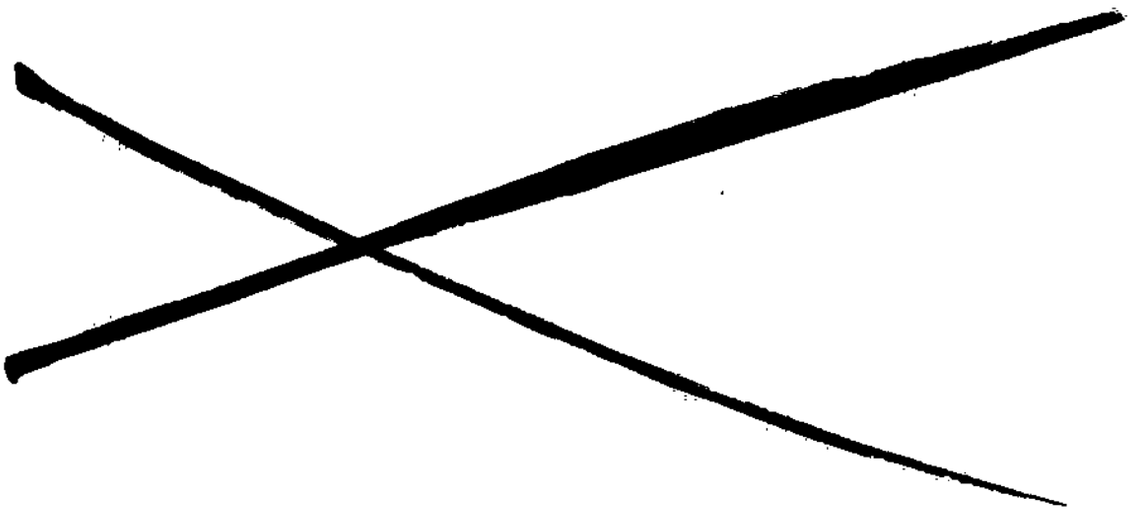
Figure 5

InGaAs/InP Photodetector



Source: Dataquest (July 1991)

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III-V Optoelectronics—Competitive Analysis

Table 1 lists the major optoelectronic device suppliers presently serving the merchant marketplace. Optek Technology became a public company in mid-1987, and Quality Semiconductor purchased the General Instrument Opto Division in late 1987. BT&D Technologies is a joint venture of British Telecom and Du Pont.

Table 1

1991 Optoelectronic Device Suppliers

North America	Japan	Western Europe	ROW
AT&T	Anritsu	ASEA-HAFO	Korean Electronics Corp. (KEC)
BT&D Technologies	Fuji Electric	CIT-Alcatel	OptoTech Corp.
Epitaxx	Fujitsu	Ericsson	
General Electric	Hamamatsu	Philips	
General Optronics	Hitachi	Plessey	
Hewlett-Packard	Kyoto Semiconductor Corp.	Siemens	
Honeywell	Matsushita	Stantel	
ITT	Mitsubishi	Telefunken	
Laser Diode Inc.	NEC	Thomson-CSF	
Lasertron	New JRC		
Lytel	Oki		
M/A COM	Rohm		
Monsanto	Sanken		
Motorola	Sanyo		
Optek Technology	Sharp		
Opto Diode Corp.	Sony		
OptoTek Ltd.	Stanley		
Ortel	Toshiba		
PCO			
Photonic Integration Research Inc.			
Quality Technologies Corp. (formerly General Instrument)			
Spectra Diode Labs			
Telcom Devices Corp.			
Texas Instruments			
Three-Five Systems Inc. (formerly owned by NSC)			

Source: Dataquest (July 1991)

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MARKET COMPETITION

The optoelectronic market is heavily dominated by Japanese suppliers, which gained 1.3 percent of market share in 1989. Dataquest market share statistics, shown in Table 2, indicate that more than 70 percent of 1989's $2.3 billion worldwide optoelectronic market was supplied by Japanese manufacturers. The Japanese dominate four sectors—lamps, displays, optocouplers, and other opto, including lasers for consumer applications. AT&T is the leading producer of OEICs.

Many U.S. suppliers have left the opto market. Those that remain do not have very significant overall sales, with the exception of Hewlett-Packard (HP) and Optek. HP held the position of leading worldwide supplier of optoelectronics until 1986, when it was displaced by Sharp, mainly as a result of an exchange-rate phenomenon. HP is currently number three worldwide in sales of opto and the major supplier to the U.S. market. Optek has grown its market share primarily by acquisition.

Japanese suppliers have grown their opto business since 1987 at a 22 percent compound annual growth rate (CAGR). Part of Sharp's 1986 ascent to the number one position was due to the devaluation of the dollar against the yen. Of the Japanese suppliers, six companies have sales of more than $90 million. These are, in order of rank, Sharp, Matsushita, Sony, Toshiba, Fujitsu, and Rohm. These companies' production of opto devices supports large sales for their affiliated consumer products divisions.

The trend of the European company base growth closely followed the worldwide opto market at more than 13 percent between 1980 and 1987, declining to 9.6 percent in 1989. Siemens and Telefunken Electronic are the prominent European suppliers, with respective sales of $97 million and $76 million.

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Table 2

Estimated Worldwide Optoelectronic Market Share

	1980	1981	1982	1983	1984
Percentage of Total	100.0	100.0	100.0	100.0	100.0
U.S. Companies	58.2	48.7	47.3	40.6	39.5
G.E. Solid State (RCA)	3.2	3.0	2.9	3.0	3.0
General Instrument	6.4	5.0	4.5	4.3	4.0
Hewlett-Packard	10.3	8.8	9.5	9.9	11.1
Honeywell	0	2.3	2.4	2.4	1.2
ITT	0.1	0.1	0	0	0
International Rectifier	0.3	0.3	0.2	0.3	0
Litronix	2.8	2.8	2.8	0	0
Motorola	1.2	1.1	1.1	1.5	1.5
National (Fairchild)	5.8	3.6	2.9	1.7	1.5
Spectronics	2.5	0	0	0	0
Texas Instruments	12.2	8.8	7.3	5.4	3.9
TRW	4.4	4.5	4.1	4.1	5.0
Other U.S. Companies	9.1	8.4	9.5	8.1	7.4
Japanese Companies	28.2	41.0	41.1	48.9	48.8
Fuji Electric	2.9	0.6	0.9	0.9	0.9
Fujitsu	1.9	1.9	1.8	3.5	4.1
Hitachi	2.9	3.8	3.6	3.4	4.1
Matsushita	2.6	3.6	3.8	4.5	6.9
Mitsubishi	0	0	0.2	0.2	1.0
NEC	3.0	2.6	2.7	2.7	2.7
New JRC	0	0	0	0	0
Oki	0	0.6	0.5	1.0	1.2
Rohm	1.6	1.6	1.6	1.9	2.3
Sanken	1.0	1.1	1.1	1.1	0.5
Sanyo	3.0	3.9	3.8	4.6	3.5
Sharp	0	7.8	9.4	11.4	9.0
Sony	0	0	0	0.9	1.0
Stanley	3.0	3.3	3.2	3.1	0
Toshiba	8.1	9.5	8.4	9.7	8.4
Other Japanese Companies	1.0	3.9	3.4	3.4	3.3
Western European Companies	13.6	10.3	1.3	10.2	11.4
ASEA-HAFO	0.1	0.1	0.1	0.3	0.3
Philips-Signetics	3.3	2.4	2.3	1.9	1.4
Plessey	0.6	0.4	0.4	0.3	0.5
Siemens	7.3	4.5	4.6	4.1	5.5
Telefunken Electronic	1.9	2.3	3.0	3.0	3.0
Thomson	0	0	0	0	0
Other European Companies	0.4	0.6	0.9	0.7	0.7
ROW Companies	0	0	0.2	0.3	0.3
Korean Electronics Corporation	0	0	0.1	0.2	0.2
Other ROW Companies	0	0	0.1	0.1	0.1

(Continued)

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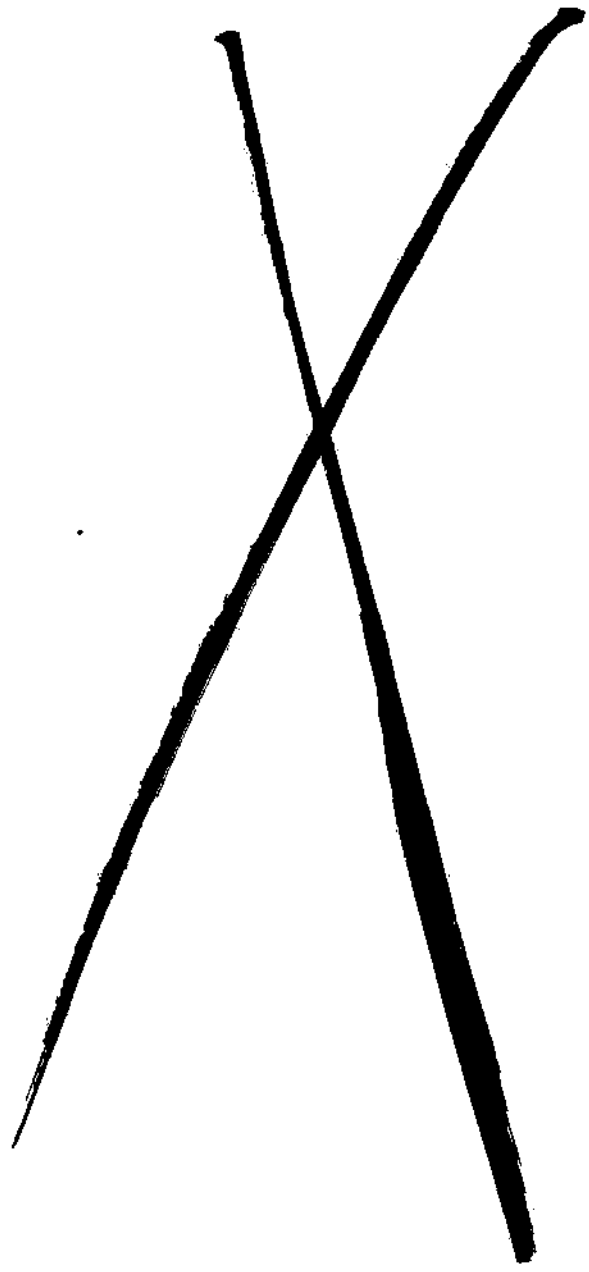
Table 2 (Continued)

Estimated Worldwide Optoelectronic Market Share

	1985	1986	1987	1988	1989	1990
Percentage of Total	100.0	100.0	100.0	100.0	100.0	100.0
U.S. Companies	36.4	29.7	26.4	19.5	17.4	17.0
AT&T	0	0	0.4	0.5	0.4	0.5
G.E. Solid State (RCA)	2.3	2.0	2.0	0	0	0
General Instrument	3.1	2.4	1.9	0	0	0
Hewlett-Packard	13.0	10.3	10.1	9.8	8.1	8.3
Honeywell	2.4	2.2	1.6	1.4	1.2	0.9
ITT	0	0	0	0	0	0
International Rectifier	0	0	0	0	0	0
Litronix	0	0	0	0	0	0
Motorola	1.3	1.1	1.3	1.1	1.0	1.0
National (Fairchild)	0.6	0.4	0.1	0	0	0
Optek	NA	NA	NA	NA	2.9	1.3
Quality Technologies	-	-	-	1.8	1.4	2.5
Texas Instruments	2.6	2.1	2.1	1.8	1.4	1.2
TRW	3.6	2.4	2.3	0	0	0
Other U.S. Companies	7.4	5.7	5.0	4.9	1.2	2.4
Japanese Companies	49.9	57.8	60.5	69.3	73.0	72.0
Fuji Electric	0.8	0.4	0.2	0.1	0.1	0
Fujitsu	3.4	3.8	3.8	4.8	4.4	4.6
Hitachi	3.3	3.7	3.7	3.2	2.5	2.6
Matsushita	6.6	7.8	8.7	8.2	11.6	12.1
Mitsubishi	1.4	1.8	1.3	1.2	1.1	1.2
NEC	2.4	2.8	2.8	4.0	4.6	4.6
New JRC	0	0.6	0.7	0.7	0.5	0.5
Oki	1.1	1.1	1.4	1.7	1.3	1.2
Rohm	2.7	3.5	3.5	5.0	3.7	3.9
Sanken	0.5	0.6	0.7	0.9	0.7	0.7
Sanyo	3.1	3.0	4.6	2.8	6.1	6.3
Sharp	10.0	12.2	12.1	13.1	12.5	12.6
Sony	4.3	7.1	7.5	10.0	9.5	10.0
Toshiba	7.5	6.7	6.9	9.9	11.7	11.6
Other Japanese Companies	2.9	2.7	2.7	3.8	2.7	0.1
Western European Companies	13.2	12.0	12.5	10.9	9.3	9.9
ASEA-HAFO	0.4	0.4	0.4	0	0.3	0.4
Philips-Signetics	2.0	1.7	1.8	1.1	0.9	1.2
Plessey	0.8	1.0	0.9	1.0	0	0
Siemens	5.9	5.3	5.2	4.6	4.4	4.9
Telefunken Electronic	3.2	3.6	3.6	3.4	3.0	2.9
Thomson	0.3	0.3	0	0	0	0
Other European Companies	0.7	0.6	0.5	0.8	0.7	0.5
ROW Companies	0.4	0.5	0.5	0.2	0.3	1.0
Korean Electronics Corporation	0.2	0.1	0.2	0.2	0.3	0.3
Other ROW Companies	0.2	0.4	0.3	0	0	0.7

Note: Some columns do not add to totals shown because of rounding.
NA = Not available
Source: Dataquest (July 1991)

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III-V Optoelectronics—Emerging Technology and Trends

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EMERGING TECHNOLOGY

Opto device technology is finding its way into applications where cost reduction via technology substitution rather than performance is a driving factor. For example, Stanley Electric Co. Ltd. now supplies Nissan Motor Co. Ltd. with LED high-mounted brake lights for the Z-model sports cars. This is the first use of LEDs for exterior illuminators on automobiles. The initial shipment rate was 6,000 units per month. Stanley intends to pursue other auto makers worldwide, including the "big three" U.S. companies.

The development of optoelectronic ICs is in its infancy. Some progress already has been made in communications systems, however, as discussed elsewhere in this module. Opto ICs will become increasingly complex as yields and chip costs are reduced, and at a rate that will closely match that of digICs for data processing equipment applications as sufficient demand develops.

The ability to integrate lasers into electronic circuits monolithically is expected to spawn a new generation of bus driver/receiver chips, for use within data processor subassemblies. This concept has been described in the open literature for some time. Microwave power distribution among surface-mount chips may also prove feasible and cost-effective for some applications, eliminating a major source of noise in present system designs. IBM made a technical disclosure in this area more than five years ago.

The availability of low-loss plastic fiber has attracted the interest of automobile manufacturers. Standards are now being developed that will allow replacement of copper cable with plastic fiber in the automobile of the future. This replacement is driven by two factors: reliability, to replace the large number of wires (30 or more) connecting the front door (driver's side) to the chassis; and cost, to eliminate the 3,000 to 7,000 feet of wire in the average automobile.

TRENDS

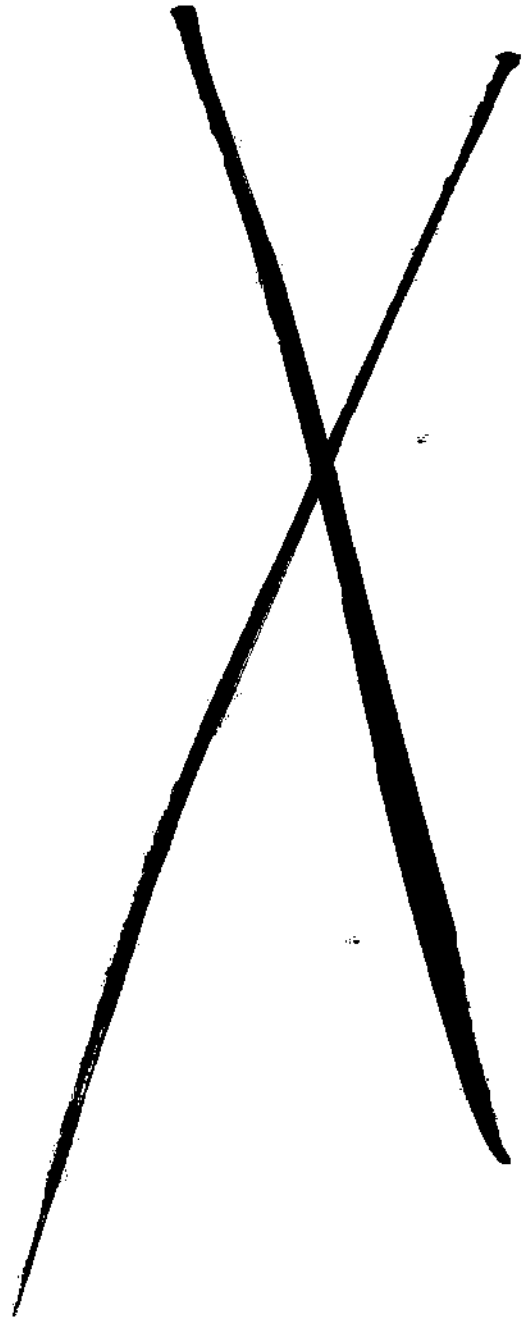
Almost all discrete optoelectronic devices have become commodity products, with evolutionary changes such as color variations of LEDs driving product development. A major exception is the laser diode, which is experiencing significant design activity and a demand level sufficient to support a small number of emerging start-up companies. For example, Lytel expects to capitalize on the demand for high-quality, cost-effective lasers for communications and other applications.

Integrated optoelectronic ICs represent a trend toward cost-effective vision systems for robotics applications. Dataquest believes that the advances made in IR transmitter-receiver circuits coupled with DSP chip evolution will lead to a new generation of robotics equipment for automated production/assembly lines and similar applications.

Integrated optoelectronics are already cost-effective in certain communications applications requiring compact repeater circuits, such as undersea cables. Evolution of this class of chips will prove effective for a range of telecommunications hardware, including both LANs and long lines.

Miniaturization of various types of optoelectronic probes and sensors has allowed development of new procedures in medicine, including surgery. Dataquest expects this trend to lead to innovative concepts in the healing arts.

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III-V Optoelectronics—Applications and User Issues

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APPLICATIONS

The unique properties of optoelectronic GaAs and other III-V compound semiconductors allow solutions to technical problems that were heretofore not economically solvable. Military and government applications including aerospace provided the initial impetus for compound semiconductor technology development. These included radar, satellite communications, electronic warfare, electronic countermeasures, smart munitions, surveillance, and high-speed signal processing.

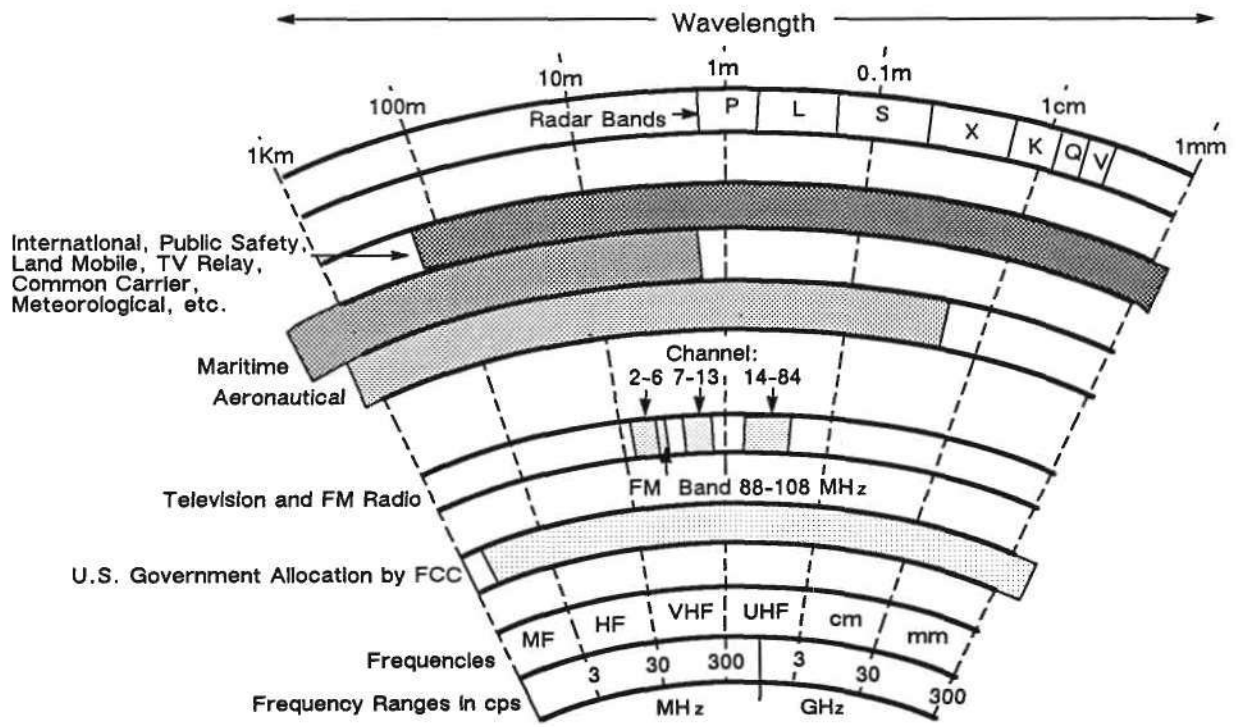
Since the early 1960s, interconnection pins have been more expensive than transistors on an IC chip. The high price and the never-ending demand for lower system cost have led to widespread development and deployment of multilayer substrate technology. Because silicon is increasingly less expensive than copper, a similar revolution is now under way in the interconnection arena: the replacement of copper wire and plated circuit paths with glass-fiber interconnects. Because glass fiber transmits photons and insulates against electron flow, opto circuits will be required. This requirement in turn is leading to optoelectronic chip developments, dictating the replacement of electronic interface circuits with photonics.

This section gives examples of the growing number of diverse applications for GaAs and other III-V compound semiconductors, many of which are shown in Figure 1. The problem of interference among applications is increasingly acute as the frequency spectrum becomes consumed; precise control of operating frequencies and radiation patterns are major system design considerations. As further cost improvements are realized, end uses are increasingly extending into the full spectrum of markets—telecommunications, computer, instrumentation, CAD/CAE/CAM, artificial intelligence, robotics, military/aerospace, automotive, and consumer.

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Figure 1

Applications by Operating Frequency



Note: Only portions of the indicated bands are allocated as shown, to avoid frequency clutter

Source: Aztek Associates

Communications

The communications applications of III-V compound devices include the broad categories of fiber-optic links and microwave radio links. Each imposes different demands on the technology, and new companies were formed to seek market advantages in each area.

In all communications systems, parallel-to-serial and serial-to-parallel conversions are used to minimize the number (and therefore cost) of links. This creates a large demand for high-speed multiplexing and demultiplexing circuits and is a driving force in GaAs chip development. Additional demand is created by the need for very fast coders and decoders for serial bit streams. Such functions readily lend themselves to GaAs implementation. For example, in fiber-optic transmission systems, a line code is often used to achieve an equal distribution of 1s and 0s to optimize performance over long distances. Because this line code adds redundancy to the signal, it can be used to monitor the link for bit errors. The low I/O count and high bit rates involved, coupled with the real-time nature of these functions, dictate the use of a highly exotic version of silicon technology or a straightforward, loose-tolerance approach with GaAs technology.

The many organizations presently involved in this field include ITT, GE, and the Center for Digital Systems Research (Research Triangle Park, North Carolina). A device developed by ITT features a 144-gate error-detection circuit that has been tested at 2.5 GHz and has experienced less

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than 12 percent speed degradation when operated at 125°C. The chip was designed, fabricated, and tested by a team of engineers from ITT Standard Telefon OG Kabelfabrik A/S (Oslo, Norway) and ITT GaAs Technology Center (Roanoke, Virginia).

An OEIC chip developed by GE incorporates an encoder, laser driver, optical detector, and decode logic; the die size is 45 mils by 90 mils. TriQuint fabricated the GE circuit using the 1u E/D process, as part of a multichip project. The first lot of wafers exhibited combined transceiver yields of 65, 70, and 82 percent for the three best wafers.

Fiber Optics—Long Lines and LANs

Since 1984, explosive growth has occurred in the fiber-optics field. The number of suppliers of lasers, LED drivers, detectors, and sensors to this market approximately doubled in less than two years (1984 to 1986) and continued to increase through 1990. The advantages of fiber-optic communications include:

- Freedom from disturbance by external electromagnetic sources
- Immunity to crosstalk
- Unidirectional signal flow; minimal reflection problems
- Ground loops and offset voltages eliminated
- Data transmission rates in excess of 4 GHz
- Simplified signal multiplexing
- Lower losses and less power consumption
- Enhanced security against "tapping"
- Reduced electrical hazards—no arcing or sparking
- Resistance to harsh environment
- Less cross-sectional area and weight and more ruggedness than electrical cable
- Reduced cable costs

Figure 2 shows a typical fiber-optic communications link and illustrates the uses of III-V devices in such a system. Multimode fiber cables, driven and sensed by GaAs or other III-V compound semiconductors, are often used in LAN and short-haul links. Monomode fiber-optic cable systems are used primarily in high-capacity, long-haul trunk routes and for underwater links.

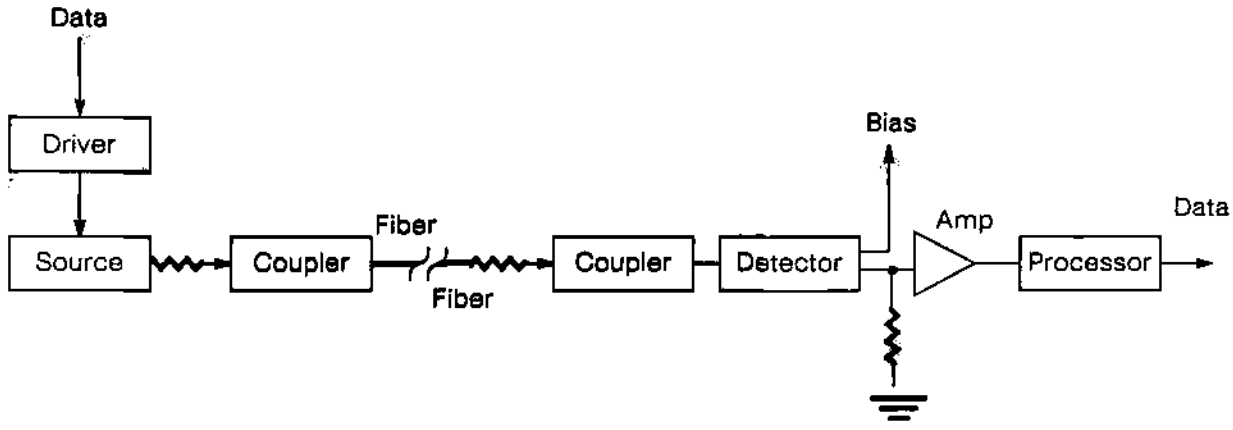
A comparison of various LAN interconnect media is presented in Table 1. The range of unrepeated fiber-optic transmissions is being extended rapidly as companies race to gain market advantage; this figure doubled in less than two years to 90km. This, coupled with the major cost and security differentials with respect to IR and microwave radiation, makes fiber the medium of choice for the foreseeable future.

An increasing number of fiber-optic system suppliers are positioning themselves for growth in the data communications market, an area expected to expand by ten times during the next four to six years. In 1984, AT&T began marketing a LAN system aimed at facilities with networks up to 1km in length and now offers a product line that can handle 3km and longer networks.

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Figure 2

Fiber-Optic Communications Link



Source: Dataquest (July 1991)

Table 1

Comparison of LAN and WAN Media

Medium	Bandwidth	Range	Security	Noise Immunity	Cost	Notes
Twisted Pair (Shielded)	100 KHz	1.2km	Fair	Very good	Low	Limited range
Twinax	200 MHz	1km	Fair	Very good	High	Controlled Z; can be 802-compatible
Ribbon Cable	10 MHz	0.1km	Fair	Poor	High	Shielding available
Coaxial Cable	400 MHz	2km	Fair	Fair	Very high	Can be 802-compatible
Fiber Optics	10 GHz	150km	Excellent	Excellent	Low	Costs continuing to decline
Telephone Line (PABX, PBX)	60 KHz		Poor	Poor	Low	Low cost, installed base
Infrared (Radiation)	20 MHz	0.3km	Fair	Good	Low	Line of sight, reduced range in fog
Microwave (Radiation)	100 MHz	50km	Poor	Poor	High	Line of sight, subject to scatter; link loss depends on antenna size
	18 GHz	10km	Fair	Poor	High	Line of sight, subject to scatter; link loss depends on antenna size

Source: Dataquest (July 1991)

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In the United States, Bell Labs has developed a 44.7-Mbps fiber-optic communication system, manufactured by Western Electric (now AT&T Technologies). Known as the FT3 Lightwave Digital Transmission System, it is used primarily for trunk applications in metropolitan areas. The first installations were in Atlanta, Georgia, in 1976 and Chicago, Illinois, in 1977. The fiber is 50u core and 125u cladding. Twelve fibers are used per ribbon and 12 ribbons are used per cable. A GaAlAs laser source is used, generating a binary coded signal of 0.5mW at 0.825u. The detector is a silicon APD. Splices are made using etched V-grove silicon chips at the factory and via biconic, molded plastic connectors in the field. Repeator spacings are 6.6 to 10km. LED sources have been used on shorter links.

In the United Kingdom, two trial systems were set up in 1977: STL/STC, Hitchin to Stevenage, 9km; and BPO (now British Telecom), Martlesham to Kesgrave, 5.75km. The STL/STC link used silicon junction technology; the BPO link used a GaAs MESFET transmitter. The BPO link was later extended 7.25km to Ipswich using LED and laser sources. Based on system success, British Telecom ordered 10,000km of a combination of 1.3u multimode fiber and monomode fiber cables for its second-generation system.

In 1985, Philips installed a fiber-optic LAN system, called Philan, in its Geldrop, the Netherlands, project center. The system allows simultaneous TDM transmission of voice and data and incorporates error control and flow control. Philan uses a meandering-ring structure to link several hundred user stations over a span of 6km. It functions both as a circuit switching net for continuous speech, video, and machine dialogues and as a packet-switching net for intermittent traffic among various equipment.

AT&T has a service with a long-haul link called the FT Series G, which is designed to operate at a 1.7-GHz bit rate. It has been tested between Philadelphia and Wayne, Pennsylvania, and can handle 24,000 simultaneous calls on a single pair of glass fibers. The GaAs regenerator circuits are spaced at 24-mile intervals. In another test, AT&T transmitted signals at a 1-GHz bit rate through a 150km long, single-mode fiber.

A fiber-optic network called TEL (Trans Europe Line) is planned to link Frankfurt, Germany, to Moscow, Budapest, and points between. The $130 million system is expected to be completed in 1993.

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Aircraft Applications

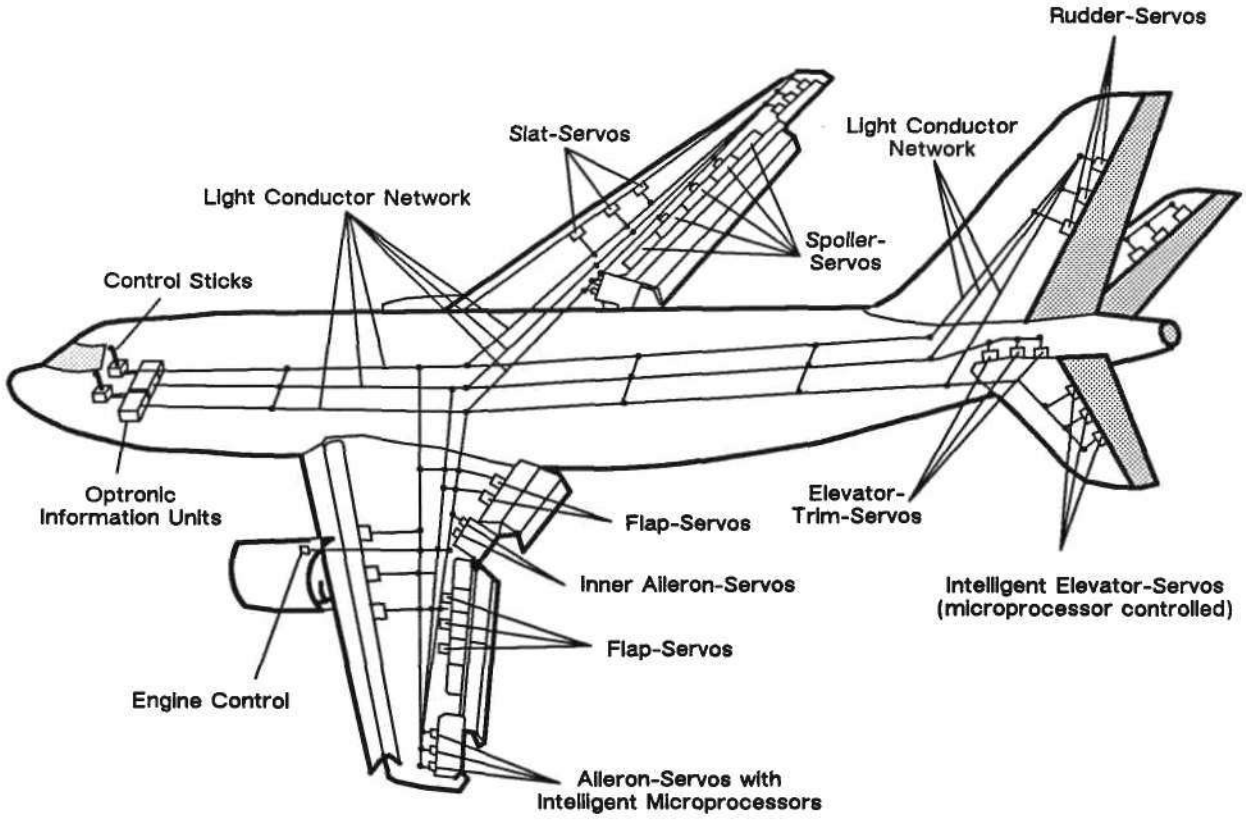
Fiber-optic network applications are increasingly pervasive. An excellent example is found in aircraft system architecture, where fiber is replacing copper, converting "fly-by-wire" control systems to "fly-by-light" (FBL). Fiber-optic links are planned for future aircraft applications; Boeing Commercial Airplane Company began to deliver aircraft using an FBL system in 1989.

Figure 3 illustrates a potential application of fiber optics in Messerschmidt Boelkow-Blohm (MBB) control systems within an Airbus Industrie aircraft.

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Figure 3

Fly-by-Light Flight Control System



Source: Dataquest (July 1991)

Microwave Links

Microwave applications of III-V compound semiconductors include earthbound systems, airborne links, and various space systems such as geosynchronous satellite systems. For example, Japan is actively engaged in converting its ground-based microwave relay system to a digital system for improved performance.

An example of a geosynchronous satellite system is ARABSAT, which comprises a series of satellites to accommodate 8,000 simultaneous telephone circuits, several TV channels, telex, and data transmission services. Twenty-two Arab League countries use the system. NEC is supplying 10 of the earth stations and the satellite control network for the ARABSAT system.

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Peripheral Storage Units for Digital Equipment

High-performance optical storage using laser readout is a potentially rapid-growth application for III-V compound devices, including GaAs. Reliable eraseability and alterability at lower system per-bit cost are key to the displacement of present high-density magnetic media.

In CD-ROM storage systems, OEICs are expected to be used for adding features such as local data conversion and simplified bussing/transfer of data. Opportunities also exist in optical storage systems for OEIC application to error detection/correction. These features could be incorporated into a single chip that also contains the reading function.

At the 1985 NCC, Verbatim Corporation demonstrated a 3.5-inch erasable optical disk with 40-Mbyte capacity. This and other activities such as work under way at Sony, Kodak, and 3M have led to a quantum jump in cost-effective storage capacity for machines ranging all the way down to personal computers. In 1990, several companies introduced CD-ROM drives for PCs. All such applications require compound semiconductor lasers for the readout function.

Other peripheral equipment applications include optical couplers and interruptors for printers and other paper-handling equipment. The replacement of mechanical sensor switches with optoelectronic components such as those manufactured by Optek, HP, and others enhances system MTBF.

Optical Computing

The ability of GaAs and other III-V compounds to function near the visible spectrum has spurred serious research into optical computing. Since the mid-1970s, interest in this field has fluctuated and has attracted the attention of the U.S. Department of Defense for potential SDI applications. AT&T is investing R&D effort in a prototype optical computer based on MQW device technology. AT&T demonstrated the prototype in 1990.

Venture capital firms such as Venrock Associates have invested in this technology, and start-up teams are presently seeking capital to fund new enterprises in this field. Although many technical problems in optical logic are unsolved, Dataquest believes that this area holds much promise for growth in the 1990s.

Instrumentation

Instrumentation applications for optoelectronic and other GaAs and III-V devices now include:

- High-speed oscilloscopes
- Logic analyzers
- Signal generators
- Spectrum analyzers

The same dilemma in testing exists today that existed when ECL was initially developed in silicon technology: What does one use to test the highest-speed components? Presently, 60- to 80-GHz testing can be accomplished at the wafer level but is limited to one or two signal probes; Cascade Microtech is considered a leader in this area. Demands for high-speed wafer-probe stations with more than three probes and for multi-GHz final test equipment for packaged devices have risen acutely with the introduction of LSI GaAs chips. Both suppliers and users are driving these requirements.

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Several recent announcements have been made regarding nonintrusive test techniques and methodology. Stanford University and others are making substantial progress in this area. The basic concept involved is the sensing of radiation from the chip at close proximity to determine on-chip signal characteristics.

Dataquest believes that the instrumentation segment of the electronics industry will increasingly adapt GaAs optoelectronic discretes and ICs to instrumentation circuitry and that the use of InP and other compound chips to solve some of the highest-speed test problems will grow.

Consumer

Consumer demand for increasingly sophisticated electronic products is driving the market for IR LED and laser transmitter and receiver chips, display chips, optical circuitry, and other III-V compound semiconductors. Broad categories of consumer applications include a wide range of remote controls, displays, toys, and optical storage devices such as audio CD players. Additionally, hundreds of millions of LED display chips are used annually in consumer electronics.

Remote Controls

The hand-held remote controls that are used for TV, VCR, and other household electronics use IR LED transmitter chips such as those produced by Optek and by the optoelectronics division of HP. Compound semiconductors will be used increasingly because of the additional flexibility of available operating frequency range, a requirement imposed by band-crowding as remote controls proliferate.

Displays

For more than 12 years, LED displays using GaAs chips have been marketed to consumers, and LEDs now represent a relatively unattractive commodity market to many high-technology companies. However, this will continue to be a substantial market to efficient producers as the number of consumer electronic products grows.

Toys

The 1986 toy market saw the introduction of a laser gun that reportedly had a first-year sales volume approaching 1 million units. The rapid decrease in pricing of certain types of GaAs lasers to less than $0.10 by 1993 is expected to inspire new toy and game products.

Optical Disks

The recent surge in demand for compact audio and videodisc players exemplifies the type of growth that can occur in the consumer market as low-cost GaAs devices become available. The recent surge of CD-ROM activity appears to be pushing costs low enough to make optical storage a home-computer peripheral and may add life to a product that many believe has matured.

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Automotive Applications

Current developments in adapting fiber optics into aircraft designs represent a trend that will spread to automotive applications, with explosive growth potential. Fiber-optic systems are already under serious consideration in vehicle design, primarily for reduced manufacturing cost of cable harness assemblies. A side benefit to lower system cost is the potentially increased reliability resulting from improved corrosion resistance and other factors.

Dataquest believes that by the mid-1990s a typical automobile will contain 30 feet of optical fiber, replacing 30 to 40 percent of the copper cabling in present designs. Dataquest estimates that in the early 1990s, the automotive industry will spend approximately $500 million per year on optical fiber.

Military/Government

Military, defense, and other government applications for GaAs IC technology include such equipment as lidar (laser radar), electronic warfare including electronic countermeasures, and communications. Several countries—including Germany, Japan, the United Kingdom, France, Canada, and the United States—have government-sponsored programs in one or more of these areas that have provided much of the R&D funding for development and application of GaAs technology.

Laser Radar (Lidar) Applications

Lidar is being used in new applications, which will drive chip demand. In addition to military applications, lidar is useful for measuring wind speed such as clear air turbulence (CAT), movement of volcanic plumes, and ozone layer. Future lidar applications include use as atmospheric pollution monitors.

USER ISSUES

Issues of concern to users include spectrum crowding, cost/technology trade-offs, assured sourcing, and safety. Cost is affected heavily by the rate of technological change. Assured sourcing is affected by rapid introduction of new products and obsolescence of existing products, and by structural changes within the semiconductor industry. Safety issues involve both the chemistry of materials and processes and the dangers of product radiation.

Spectrum Crowding

As more equipment operates at optical frequencies, crowding of the frequency band becomes a major issue. Fortunately, photon emissions are easily shielded, and lasers by their nature collimate transmissions; otherwise, spectrum crowding would have already reached an intolerable state. Although the U.S. FCC and the agencies of other governments regulate emissions, the semiconductor user must not ignore the basic problems that arise from a lack of attention to the end-use environment.

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Cost Factors

Compound semiconductor costs are decreasing dramatically, especially for lasers and integrated optoelectronics devices. The cost of lasers for telecommunications applications decreased by a factor of 3 between 1987 and 1990; CD laser prices dropped more than 50 percent in less than one year. Recent industry experience shows that the user should seek forward price projections when planning a new design.

Product Availability

The maturation of discrete opto technology caused suppliers such as TRW and General Instrument to reassess their positions in the optoelectronic device marketplace. The National Semiconductor and TRW optoelectronic product divisions changed ownership during 1986 and 1987, and others may follow before the industry completes its readjustment to today's realities.

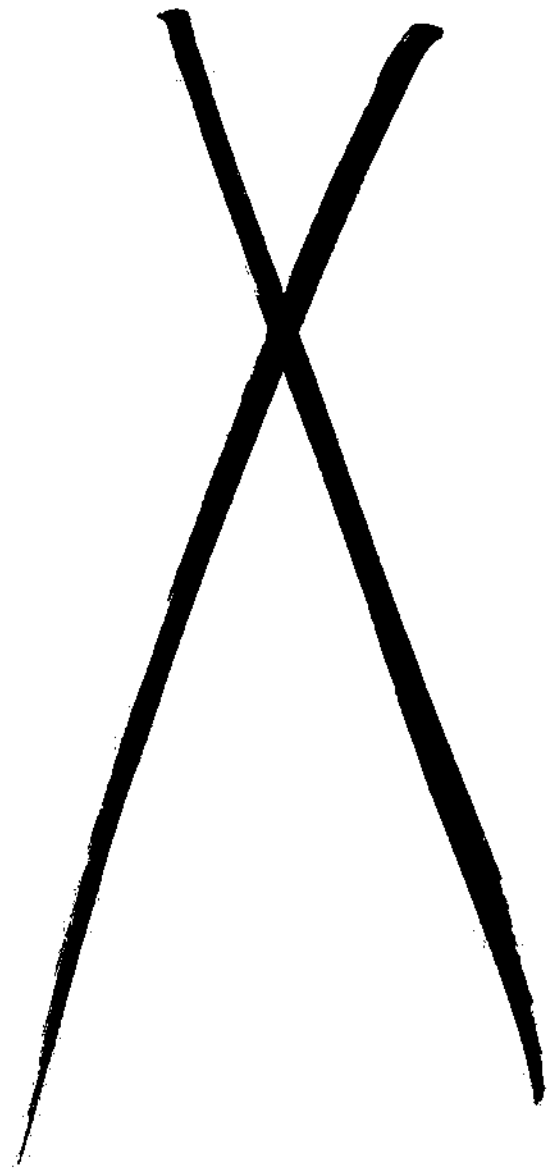
Safety Issues

Lasers are point-sources of light and therefore may represent a safety hazard because of the potential for eye damage as well as for radiation burns. Microwave amplifiers may represent sources of dangerous radiation, depending on frequency of operation. Whereas cancer-causing and other hazardous effects of X-rays have long been known, the real and potential adverse effects of microwave and near-visible radiation are less understood. However, there is evidence that long-term exposure to UV radiation is carcinogenic. Organizations such as the University of Washington School of Medicine are studying the effects of pulsed microwaves on human tissue such as heart muscle.

The problems are complex; for example, the most radiation-resistant, microwave-protective suits in a recent test at 2.5 GHz proved to be less flame-retardant than were other suits having higher resistance to radiation at this frequency. All of the suits tested appeared to provide reasonably good protection above 700 MHz, but they were not satisfactory at the VHF frequencies that are used for commercial and civil television and communications bands.

In another example, lidar operating at 780nm and 10mW power in RM-CW (random modulation continuous wave) mode has been determined to be eye-safe within ANSI standards, according to the National Institute for Environmental Studies, Tsukuba, Japan; however, the ANSI standards may not be sufficiently stringent to prevent long-term damage to the eye or other tissues. Thus, manufacturers and users alike need to carefully determine whether safety hazards exist or will be created in their particular environments as changes are made and as new chips and applications evolve.

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III-V Optoelectronics—Historical Shipment Data

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Historical Shipment Data

This section presents historical shipment data for the GaAs and Other III-V semiconductor optoelectronic device market from 1985 through 1990. Tables 1 through 6 show estimated shipment revenue by product category and by major geographic regions of origin. Where an estimate is not yet available, none is given.

Table 1
Estimated Worldwide Optoelectronic Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total Optoelectronics	1,213	1,486	1,709	2,179	2,627	2,687
LEDs and LED Arrays	588	662	509	585	647	669
Optocouplers, Isolators, Interruptors	228	273	329	448	541	552
Lasers/Transmitters	276	325	376	411	558	577
Detectors	70	87	108	129	161	156
Photovoltaic Cells	43	85	104	115	152	162
Other (including CCD and OEICs)	8	54	283	491	568	571

Source: Dataquest (May 1991)

Table 2
Estimated U.S. Optoelectronic Merchant Shipments
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total Optoelectronics	405	373	383	425	458	457
LEDs and LED Arrays	177	120	114	123	105	98
Optocouplers, Isolators, Interruptors	92	96	103	108	118	112
Lasers, Transmitters, Detectors, Photovoltaic, Other	136	157	166	194	235	247

Source: Dataquest (May 1991)

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Table 3
Estimated Western European Optoelectronic Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total Optoelectronics	169	206	230	238	244	267
LEDs and LED Arrays	106	109	133	136	137	152
Optocouplers, Isolators, Interruptors	28	31	37	40	38	41
Lasers, Transmitters, Detectors, Photovoltaic, Other	35	66	60	62	69	74

Source: Dataquest (May 1991)

Table 4
Estimated Japanese Optoelectronic Merchant Shipments by Technology
(Millions of Dollars)

Category	1985	1986	1987	1988	1989	1990
Total Optoelectronics	637	905	1,093	1,511	1,918	1,935
LEDs and LED Arrays	303	402	262	323	401	405
Optocouplers, Isolators, Interruptors	108	142	93	299	383	391
Lasers, Transmitters, Detectors, Photovoltaic, Other	226	361	738	889	1,134	1,139

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (May 1991)

Table 5
Estimated Japanese GaAs Merchant Shipments by Technology
(Billions of Yen)

Category	1985	1986	1987	1988	1989	1990
Total Optoelectronics	159.3	151.2	174.9	193.4	264.7	267.0
LEDs and LED Arrays	75.8	67.1	41.9	41.3	55.3	55.8
Optocouplers, Isolators, Interruptors	27.0	23.7	14.9	38.3	52.9	54.0
Lasers, Transmitters, Detectors, Photovoltaic, Other	56.5	60.3	118.1	113.8	156.5	157.2

Note: Some columns do not add to totals shown because of rounding.
Source: Dataquest (May 1991)

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Table 6
Estimated Asia/Pacific Optoelectronic Merchant Shipments by Technology
(Millions of Dollars)

Category	1988	1989	1990
Total Optoelectronics	5	7	28
LEDs and LED Arrays	3	4	14
Optocouplers, Insolaters, Interruptors	1	2	8
Lasers, Transmitters, Detectors, Other	1	1	6

Source: Dataquest (May 1991)

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Foundries

GaAs foundry activity is intensifying, as commercial usages of digICs and MMICs gain market momentum. The lineup of players is changing, and new services are entering the market. Significant improvements in responsiveness occurred in 1987 and 1988, as processes were debugged and yield enhancements were made. In 1988, GAIN Electronics and Siemens (MSC) discontinued foundry operations.

At least 19 GaAs foundries now serve the free-world marketplace. Thomson-CSF is expected to join the ranks in the near future. Japan's candidates include at least four of the major silicon suppliers, a situation very different from that in the United States. Since early 1987, processes have advanced below 0.5u at several facilities to support microwave performance demands.

The GaAs industry clearly has an abundant capacity to support MSI/LSI-density digital and microwave analog custom and semicustom IC production. Substantial advancement in yields and level of service has been noted since 1987. Commercially viable products are increasingly evident in the many multiproject wafer and semicustom activities now under way throughout this industry. The infrastructure is rapidly evolving to provide improved CAD tools and other necessary support.

This section summarizes the major announced GaAs foundry services and facilities. Table 1 shows the capabilities by company. Tables 2 and 4 provide the mid-1989 locations, telephone numbers, and foundry contacts by company. Additional data on services and costs are in Tables 3 and 5. The text provides further details about each company's capabilities.

Table 1

Merchant Market GaAs Foundries

Company	Process	Product	Comments
Adams-Russell	0.5u D-MESFET	MMICs	Multiproject wafers
ANADIGICS	0.5u D-MESFET	MMICs, digICs	Multiproject wafers
Avantek	0.5u MESFET	MMICs	150,000-square-foot facility
COMSAT Labs	0.25u MESFET and HEMT	MMICs	Above 90 GHz
Ford Micro-electronics	0.5u, 1.4u E-/D-MESFET	MMICs, digICs	500 wafers/week
GAIN	See text		

(Continued)

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Foundries

Table 1 (Continued)

Merchant Market GaAs Foundries

Company	Process	Product	Comments
GigaBit Logic	D-MESFET	DigICs	Extensive macrocell library
Harris Micro	1u, 0.5u MESFET	MMICs, digICs	Cell library
Honeywell			Relocated to Minneapolis, MN
ITT GTC	0.4u, 0.5u D-, E-/D-MESFET	MMICs, digICs	Superior temperature test capacity
M/A-COM	0.8u, 0.5u, 0.25u	MMICs	Decreased production
MSC	See text		
Plessey Three-Five	0.7u D-MESFET	MMICs	Emphasis on quality control
Raytheon	0.5u, 0.25u D-MESFET	MMICs	Foundry under construction
Rockwell	D-MESFET, HEMT	DigICs	250 3-inch wafers/shift/week
Sanders	0.5u, 0.25u	MMICs	To 40+ GHz
Tachonics	0.5u, 0.25u E-/D-MESFET	MMICs	Deemphasized digICs
TI MMCD	0.5u D-MESFET	MMICs	Three process profiles
TriQuint	1u, 0.7u, 0.5u E-/D-MESFET	DigICs, MMICs	Multiproject wafers
Varian	0.25u HEMT	MMICs	To 40 GHz
Vitesse Semi	1.2u E-/D-MESFET	DigICs	Technology exchange with AMD

Source: Aztek Associates

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Foundries

Analog/Linear GaAs Foundries

Microwave, millimeter wave, and other analog functions represent a continuing opportunity for many GaAs foundries. Because unique specifications are usually imposed by each customer and each application, and because the NRE costs are significant, the responsive foundry has an opportunity to support repeat business. Most foundries are continuing to develop and implement ASIC capabilities in response to specific market needs.

Increasing availability of 3–inch and 4–inch MOCVD and MBE wafers with improved defect densities, coupled with enhanced modeling of GaAs functions on relatively inexpensive workstations, has caused a rapid migration toward monolithic ASIC solutions to multifunctional microwave design problems. As is the case in silicon technology, GaAs ASICs often provide the most cost–effective approach for both customer and supplier.

Several companies offer GaAs ASIC support via foundry services. Major MMIC ASIC foundries, locations, and contacts are summarized in Table 2, and the capabilities of these foundries are listed in Table 3.

Table 2

Analog/Linear GaAs Foundry Contacts

Company/Location	Phone	Foundry Contact
Adams-Russell Burlington, MA	(617) 273-5830	David Williams Marketing director
ANADIGICS Warren, NJ	(201) 668-5000	Michael Gagnon Director, marketing & sales
Avantek Santa Clara, CA	(408) 727-0700	Peter Manno Marketing director
COMSAT Labs Clarksburg, MD	(301) 428-4000	Dr. Ho Chung Huang Executive director, Micro Division
Ford Microelectronics Colorado Springs, CO	(719) 528-7916	Douglas L. Finch Vice president, Advanced Technical Requirements
Harris Milpitas, CA	(408) 433-2222	Jim Klug Program director

(Continued)

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Foundries

Table 2 (Continued)

Analog/Linear GaAs Foundry Contacts

Company/Location	Phone	Foundry Contact
ITT GTC Roanoke, VA	(703) 563-3912	Joe Grzyb Project manager
M/A-COM Lowell, MA	(508) 453-3100	Larry Ward Vice president, marketing and sales
Plessey Three-Five Towcester, United Kingdom	(0327) 51871	Jim Arnold Applications executive
Sanders Nashua, NH	(603) 885-1054	Dr. John Heaton Deputy Director, Microwave Tech. Center
Tachonics Plainsboro, NJ	(609) 275-2500	Dr. Chuni Ghosh President and acting marketing director
TI MMCD Dallas, TX	(214) 995-6462	Steve Lazar Foundry services manager
TriQuint Beaverton, OR	(503) 644-3535	Dr. Ajit Rode Vice president, foundry products
Varian Associates Santa Clara, CA	(408) 562-2834	Michael Kopek III-V sales manager

Source: Aztek Associates

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Foundries

Table 3

Analog/Linear GaAs Foundry Capabilities

Company	Wafer Size (Inches)	Capacity (Starts/Wk.)	Turnaround Time (Weeks)	Services	NRE Costs ($K)
Adams-Russell	2, 3	100	12	RF probing	$45/4 wafers
ANADIGICS	3	200	8	Training	$15 to $50
Avantek	2, 3	270	N/A	Die bank	$40/1st wafer, $10/each additional
COMSAT Labs	2, 3	25	16	GaAs MESFET and HEMT processes	N/A
Ford Micro-electronics	3	500	10	RF probing	N/A
Harris	2, 3	100	14	100% visuals	$25 to $100
ITT GTC	3	100	9	Ion implant	$68
M/A-COM	2, 3	N/A	N/A	N/A	See text
Plessey Three-Five	2	100	8-12	Strict QC	$48 plus $6.5/wafer
Sanders	2, 3	50-125	14	RF probing	$90/4 wafers, plus mask charges
Tachonics	3	300	8	Ion implant	$45
TI MMCD	3	60	12	e-beam	$69.5
TriQuint	3, 4	600	10	Multiproject	$50 to $90
Varian Associates	2, 3	N/A	16	e-beam, HEMT	$40 first wafer, $15 next 10 wafers

N/A = Not Available

Source: Aztek Associates

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Foundries

GaAs DigIC Foundries

Similar to integrated circuits in the GaAs analog/linear world, GaAs application-specific digital integrated circuits (ASIC digICs) offer a relatively attractive means of evolving system designs from silicon to GaAs. Several companies, including recent start-ups, have mounted substantial foundry programs to support GaAs ASICs. Table 4 lists locations and contacts for merchant market foundries in the United States and in Western Europe offering GaAs digIC services in mid-1989. There were no announced merchant GaAs digIC foundries in Japan at press time.

Table 4

GaAs DigIC Foundry Contacts

Company/Locations	Phone	Foundry Contact
ANADIGICS Warren, NJ	(201) 668-5000	Michael Gagnon Director, marketing & sales
Ford Microelectronics Colorado Springs, CO	(719) 528-7916	Douglas L. Finch Vice president, Advanced Technical Requirements
GigaBit Logic Newbury Park, CA	(805) 499-0610	Tony Conoscenti Product marketing engineer
Harris Milpitas, CA	(408) 433-2222	Jim Klug Program director
Honeywell Minneapolis, MN	(612) 887-4047	Dr. Richard Cirillo Program manager
ITT GTC Roanoke, VA	(703) 563-3912	Joe Grzyb Project manager

(Continued)

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Foundries

Table 4 (Continued)

GaAs DigIC Foundry Contacts

Company/Locations	Phone	Foundry Contact
Plessey 3-5 Towcester, United Kingdom	(0327) 51871	Jim Arnold Applications executive
Rockwell Anaheim, CA	(714) 833-4123	Fred Cherrick Marketing director
Tachonics Plainsboro, NJ	(609) 275-2500	Dr. Chuni Ghosh President and acting marketing director
TriQuint Beaverton, OR	(503) 644-3535	Dr. Ajit Rode Vice president, foundry products
Vitesse Semi Camarillo, CA	(805) 388-3700	Tom Dugan Marketing vice president

Source: Aztek Associates

TriQuint and others are marketing multiuser prototype wafer programs that allow several customers to design devices according to the respective suppliers' ground rules and receive the first prototype devices from wafers fabricated during a single run. To accomplish this, the vendor assigns standardized reticle areas (e.g., 80 mils x 80 mils) for chip locations so that several customers' chips can be interspersed on the same wafer. This represents a major breakthrough in economies of scale in developing GaAs devices. Cost reduction for the user can be as much as 80 percent per wafer run.

GigaBit Logic has experienced particularly impressive foundry yields on the CRAY-3 GaAs ASIC program. Yields of the cell-based MSI-density chips have continued to advance well beyond 50 percent for several months. As a result, the CRAY-4 machine is expected to advance to E/D gate arrays or CBICs of at least a 2,000-gate density.

Table 5 summarizes digIC foundry data including wafer sizes, plant capacities, turnaround times, services, and NRE charges.

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Foundries

Table 5

GaAs DigIC Foundry Capabilities

Company	Wafer Size (Inches)	Capacity (Starts/Wk.)	Turnaround Time (Weeks)	Services	NRE Costs ($K)
ANADIGICS	3	200	8	Training	$15 to $50
Ford Micro-electronics	3	500	10	RF probing	N/A
GigaBit Logic	3	N/A	6-8	100% speed testing	$35 to $48 depending on process
Harris	2, 3	100	14	100% visuals	$25 to $100
Honeywell	N/A	N/A	N/A	N/A	Deemphasizing foundry activity
ITT GTC	3	100	9	Ion implant	$60
Plessey Three-Five	2	100	8-12	Strict QC	$48, plus $6.5/wafer
Rockwell	3	250/shift	N/A	Full	N/A
Tachonics	3	300	8	Ion implant	$45
TriQuint	3	600	10	Multiproject	$50 to $90
Vitesse	3	N/A	3	E/D process	N/A

N/A = Not Available

Source: Aztek Associates

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Foundries

Companies That Supply Foundry Services

The following companies offer foundry services in one or more aspects of GaAs technology.

Adams-Russell

Adams-Russell offers custom-fabricated GaAs MMICs, 1u and 0.5u MESFET foundry service, and a design seminar for GaAs IC users. The company's 54,000-square-foot semiconductor center was established in Burlington, Massachusetts, in 1982. Foundry charges are approximately $45,000 per four-wafer prototype lot for customer-owned mask set and tooling. Multiproject design participation is priced at $10,000 per group (up to four persons per group). The available library of MMIC components includes transistors, diodes, capacitors, resistors, and spiral inductors for MMIC design. The company accepts Calma GDSII or CIF data base tapes and offers 10- to 12-week throughput for tested chips.

In June 1989, M/A-COM made an offer to acquire Adams-Russell. Representatives of Adams-Russell at MTT indicated this would have no immediate impact on its foundry.

ANADIGICS

ANADIGICS offers GaAsIC (a trademark of ANADIGICS) foundry services. The process is 0.5u gate length D-MESFET with 24-GHz f_T standard transistors. ANADIGICS' design tools include the following trademarked services and support: AISPICE design software, AIGRAPH layout, and AICHECK verification programs. Examples of microwave circuits that can be designed using the company's tools and processing are: wideband, power, and low-noise amplifiers; limiters, buffers, and mixers; and switches, VCOs, and phase shifters. Linear and digital circuit examples include: transimpedance amplifiers, mux/demux circuits, laser drivers, A/Ds and D/As, dividers, and ECL-compatible logic.

Capacity of ANADIGICS' 6,400-square-foot, Class 100 clean room is approximately 200 3-inch wafers per week. Wafer probe equipment is rated to 40 GHz; final testing is rated at DC to 26.5 GHz (rf) and 4 Gb/s (digital). High-speed linear testing includes automatic on-wafer laser trimming. In addition to wafer fab, dicing, packaging, and screening, ANADIGICS offers backside processing including thinning metallization and via holes. Packaging includes DIPs, LCCs, flatpacks, and proprietary metal-ceramic packages to 20 GHz.

Avantek

Avantek recently expanded its 150,000-square-foot facilities to include a 3-inch wafer fab. Process is state-of-the-art 0.5u GaAs MESFET. Foundry charges are $40,000 for the first wafer, which includes design rule package and engineering services, and $10,000 each for additional wafers (minimum lot size is five wafers).

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Foundries

COMSAT Labs

COMSAT Labs became a GaAs foundry in 1987. Capacity at press time was approximately 25 wafers per week, limited by personnel, not facilities. The company offers custom GaAs MMIC capability based on MESFET and HEMT technology with an operating frequency of more than 90 GHz. NRE charges are negotiable.

Ford Microelectronics, Inc.

Ford Microelectronics, Inc., has a 12,000-square-foot GaAs foundry at Colorado Springs, Colorado, with a 3-inch capacity of 500 wafers per week. The clean room exceeds Class 10 criteria and is producing LSI/MSI-density devices on a self-aligned E/D process. The circuits feature loaded gate delays of 150ps at 0.7mW per gate P_d and a worst-case noise margin of 300mV.

Ford offers proprietary SPICE-based circuit simulation software called GASSIM (a trademark of Ford Microelectronics). Hermetic IC packaging capability includes a variety of standard packages. The fab site has both environmental screening and 100 percent burn-in capabilities. Electrical testing is performed on Sentry 21 and MegaTest MegaOne VLSI testers.

GAIN Electronics Corporation

GAIN Electronics Corporation discontinued its foundry operations in November 1988.

GigaBit Logic

GigaBit Logic (GBL) has developed a standard cell library for custom digital designs to support chips of up to 4,000-gate density. GBL states that it chose D-MESFET technology for this family because it has obtained yields of more than 35 percent on 14,000-transistor, 28,000-component circuits at its Newbury Park, California, facility. The macrocell family offers gate delays of less than 100ps and flip-flop toggle rates above 2 GHz. Foundry charges are $35,000 to $48,000 for two prototype runs and $35,000 per production run at eight wafers per run, depending on the process. GBL has a second-source agreement with Tachonics.

Harris Microwave Semiconductor, Inc.

In April 1987, Harris Microwave Semiconductor, Inc., announced the availability of a library of GaAs standard cells for semicustom digital designs. The process is Harris' proprietary DIGI-2, 1u MESFET using two-layer metal; t_{pd} is typically 280ps/cell at 10 to 40mW/cell ps. I/Os consume 11 to 88mW each and may be ECL, TTL, CMOS, and GaAs compatible. The cells range in complexity from two-input NAND gates to a two-bit full adder.

Harris' CAD/CAE tools are a modification of tools developed by Silicon Design Automation for the ASIC business. Other tools include a logic simulator, developed by SIMUCAD, and place-and-route software. The system is UNIX-based and runs on the Harris MCX-3, Sun 3/160, Apollo, Masscomp, and other workstations.

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Foundries

Harris states that a typical prototype digIC chip design effort costs approximately $60,000, which includes a CAE user's manual, a cell library manual, and 25 packaged, tested prototypes. The company plans to expand the existing library of 38 standard cells during 1987. Harris' Milpitas, California, facilities include a 0.5u foundry that also supports custom MMIC production. Cost for a prototype two-wafer run for MMICs is similar to that for a prototype digital run and ranges from $25,000 to $100,000.

Honeywell

During a 1986 reorganization of Honeywell operations, the company consolidated its GaAs activities into the corporate R&D center at Minneapolis, Minnesota, under the direction of Dr. Richard Cirillo, GaAs Department Program Manager. New opportunities are being addressed on a case-by-case basis. The Richardson, Texas, GaAs facility was transferred to the control of the Opto Division of Honeywell.

ITT GTC

ITT's Roanoke, Virginia, GaAs Technology Center (GTC) offers MMIC and high-speed digital IC foundry support on a limited basis for military and commercial applications. Foundry charges are approximately $60,000 depending on design complexity and other factors.

M/A-COM

M/A-COM has one of the largest GaAs foundry production facilities available, exceeding 90,000 square feet. The company primarily supports MMIC designs and offers processing to 0.8u, 0.5u, and 0.25u design rules. Wafer runs processed to 0.8u fab cost $25,000; processing to 0.5u rules costs $30,000 per run. Mask charges usually involve 9 to 14 levels at $1,200 per level. Special testing and other services are negotiable.

In June 1989, M/A-COM made an offer to acquire Adams-Russell. Future impact, if any, on foundry operations had not been announced as of press time.

MSC

Siemens sold its subsidiary, Microwave Semiconductor Corporation (MSC), in the fourth quarter of 1988. Foundry operations have been discontinued.

Plessey Three-Five

Plessey's Three-Five Group offers its F1 foundry process based on D-MESFETs with 0.9u nominal gate length. A 0.7u process is also available. Available circuit elements include FETs, diodes, resistors, capacitors, and inductors. NRE costs are $48,000 plus $6,500 per wafer. Plessey prefers projects that require at least two to five runs per year.

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Foundries

Raytheon

Raytheon is constructing a major foundry facility at a Massachusetts site, with more than 30,000 square feet of fab area. Initial focus will be on 0.5 and 0.25u processes for custom MMICs. Capacity is expected to be on-line in 1989.

Rockwell

Rockwell's Microelectronics Research and Development Center (MRDC) pioneered the development of GaAs materials and ICs. Its 41,000-square-foot Newbury Park facility near Thousand Oaks, California, is equipped to produce 250 3-inch wafers per week per shift. Foundry operations started in August 1985, initially supporting D-MESFET designs including LSI density chips. HEMT and HBT processes are in development. Calma and Daisy Chipmaster systems are in place; additional design tools are added as needed. Foundry charges are negotiable.

Sanders Associates (Lockheed)

Sanders Associates, owned by Lockheed, offers 0.5 and 0.25u MESFET MMIC foundry services at its Nashua, New Hampshire, facility. The company has a 3-inch fab capacity of more than 50 wafer starts per week.

Tachonics

A subsidiary of Grumman, Tachonics has a GaAs IC standard product and foundry facility in Plainsboro, New Jersey, with initial capacity of 300 3-inch wafer starts per week. It is developing a 0.25u-micron microwave process. The company provides workstation capability and support for Mentor workstations on the Apollo network. Tachonics is a second source to GigaBit Logic but has deemphasized its digital capability.

Texas Instruments MMCD

In April 1987, Texas Instruments announced availability of MMIC foundry services at its Microwave Military Components Division (MMCD). The division has an 8,000-square-foot fab that runs three process profiles on 3-inch wafers. The 0.5-micron processes are each optimized with special characteristics, such as low noise high gain or high power intermediate gain. Texas Instruments offers a training course to familiarize designers with design runs, process parameters, and circuit examples. NRE costs are approximately $70,000, depending upon design and process.

TriQuint

TriQuint offers its foundry customers Q-chip, multiproject chip, full-custom, and ASIC services. Full-custom charges for customer-designed chips range from $42,000 for a 1-micron D-MESFET design to $60,000 for a 1-micron E/D design. These charges include design manual, mask making, and first prototype wafer run. ASIC charges for TriQuint designs to customer specifications are negotiable and range from approximately $50,000 to $90,000 per design.

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The company charges $55,000 for the first 5 to 10 Q-chip samples, including design manual, standard cells on Daisy equipment, and evaluation board. Multiproject wafer cost is $9,900 for MSI-density design samples.

TriQuint periodically offers multiproject chip design courses in Portland, Oregon. The courses are led by 14 of TriQuint's expert staff members who have combined engineering experience of more than 190 years. The microwave design course typically consists of lectures on design logistics, GaAs processing, circuit models and SPICE modeling, chip design, packaging, testing, and reliability. The digital design course is similar, focusing on E/D processing, digital IC design, and standard cells. Informal design consulting is included in each course. TriQuint offers each of the attendees the opportunity to successfully specify, design, and evaluate samples of a custom state-of-the-art GaAs IC.

Varian Associates

Varian Associates began offering foundry services at its Santa Clara, California, facility in 1987. The company provides processing of 0.25u HEMT devices on 2-inch and 3-inch wafers. NRE charges are approximately $40,000 including the first wafer, plus $15,000 for the next 10 wafers.

Vitesse Semiconductor Corporation

Vitesse's facilities in Camarillo, California, include an E/D foundry. The company has demonstrated production capability in such standard products as the VE29GO1, a GaAs equivalent of the popular silicon 2901 4-bit microprocessor slice. Vitesse's foundry has implemented a proprietary process called VEGA (Vitesse E-D GaAs), a 1.25-micron, enhancement/depletion mode self-aligned, nine-mask process featuring three levels of interconnects and subloop gate delays. Figure 1 illustrates a typical Vitesse and customer relationship and flow chart for a typical foundry project.

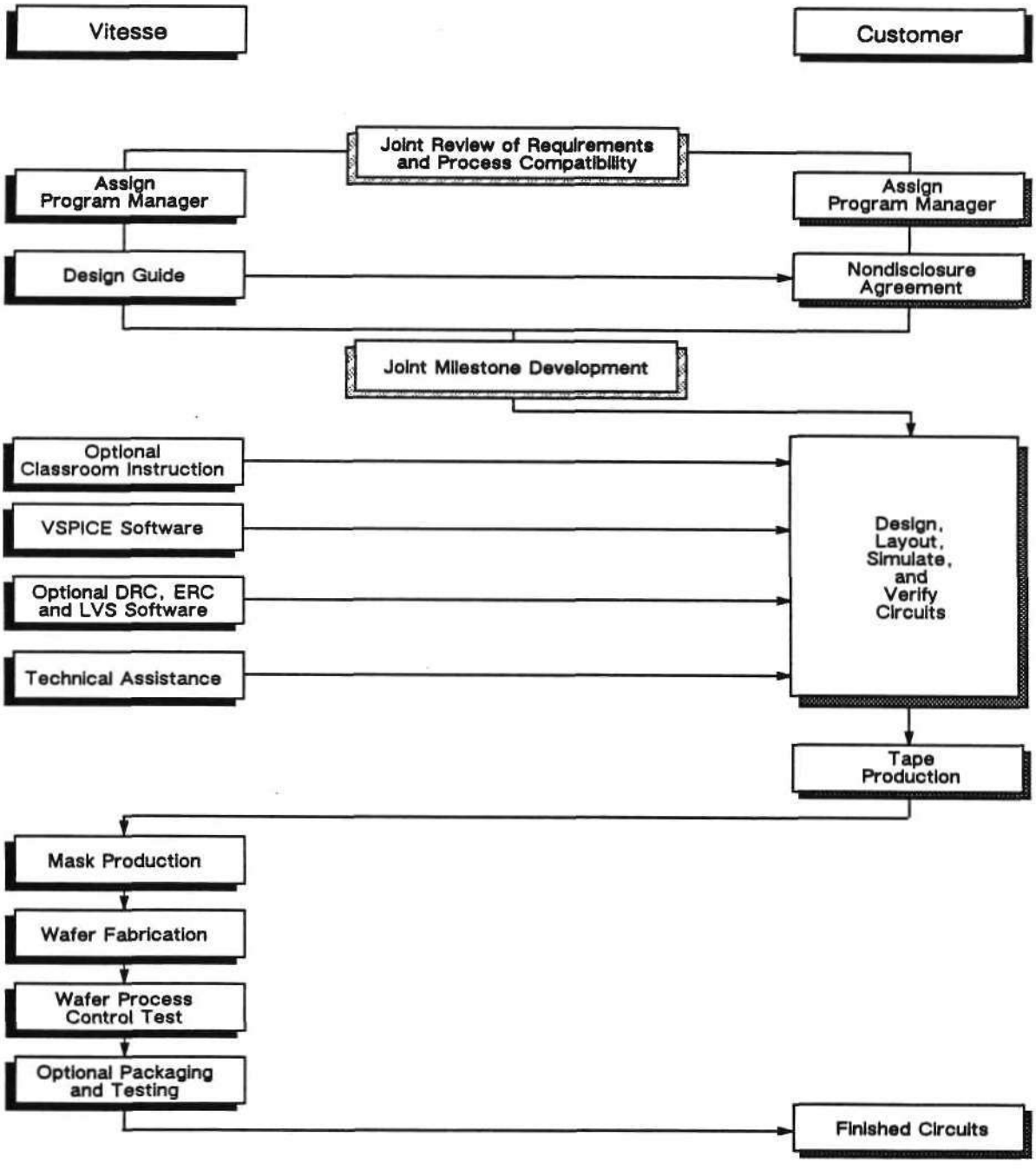
Vitesse has a one-time setup charge of $33,000 per design for a typical nine-layer chip. V-SPICE software, rule-check software, and a design guide cost $5,000. Engineering consultation costs $100 per hour. Processing cost for the first five wafers is approximately $6,000 per wafer; charges for more than five wafers are negotiable.

Vitesse has a technology exchange agreement with AMD and an alternate-source agreement with Ford Microelectronics.

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Figure 1

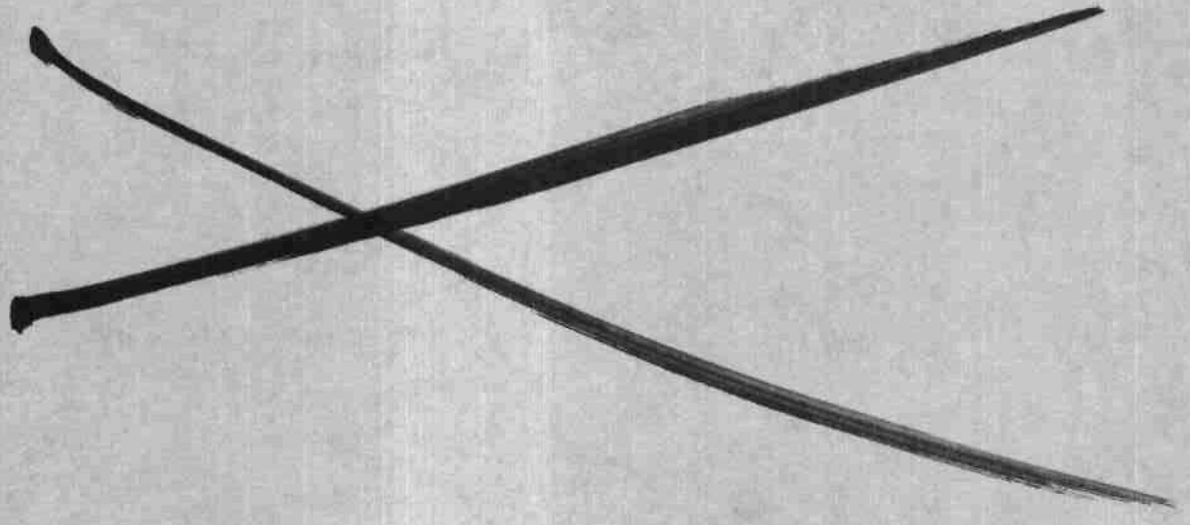
Foundry–Customer Interface and Project Flow

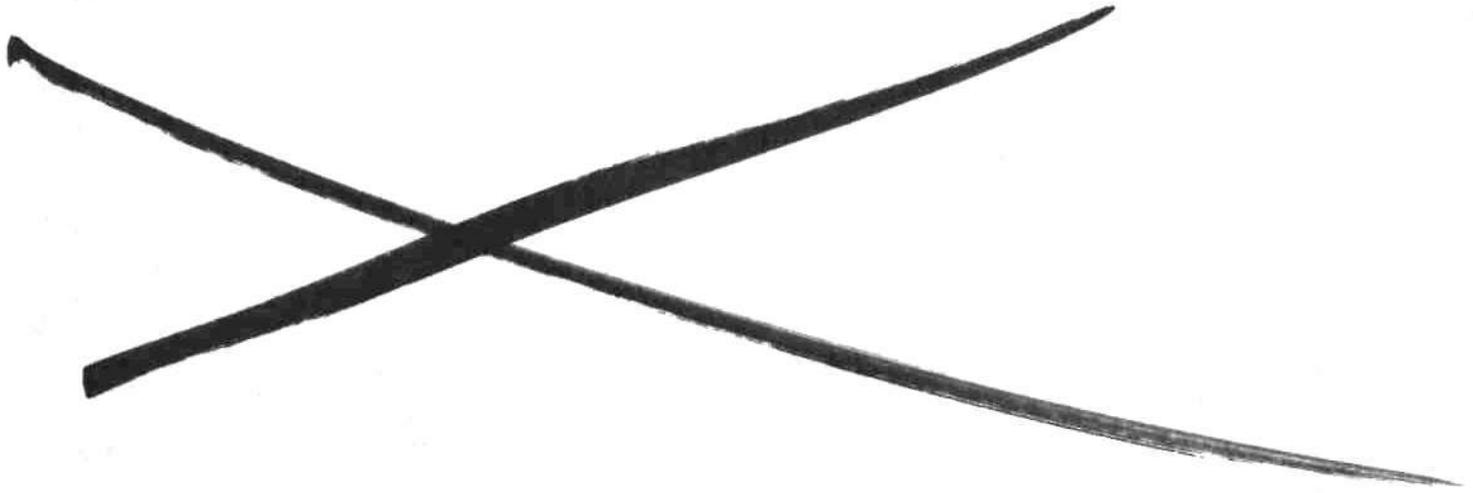


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Source: Vitesse Semiconductors

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Technology

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This section is included as a briefing on various gallium arsenide (GaAs) and other III-V related topics for use by a client that has had some experience in semiconductor technology but whose familiarity with III-V compound semiconductors is relatively limited. The information starts with properties of the basic elements used in device structures and progresses through manufacturing and functional concepts to such topics as electromagnetic interference (EMI) considerations in systems containing GaAs devices. To assist the reader, the terminology and acronyms used in this section are defined in the Glossary section of this notebook.

ELEMENTS

The elements gallium, arsenic, indium, and phosphorus are used along with such metals as aluminum in the production of III-V wafers. The most predominant III-V substrate is GaAs, followed by InP (indium phosphide). The characteristics of these elements are discussed in the following paragraphs.

Gallium

The symbol for the element gallium is Ga. Gallium was discovered in 1875 by Paul-Emile Lecoq de Boisbaudran and named after the Latin word for France. The element constitutes about 0.0015 percent by weight of the earth's crust (about as plentiful as lead) and is widely distributed but does not occur free or in independent minerals except as gallite, CμGaS^2. Gallium is available as a by-product of zinc blende, iron pyrites, bauxite, and germanite.

Gallium, a metal, has the atomic number 31; its atomic weight is 69.72. At standard conditions, its melting point is 29.78°C and its boiling point is 2,403°C, ±0.5°C; this is the widest useful liquid temperature range of any known element. The specific gravity of gallium is 5.904 at 29.6°C (solid); 6.095 at 29.6°C (liquid). The element has a valence of 3 and electron configuration of 2-8-18-3; it combines with elements of valence 5 such as arsenic (As) and phosphorus (P).

In the last 25 years, GaAs has become increasingly valuable to the electronics industry. Thus, the availability of highly pure gallium is an important consideration to many companies. It is presently believed that the earth's reserve of gallium is 110 million kilograms. In addition, there is a subeconomic quantity of 900 million kilograms in bauxite and a somewhat larger subeconomic quantity in zinc ores. Free world demand for gallium is approximately 20,000 kilograms per year.

Arsenic

Arsenic, whose symbol is As, is extremely toxic. The element arsenic was discovered in 1649; compounds of arsenic were known to Aristotle and others as early as 4 B.C. It is found uncombined in antimony and silver ores; in the sulfides realgar and orpiment, and many metallic sulfides (arsenopyrite is most abundant); and as an oxide. Arsenic is used to manufacture lead shot (adds roundness), as a weedkiller, and in insecticides. The element adds high-temperature strength in certain alloys. The trioxide As_2O_3 is a by-product of roasting ores of copper, lead, and other metals.

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Arsenic has the atomic number 33; its atomic weight is 74.9216 and atomic radius, 220pm. It has electronegativity of 2.05 and ionization energy of 8.64 eV/atom. Arsenic's melting point is 814°C at 36 atmospheres and 817°C at 28 atmospheres. Its density is 5.73 g/cc at 14°C in gray form and 2.03 g/cc at 18°C in yellow form. Its oxidation states are -3, +3, and +5; the electron configuration is 2-8-18-5. Its conductivity is 4.6 (silver = 100).

Arsenic Toxicity

Arsenic is not essential for human nutrition, but it appears in human tissues in amounts below 0.1 ppm. No role in natural biological phenomena has been discovered for arsenic as of 1990. Arsenic has been identified as a carcinogen, although the mechanism of arsenic carcinogenesis is not fully understood. Arsenic compounds generally are protoplasmic poisons that block cell respiration. Certain arsenic compounds prevent cell division, and arsenites inhibit the function of enzymes. Two oxides, As_2O_3 and As_4O_6, are considered lethal to humans in dosages of 0.1g. Arsenic salts are rapidly absorbed through the skin, and vapors are absorbed by the lungs. The most common form of industrial arsenic poisoning is the inhalation of arsenic hydride or arsine (AsH_3).

Indium

The symbol for the element indium is In. Indium was discovered in 1863 by Ferdinand Reich and Theodor Richter. The element constitutes approximately 0.0001 percent by weight of the earth's crust (about as plentiful as silver) and is widely distributed but does not occur free or in independent minerals except as a trace in zinc and lead deposits. Indium is available as a by-product of zinc- and lead-refining processes; thus the availability of indium is affected by zinc production.

Indium has the atomic number 49; its atomic weight is 114.82. At standard conditions, its melting point is 156.61°C and its boiling point is 2,080.00°C. The specific gravity of indium is 7.31 g/cc at 20.00°C. The element has a valence of 1, 2, or 3 and electron configuration of 2-8-18-18-3; it combines with elements of valence 5 such as arsenic (As) and phosphorus (P). Indium is relatively unaffected by air at temperatures below its melting point; however, at a red heat it burns to form the yellow oxide In_2O_3.

Until 1924, the world's supply of isolated indium was approximately 1 gram. In recent years, InP has become valuable as a substrate material in the electronics industry; also, indium oxide has found a use in electroluminescent panels. Thus, the availability of indium has taken on an increased importance. Approximately 4 million Troy ounces of indium are produced annually in the free world.

Phosphorus

The symbol for the element phosphorus is P. Phosphorus was discovered in 1669 by Hennig Brand and named for the planet Venus as it appears before sunrise. (Phosphorus is Greek for "light bringer.") This element is the twelfth most abundant on earth, constituting about 0.12 percent by weight of the earth's crust. It is widely distributed but does not occur free in nature except occasionally in meteorites. Commercially, phosphorus is available primarily from the refinement of phosphate rock. Large deposits are found in the USSR, Morocco, several of the United States, and elsewhere.

The element has approximately 10 forms that occur as white, red, or black. Ordinary white phosphorus burns spontaneously when exposed to air; contact with skin may cause severe burns. It

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is extremely poisonous; approximately 50mg constitutes a fatal dosage. White phosphorus may be stored in water to avoid spontaneous combustion. The red form is relatively stable; it is used in "safety" matches and in munitions.

Phosphorus has the atomic number 15; its atomic weight is 30.97376. At standard conditions, its melting point (white) is 44.1°C and its boiling point (white) is 280°C. The specific gravity of phosphorus is 1.82 (white). The element has a valence of 3 or 5 and electron configuration of 2-8-5; it combines with many metals such as gallium and indium. Phosphorus finds increasing applications in compound semiconductors such as LEDs, optoelectronic ICs, and other circuit functions.

Phosphorus Toxicity

Phosphorus is essential to all known forms of life and is one of the most important mineral constituents of living tissues. All DNA molecules contain phosphorus. However, elemental phosphorus is very toxic and has an acute effect on the human liver. Additionally, phosphine gas inhalation can lead to tremors, fatigue, nausea, coma, convulsions, and death. Phosphorus halogen compounds are also quite toxic.

COMPOUNDS

The III-V compounds of technological interest in high-frequency electronics and optoelectronics include GaAs, GaSb, GaP, InAs, InSb, and InP. Table 1 compares certain characteristics of these compounds that relate to optoelectronics applications.

Table 1

III-V Compounds for Optoelectronic Applications

Substrate Compound	Bandgap eV(300K)	Wavelength Micrometers	Epitaxial Compounds	Comments
Gallium Arsenide	1.42	0.87	GaAs, AlGaAs	Good substrate for opto devices for audio disks and μwave, mm-wave, and optical communications; grown in wafers to100mm; can be used as substrate for HgCdTe and other II-VI compounds
Gallium Antimonide	0.69	1.79	GaAsSb, AlGaAsSb, AlInAsSb	Substrate for LW detectors; substrate technology not yet mature
Gallium Phosphide	2.25	0.55	GaP, GaAsP	Substrate for visible LEDs; also provides best lattice match of III-Vs to Si

(Continued)

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Table 1 (Continued)

III-V Compounds for Optoelectronic Applications

Substrate Compound	Bandgap eV(300K)	Wavelength Micrometers	Epitaxial Compounds	Comments
Indium Antimonide	0.16	7.75	II-VI compounds	Can be used for lattice-matched II-VI compounds; good for cooled (70°K) IR detectors
Indium Arsenide	0.36	3.44		Used for cooled IR detectors
Indium Phosphide	1.35	0.92	InGaAs, AlInAs, InGaAsP	Good for optical ICs for LW fiber optics; made in wafers to 5cm; technology is immature

Source: Dataquest (August 1991)

Properties of GaAs

The properties of GaAs that make it unique for certain applications are compared with those of silicon in Table 2. GaAs has a cubic crystal structure. Each ion of gallium is symmetrically surrounded by 4 ions of arsenic, and vice versa. At standard conditions, the distance between nearest-neighbor GaAs pairs of atoms is 0.25 nanometers (nm). The types of structural imperfections that can occur in a GaAs crystal lattice include vacancies, substitutions, and impurities substitutions. In 1990, the state of the art for impurity levels of GaAs was approximately one foreign atom in 10^8 to 10^{11}.

Table 2

Comparison of GaAs and Si

Property	GaAs	Si
Relative Dielectric Constant	12.9	11.7
Energy Gap (eV)	1.42	1.12
Intrinsic Carrier Concentration (cm^{-3})	1.79×10^6	1.45×10^{10}
Linear Coefficient of Thermal Expansion ($°C^{-1}$)	6.86×10^{-6}	5.8×10^{-6}
Minority Carrier Lifetime (S)	10^{-8}	2.5×10^{-3}
Electrons	8,500	1,500
Holes	400	450
Resistivity (ohms-cm)		
Electrons	0.02	0.08
Holes	0.25	0.11
Semi-insulating ($10^7 cm^{-3}$ Doping)	10^7-10^9	10^3-10^5
Thermal Conductivity (W/cm-°C)	0.46	1.5
Saturated Electron Velocity (cm/S)	1.3×10^7	-

Source: Dataquest (August 1991)

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GaAs semiconductors offer several advantages over those made of silicon, but usually at a higher product cost than equivalent silicon functions of equivalent density. High mobility allows circuit-switching times of 3 to 10 times faster than silicon devices. Thus, it is possible to operate GaAs devices in excess of 40 GHz, and TI and others have performed experimental work above 100 GHz. Such speed potential accommodates present and planned microwave applications.

The speed-power product of GaAs is more efficient than (lower than) that of silicon (see Figure 1 in the section entitled "Executive Summary"). GaAs circuits are relatively insensitive to temperature and power supply variations and have an upper temperature range of 350°C, as compared with approximately 175°C for silicon. Also, GaAs devices tolerate higher levels of radiation than do silicon devices. The processes used to produce GaAs ICs contain 35 percent fewer masks and operations than those used for silicon CMOS and ECL ICs. Digital GaAs ICs can be manufactured without using any diffusion steps in the process.

III-V CRYSTAL GROWTH

Several techniques have been used to grow single crystals of GaAs. These include horizontal Bridgman (HB), vertical Bridgman, gradient freeze (GF), Czochralski (CZ), liquid-encapsulated Czochralski (LEC), LEK, float-zone, horizontal and vertical zoned melting, and magnetic LEC (MLEC).

Horizontal Bridgman Method

The HB technique starts with high-temperature formation of GaAs from gallium contained in a quartz boat and arsenic sealed in a quartz ampule. This process can also begin with polycrystalline GaAs. The gallium-filled boat is heated to 1,250°C; the arsenic is heated to 613°C. The ampule and boat are slowly pulled from the furnace to propagate single-crystal growth by freezing the melt to a seed crystal.

The major advantages of the Bridgman technique over LEC appear to be low equipment cost and low labor cost. The major disadvantages are as follows:

- Nonuniformities result from the requirement to cut at 54° from the growth axis to produce (100)-oriented wafers.
- The typical as-cut HB wafer is "D"-shaped, whereas LEC wafers are round.
- The HB material must be chromium doped to make it semi-insulating, resulting in redistribution of chromium that can cause device failure.

Czochralski (CZ) Methods

The LEC process used for growing GaAs crystals is similar to the CZ process for silicon. Both high- and low-pressure processes have been developed.

In the high-pressure process, boric oxide, gallium, and arsenide are placed in a quartz or pyrolytic boron crucible. As the temperature is increased, the boric oxide melts at 460°C, and GaAs formation occurs rapidly at 820°C. The high pressure (about 40 atm, nitrogen or argon) combined with the liquid boric oxide encapsulates the surface of the GaAs to prevent sublimation of poisonous arsenic. Pressure is then reduced to less than 20 atm to minimize crystal defects, and a seed crystal is pulled and rotated from the melt through the boric oxide layer.

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In the low-pressure method, gallium is melted in a crucible; then arsenic is injected by performing a vapor transfer through a fused silica or PBN tube under controlled temperature conditions. This offers the advantage of very precise control of the initial melt stoichiometry and also allows for an extra purification step for the arsenic.

Five approaches are reported for improving LEC-grown GaAs uniformity:

- Reducing the thermal gradient from the center to the outside of the crystal (LEK)
- Doping the melt with indium or some other material
- Growing the crystal in a rotating magnetic field (MLEC)
- Computer control of crystal diameter
- Injection of arsenic during crystal growth

In 1988, Sumitomo reported developments in its GaAs wafer production process that increased the yield of good wafers per ingot by a factor of three. Other improvements increased GaAs wafer diameter by 35 percent and significantly reduced defect density. However, these improvements have not been fully reflected in market prices.

Several companies specialize in crystal-growing equipment. Typical cost of a GaAs crystal grower ranges from $120,000 to $450,000 depending on the methodology and other requirements. Table 3 gives examples of recent offerings.

Gradient Freeze Method

The horizontal gradient freeze (HGF) technique is similar to Bridgman except that growth of a single-crystal ingot from a seed crystal is performed by slowly moving a temperature gradient of 3° to 5°C per inch through the furnace. HGF was one of the earliest-used methods for GaAs crystallization.

Table 3

GaAs Crystal-Growing Equipment

Approximate 1990 Supplier	Maximum Ingot Size	Type	Price Range ($)
Cambridge Instruments	4" x 12"+	MLEC	180K-350K
Crystalox Ltd.	2" x 12"	HB	110K-125K
Ferrofluidics Corp.	5" x 50"	LEC	NA
Kokusai Electric Co. Ltd.	3" x 20"	LEC	300K-400K
Leybold-Haraeus Tech.	3" x 20"	LEC	NA
Mellen Co. Inc.	0.75" x 12" to 4" x 22"	HB	149K-210K

NA = Not available
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GaAs Versus Si Growth

The growth of GaAs crystals poses unique problems. Because GaAs is a composite rather than a single element, the exact ratio of gallium to arsenic in the melt is an important equipment design and use factor. The slower freezing process of GaAs requires one-tenth the lift rate of silicon and a more stable, reliable system. Diameter control is more difficult to maintain with GaAs because the meniscus is below the layer of boron oxide and therefore not visible. All of these factors contribute to higher costs of GaAs wafers compared with silicon wafer costs.

WAFER SLICING

Wafer slicing of GaAs makes use of equipment similar to that used for silicon. Changes must be made to accommodate as much as 54° variation in orientation of the ingot holding mechanism. Thus, GaAs slicing equipment is somewhat more expensive than that for silicon.

LAPPING AND POLISHING

Conventional wafer lapping equipment used for silicon will handle GaAs without modification. The polishing media must be changed because material used for polishing silicon is highly corrosive to GaAs.

E-BEAM DIRECT WRITING

Once the wafer has been prepared for further processing, a photolithographic or similar method is used to start device formation. E-beam lithography is gaining acceptance among III-V device suppliers. E-beam equipment accommodates low-volume production, quick turnaround of new designs, submicron geometries, and critical mask layers in mix-and-match lithography.

CHEMICAL VAPOR DEPOSITION (CVD)

A variety of CVD techniques has been developed, including low-pressure (LP), plasma-enhanced (PE), photochemical (P), and metal organic (MO). Four major factors must be considered in the design of a CVD system: reactor configuration, method of heating, gas flow system, and method of process-parameter control.

EPITAXY

There are three major categories of GaAs, InP, and other III-V compound epitaxial layer processes: OMVPE, MBE, and MOMBE. These are briefly described as follows.

OMVPE

Organo-metallic vapor-phase epitaxy (OMVPE) is another name for metal-organic chemical-vapor deposition (MOCVD) also known as MOVPE and as OMCVD. This is the earliest-used epi

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process for the manufacture of GaAs devices and is still in wide usage, especially for the production of LEDs and many other opto devices.

MBE

Molecular-beam epitaxy (MBE) presently offers the most precise control of layer thickness. Producers of MBE wafers claim that the number of atomic layers can be controlled exactly. Very thin MBE layers are referred to as monolayers. MBE wafers are more costly than those produced by MOCVD or OMVPE because of equipment cost and throughput constraints; these costs are being reduced as a result of concerted equipment design effort.

MOMBE

Recently, industry efforts have been directed toward combining the best qualities of OMVPE and MBE in a process called MOMBE. The resultant process is intended to be used in production environments.

IMPLANTATION

Some GaAs device manufacturers are using an "all implanted" process that requires no diffusion tubes. Both ion implantation and proton implantation methodologies are now in use. Critical parameters of implant equipment are implant energy, wafer-handling characteristics, and doping uniformity. A major advantage of implantation is precise control over the depth and concentration of impurities, which enhances mass reproducibility. Another significant cost advantage is the reduction of the number of process steps required by as much as 35 percent.

WIRE BONDING

Although new bonding techniques are in development, the predominant method of connecting a GaAs die to package terminals or to other dies is wire bonding. Automatic bonders allow consistency of wire lengths and bonding strength, as well as reduced contamination during assembly. Siemens now offers some GaAs devices mounted on tape for use in TAB equipment. Manual bonding equipment is still used for the highest-performance GaAs microwave devices to ensure the desired impedance properties of the interconnections.

TEST AND MEASUREMENT

Test equipment continues to be a basic limitation to the volume production of GaAs and other III-V compound semiconductor devices, especially microwave monolithic ICs (MMICs) and digital ICs (digICs). Discrete devices now can be tested to 60 GHz, although most GaAs transistors are specified at 12 GHz and 18 GHz. Commercially available analog/linear systems are limited to approximately 100-MHz analog frequency and 40-MHz digital frequency, and resolution limit is 100ps. Overall system timing accuracy of commercially available digIC memory and LSI testers is limited to 350ps. The cost of specialized test equipment and the time required to guarantee parametric limits for GaAs devices cause total manufacturing costs to be higher than for comparable

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density, slower-speed Si functions. Companies such as TriQuint have developed their own test equipment in-house to overcome some of these limitations.

III-V DEVICES

Like silicon devices, III-V semiconductors range from diodes and transistors to VLSI circuits. Examples are described in the following paragraphs.

Gunn Diodes

The Gunn effect is named after J. B. Gunn of IBM, who discovered the effect in 1962. Gunn diodes are used primarily as microwave oscillators or sources of carrier frequencies for microwave circuits.

LEDs

Light-emitting diodes (LEDs) are the most prevalent III-V devices. LEDs are p-n heterostructures that emit visible light (photons) when electrons or holes injected through the junction collide and re-form. They are used as indicator lamps, displays, and other photonic sources.

Lasers

A laser (the acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation) is a device containing a medium into which energy is pumped, causing emission of an amplified light beam formed between mirrors at each end of the medium. One of the mirrors is partially transmitting, allowing emission of the amplified, collimated, coherent light beam. Semiconductor lasers constitute a small subset of laser devices. The term *solid-state* as applied to lasers does not imply semiconducting properties.

Laser emissions are highly chromatic (single-colored) and are available in wavelengths ranging from microwaves to X rays. Lasers may operate continuously or may be strobed at pulse durations ranging upward from less than 1ps (the time required for light to travel 0.3mm). Depending upon construction, power levels may range from less than 1μW to more than a terawatt (trillion watts). The energy of a laser is a function of photons emitted during a unit of time. Table 4 exemplifies single-photon energies for various frequencies of radiation.

The world's first laser, a solid-state (ruby) laser, was built and first operated in May 1960 by Dr. Theodore Maiman of Hughes Research Laboratories. His work followed the invention of the maser (*m*icrowave *a*mplification) by Dr. Charles Townes in 1954 and much work by others in the field. The second and third operable lasers were built of rare earth salts by Peter Sokorin and Mirek Stevenson of IBM. The first gas laser was developed at Bell Labs using a mixture of helium and neon; HeNe lasers are very popular today. None of these early lasers were semiconductors.

The semiconductor laser concept was first treated essentially and substantially correctly in John von Neumann's manuscript in 1953. The GaAs p-n junction laser diode was independently invented and reported by persons at IBM, GE, GTE, MIT Lincoln Laboratories, and RCA in 1962.

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Table 4

Energy of a Photon

Radiation	Typical Wavelength	Single-Photon Energy
IR	5000nm	0.00004fJ
Visible	500nm	0.0004fJ
UV	100nm	0.002fJ
X ray	0.5nm	0.4fJ
Gamma	0.005nm	40fJ

Source: Dataquest (August 1991)

The first CO_2 laser was demonstrated by Bell Labs in 1963, and the first metal-vapor laser was operated in 1965. Peter Sorokin discovered that dyes can be made to "lase" in 1966. A summary of major characteristics of several popular types of lasers is given in Table 5.

Semiconductor lasers in production today are made of GaAs and other compound semiconducting materials. Operated continuously, GaAs diode lasers may have output power ranging from less than 1μW to more than one-half watt. Commercial single-heterojunction diodes may be operated in pulse mode at up to 30 watts peak lasting less than 1us. Prices of semiconductor lasers range from less than 80 cents to more than $800,000 each, and intense effort is being directed toward producing GaAs lasers at a cost below 10 cents each.

IMPATT Diodes

An impact avalanche and transit time (IMPATT) diode consists of a Schottky junction reverse-biased into avalanche breakdown, a drift region, and an ohmic collecting contact. An IMPATT diode is used primarily as a high-power microwave carrier source. Because the avalanche process in

Table 5

Properties of Lasers

Name	Type	Wavelengths (Microns)	Output Power	Approximate Efficiency (%)	Typical 1990 Cost Range ($)
Nd:YAG	Solid	353; 530; 1,060	200MW	1	3,000-1M
Nd:Glass	Solid	350; 525; 1,050	500teraW	NA	3,000-176M
Eximer	Gas	157; 350	20GW	2	25,000-100,000
Diode	Semiconductor	633 to 30,000	600mW	10	0.80-800
Argon	Gas	488; 515	25W	0.01	5,000-25,000
CO_2	Gas	9,600; 10,600	30kW to 400kW	20	2,500-10,000
HeCd	Metal vapor	442	50mW	0.06	4,000-12,000
Dye	Liquid	380 to 1,000	1MW	1	3,500-60,000

NA = Not available
Source: Dataquest (August 1991)

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GaAs is relatively slow, it was believed that GaAs IMPATTs would be limited to a maximum of 30 GHz. The development of delayed secondary avalanche (DSA) mode IMPATTs has extended operation beyond 94 GHz. Typical applications are in mm-wave radars for smart munitions and minimissiles.

Power FETs

Power JFETs find many applications as high-frequency, high-power switches. The JFET has a high-input impedance and therefore requires low drive current. The use of GaAs increases the frequency response and power-handling capability over what is achievable using silicon. Dual-gate medium-power FETs, available in increasing numbers since 1985, allow the microwave module designer flexibility beyond that of single-gate power devices.

High-Power Amplifiers

Mid-1990 development activities in the area of power amplifiers were focused on broadband, 1W FETs with efficiencies above 40 percent and gain of more than 12dB.

Low-Noise Amplifiers (LNAs)

Low-noise amplifier (LNA) is a term used to refer to certain FETs as well as to certain ICs and modules. LNA FET devices are used in applications such as radar and EW. State-of-the-art LNA devices in 1990 function to more than 110 GHz with gains of 6db to 10dB.

FET Oscillators

Ten-GHz GaAs oscillator devices with well-defined temperature coefficients and Q values of 10,000 are available, and devices operating above 120 GHz have been achieved.

SDHTs (HEMTs)

Selectively doped heterojunction transistors (SDHTs), also referred to as high electron mobility transistors (HEMTs), outperform more conventional GaAs FETs at frequencies above 12 GHz. AT&T holds and has licensed the basic patent on this technology. In 1986, Gould, Inc., began marketing 0.50μ technology HEMTs and was quickly followed by Toshiba with 0.25μ devices. Sony and Fujitsu are close behind Toshiba in this technology, and several other manufacturers entered this market in 1988 and early 1989. By mid-1990, Fujitsu was producing 3 million HEMTs per month with plans to increase the run rate to 5 million per month.

HBTs

Heterojunction bipolar transistors (HBTs) have been developed by TRW, Rockwell, and others. This technology is expected to lead to another factor-of-three increase in GaAs logic speed.

Analog ICs

Although analog ICs may be designed for achievable frequency, the term analog as applied to III-V compound semiconductor ICs usually refers to ICs designed to operate below 3 GHz. Current

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production state of the art of GaAs analog ICs is at the SSI/MSI level, depending on the supplier's capabilities. Available functions include operational amplifiers, mixers, and other functions. This aspect of III-V technology is in the early growth phase of the product life cycle. At least one company, TriQuint, is presently producing combinations of analog and digital circuits on the same die.

MMICs and MIMICs

MMIC is a general term referring to analog ICs designed to operate at microwave frequencies (above 3 GHz). MMICs have been available since the late 1960s. The term MIMIC refers to a United States Department of Defense (DOD) initiative that will result in millimeter-wave/ microwave ICs for military applications or to circuits developed under the program. The MIMIC program started in 1987 with Phase 0 awards to 12 teams of companies. In mid-1988, Phase 1 awards were made to 4 teams. The MIMIC program is expected to be completed in the early 1990s. MIMIC circuits will function as the "eyes and ears" of military hardware, to complement the VHSIC "brains." Awards of Phase II contracts were imminent at press time (early August 1991).

Digital ICs

Initial digIC (digital IC) functions implemented in GaAs were based on D-MESFET technology. In the mid-1980s, Vitesse and other companies were working on enhancement/depletion (E/D) implementations in an effort to increase the level of integration of digICs. The state of the art in mid-1990 was represented by 16K and 64K SRAMs and 100K gate arrays in low-volume production at a small number of suppliers and by larger SRAMs and 100K to 350K gate arrays in prototyping. E/D IC development is advancing rapidly at several companies, including IBM, TriQuint, and Vitesse.

Photovoltaics

GaAs and other III-V compound materials are used to construct photosensitive diodes and transistors. Such diodes and transistors may be used as detectors for fiber-optic and microwave links. The junction solar cell is a special case of photovoltaics; silicon solar cells were first reported in 1954. Conversion efficiency is a major consideration in photodetectors and limits their applicability to situations where performance or other factors override cost. GaAs device conversion efficiencies approaching 30 percent have been reported.

Optocouplers

Optocouplers consist of semiconductor emitters and photodetectors in the same package. Optocouplers are used to accomplish isolation in electronic systems. The emitter is a III-V diode, and the detector may be either a III-V device or a silicon device, depending on the desired operational properties. Previously this function area was restricted to much lower-frequency operation by the limitations of mechanical devices and silicon emitters. Companies such as Optek offer a variety of such GaAs products.

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Interruptors

Like optocouplers, an interruptor consists of an emitter and a photodetector in the same package. Interruptors act as switches and are used to detect motion in electronic systems. The emitter is a III-V diode, and the detector is usually a silicon device. Like the applications areas of optocouplers, this function area was previously restricted to much lower-frequency operation by the limitations of mechanical devices and silicon emitters.

Integrated Optoelectronics

Optoelectronic ICs consisting of both electronic and photonic switching and other functions on the same die such as, for example, the multiplexer, timer, and laser driver for a fiber-optic link, are opening new markets and applications. In future systems, high-speed digICs may be connected optically instead of electrically for added performance. AT&T, IBM, Litton, Rockwell, and others are making significant progress in this area.

ASICs

In mid-1991, there were approximately 16 foundries in the free world offering GaAs ASICs to the merchant market. One driving force behind this is the requirement for design security, particularly for government and leading-edge commercial applications. Both linear and digital functions are now available in standard cell ASICs, and many foundries offer gate arrays as well as full-custom services. Mask-programmable ROMs and laser-programmable logic devices (PLDs) also are available.

EMI Considerations in GaAs IC Systems Design

The high-frequency operation of GaAs circuits necessitates that subsystem or system designers take special precautions against electromagnetic interference (EMI). The point-to-point wiring techniques normally allowable in designing with TTL or CMOS cannot be used because provision must be made for impedance-matching in even the shortest interconnects. The following examples illustrate voltage differentials encountered in real-world situations, further complicating GHz-frequency systems design:

- In a rack or bay of electronic equipment, several hundred millivolts differential can develop between boxes.
- In a land-based vehicle, several volts potential may exist among various points in its steel structure.
- Throughout the volume of an aircraft, differentials of as much as 100 volts may exist between structural points.
- On a ship, several hundred volts differential may exist between decks, superstructures, and rigging.
- In a building, several kilovolts may develop in case of power failure, nearby lightning, and other conditions.

In GaAs structures, thresholds may be as low as 50 to 60 millivolts instead of 400 to 2,000 millivolts experienced in silicon circuits. Signals may change logic states in 10ps to 200ps as

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compared with 250ps to 2ns for silicon circuits. These factors each make EMI protection more difficult and, combined, dictate the need for transmission line considerations in any interconnections operating at or above silicon ECL frequencies.

RADIATION HARDNESS OF GaAs

Like any other semiconductor circuits, GaAs ICs are affected by neutrons, protons, electrons, gamma rays, and cosmic rays; these induce displacement of atoms, ionization of atoms, and internal energy changes. Compared with silicon devices, GaAs ICs are generally more radiation-resistant. In practical applications, the effects of EMP and X rays are minimized by shielding, current limiting, or other circumvention circuitry.

Total dosage of 5×10^7 rad (GaAs) causes no noticeable changes in today's GaAs ICs; this is 5 times better than silicon ECL and 50 times better than silicon T^2L. Pulsed ionizing radiation of 20ns maximum must reach 10^{10} to 10^{11} rad (GaAs) per second to cause logic upset for 1-micron channel-length devices, which is comparable to silicon. DCFL circuits have been tested at 10^{14}n/cm^2 (E>10keV) neutron exposure with no failures; however, further testing is needed to establish the ultimate tolerance to fast neutrons. SEU susceptibility is still under investigation. It is reported that radiation studies on GaAs devices have been performed with the support of AFWAL and DARPA contracts.

A good indicator of production-worthiness of ICs for military applications is the extent to which rad-hard testing has been performed and the range of products under test. Recent papers on this subject describe a number of advances made in the hardness of GaAs ICs.

Transient radiation effects on GaAs BFL ICs have been studied by TriQuint and others. Measurements were made on NOR gates, ring oscillators, ripple counters, and gate arrays. Upset levels for transient radiation pulses of 3ns, 50ns, and 1.5µs (1,500ns) duration were investigated in terms of dosage and dose rate. Test results showed that the dose per pulse had more impact on upset level than did dose rate. The results also showed that the apparent hardness level increases with increasing dose rate.

A design constraint of the Rockwell 16K GaAs SRAM chip design was a requirement for radiation hardness. Test results indicate that an additional benefit of the hardness of the design is assurance that alpha-particle errors will be nonexistent.

Radiation hardness tests have been performed by Honeywell on GaAs ring oscillators. Degradation in transconductance was shown to be less than 4 percent at 250 Mrads (GaAs) total dose. Shift in FET threshold was less than 15 percent, several orders of magnitude better than for silicon chips. Flash X-ray exposure tests showed hardness to 2×10^{10} rads(GaAs)/s dose rate for frequency divider and digital multiplier circuits, at least one order of magnitude harder than for silicon circuits. The particular circuits under test were not designed specifically for tolerance of radiation.

GaAs ON SILICON

The first paper on GaAs-on-Si was presented by MIT researchers in 1981 in the IEEE Electron Device Letters. Since then, the potential for large-diameter wafers for GaAs manufacture and for monolithic integration of photonic and electronic functions at low cost has attracted R&D talent and investment capital.

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Kopin Corporation disclosed at the 1987 GaAs IC conference that it has sampled 2-inch, 3-inch, and 4-inch GaAs-on-Si wafers to more than 10 beta sites. Kopin began shipping 4-inch production wafers by December 1987. The growth of GaAs on silicon wafers on a production basis is described by John C. C. Fan, founder of Kopin, as "the enabling technology for future GaAs market growth."

Initial beta sites for Kopin wafers included TriQuint, which reported satisfaction with the mechanical properties of 3-inch material. From the standpoint of interface defects due to lattice mismatch, GaAs-on-Si is believed to be equivalent to GaAs wafers for FETs and other majority-carrier devices, but inferior for minority-carrier devices such as lasers and solar cells.

Kopin's proprietary approach minimizes the propagation of lattice mismatches at the Si-GaAs interface, into the GaAs layer. Kopin starts with a variation of 1-0-0 Si wafers for processing through a series of steps including a proprietary cleaning procedure, CVD-growth of approximately 5μ of GaAs, then thermal cycling to remove stress and lattice mismatches.

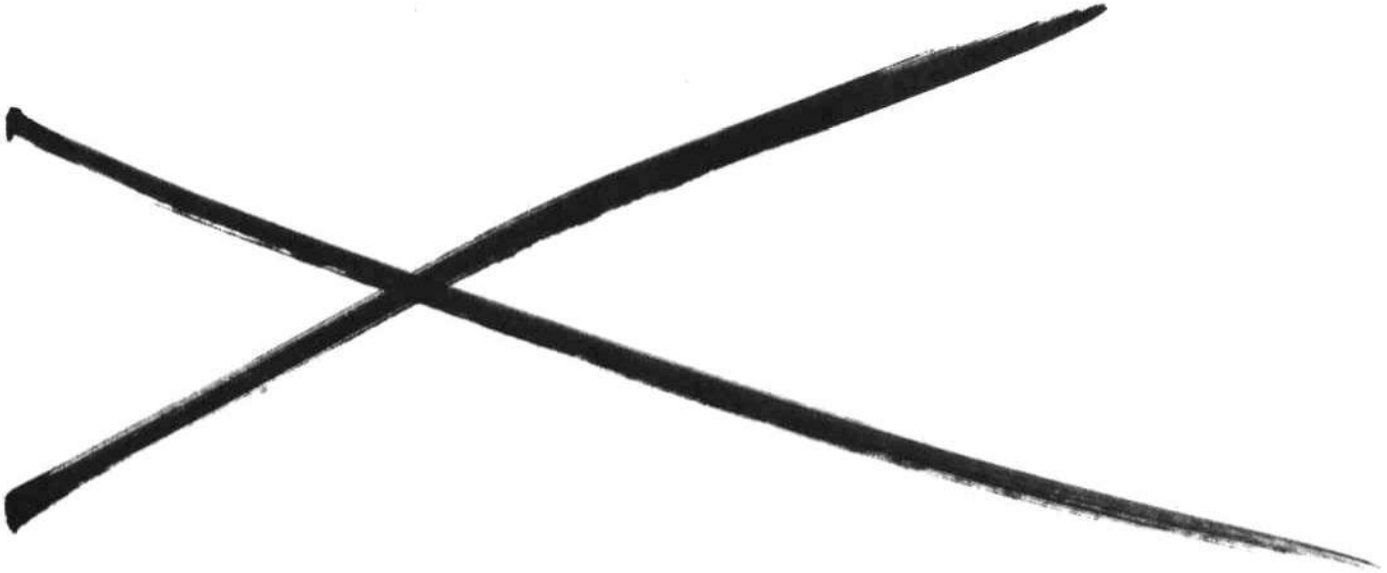
Several Japanese companies have attempted to produce GaAs-on-Si, but none has matched Kopin's performance to date. GaAs-on-Si is expected to have a major impact on the industry by reducing manufacturing costs at the IC houses, but this has not been realized as of mid-1991.

Other companies and groups involved in GaAs-on-Si technology include AT&T Bell Labs, GTE, Hewlett-Packard, MIT, Spire Corporation, TI Materials Science Laboratory, and the University of Illinois. Some examples are as follows:

- TI fabricated 1K SRAMs using GaAs-on-Si starting in 1986.
- In 1987, University of Illinois researchers fabricated the first reported GaAs-on-Si continuous-wave (cw) lasers that operate at room temperature.
- Ford Microelectronics planned products that combine III-V and II-VI materials on Si substrates of up to 200mm (8 inches) diameter. Ford fabricated functional chips, containing 6,600 GaAs transistors each, on silicon 3-inch substrates. However, Ford withdrew from the market in 1990.

Much research is under way to determine whether GaAs-on-Si continuous wave lasers can be reduced to practice. Should long life and reproducibility be established, GaAs cw lasers would be obsoleted rapidly by GaAs-on-Si, which would foster significant high volumes of innovative products.

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APPENDIX A--SHIPMENTS AND CONSUMPTION DATA

INTRODUCTION

Appendix A consists of a set of detailed tables that estimate GaAs semiconductor industry production and consumption for 1984 and 1985 and a worldwide consumption forecast through 1990. A list of Appendix A tables detailing the type of data, years, and units is as follows:

Table Number	Type of Data	Calendar Years	Units
A-0	Exchange Rates	1984-1985	Various
A-1	Shipments History	1984-1985	Dollars
A-2	Shipments History	1984-1985	Dollars
A-3	Shipments History	1984-1985	Dollars
A-4	Shipments History	1984-1985	Dollars
A-5	Shipments History	1984-1985	Yen
A-6	Consumption Forecast	1984-1990	Dollars
A-7	Consumption History	1984-1985	Dollars
A-8	Consumption History	1984-1985	Dollars
A-9	Consumption History	1984-1985	Dollars
A-10	Consumption History	1984-1985	Dollars
A-11	Consumption History	1984-1985	Yen
A-12	Shipments History	1984-1985	Dollars
A-13	Consumption History	1984-1985	Dollars

DEFINITIONS AND CONVENTIONS

Dataquest uses a common manufacturer base for all data tables. This base includes all suppliers to the merchant semiconductor market. It excludes captive suppliers that manufacture devices solely for the benefit of the parent company, such as AT&T Technologies (formerly Western Electric), Burroughs, and IBM. Included, however, are companies that actively market semiconductor devices to the merchant market as well as to other divisions of their own companies. A recent case in point is NCR, previously a captive supplier, which in 1982 offered products on the merchant market for the first time. For such companies, both external shipments and internal consumption are included. Devices that are used internally are valued at current market prices.

Consumption

Dataquest defines consumption as the purchase of a semiconductor device or devices. This definition must be differentiated from actual use of the device in a final product. Devices that are inventoried at the user level are considered consumption according to our definition.

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Factory Shipment Location

The fabrication and assembly of a semiconductor device can be performed in several different locations. Factory shipment is defined as occurring from the point where the device was tested and marked, irrespective of where the device was assembled or where the initial wafer fabrication was performed.

Power Devices

The difference between low-power and high-power transistors is set at the 1-watt power-handling capability.

Regions

North America includes both the United States and Canada. Latin America, including Mexico, is considered part of the Rest of World (ROW) category. "Worldwide" comprises data from ROW, Western Europe, and Japan, as opposed to North American data.

DATA SOURCES

The information presented in the consumption/factory shipment data is consolidated from a variety of sources, each of which focuses on a specific part of the market. These sources include U.S. Commerce Department trade statistics and the Semiconductor Trade Statistics Program (STSP) marketing data, which are used in determining North American consumption and factory shipments.

Dataquest believes that the estimates presented here are the most accurate and meaningful that are generally available today. The sources of these data and guidelines for the forecasts presented in the tables are:

- Unit sales or revenues (or both) published by major industry participants, both in the United States and abroad
- Estimates presented by knowledgeable and reliable industry spokespersons
- Government data or trade association data such as those from the Electronics Industry Association (EIA), MITI, SIA, and the U.S. Department of Commerce
- Published product literature and price lists
- Interviews with knowledgeable manufacturers, distributors, and users
- Relevant projected world economic data

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CONSISTENCY

One of the key objectives in preparing these estimates is to achieve consistency among the various data elements that constitute the forecast and the historical data base. To ensure the accuracy and consistency of the estimates, we have compared the value of directly obtained data elements with values obtained by indirect means, wherever possible.

ACCURACY

The tables presented here represent Dataquest estimates that we believe are reasonably accurate. Where we have no reasonable estimate, none is given. A blank space in a table indicates that a reasonably accurate estimate is unavailable, and a zero in a table represents an estimate.

FORECASTS

Historical data are expressed in current dollars or dollars that include the given year's inflation rate and exchange rates. However, the consumption forecasts use constant dollars with no allowance for inflation. All estimates for 1985 and beyond are made as if 1985 monetary conditions will continue through 1990 and, therefore, show the absolute year-to-year growth during this period.

NEED FOR CAREFUL INTERPRETATION

Despite the care taken in gathering and analyzing the available data and in attempting to categorize those data in a meaningful way, careful attention must be paid to the definitions and assumptions used herein when interpreting the estimates presented in these tables. Various companies, government agencies, and trade associations may use slightly different definitions of product categories and regional groupings, or they may include different companies in their summaries. These differences should be kept in mind when making comparisons between these data and those provided by others.

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Table A-0

EXCHANGE RATES

	1984	1985
Yen/Dollar	237	238
Pounds/Dollar	0.75	0.78
Deutsche Marks/Dollar	2.85	2.94
French Francs/Dollar	8.74	8.98

Source: IMF

Table A-1

WORLDWIDE GaAs MERCHANT SHIPMENTS BY TECHNOLOGY
(Millions of Dollars)

Category	1984	1985
Analog ICs	43	75
MMIC Amps	18	25
ASICs	14	31
Other	11	19
Digital ICs	11	26
Standard Logic	1	4
RAMs	0	1
ASICs	8	18
Other	2	3
Optoelectronics	1,392	1,411
LEDs	869	812
Optocouplers/Isolators (GaAs content only)	327	309
Lasers	133	218
Detectors	25	29
Photovoltaic Cells	30	23
Integrated Opto Devices	8	20
Other Discretes	141	196
SS Transistors	82	125
Power Transistors	49	61
Hall Elements	10	10

Note: Totals may not add due to rounding.

Source: Dataquest
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Table A-2

U.S. GaAs MERCHANT SHIPMENTS BY TECHNOLOGY
(Millions of Dollars)

Category	1984	1985
Analog ICs	42	73
MMIC Amps	17	24
ASICs	14	30
Other	11	19
Digital ICs	10	24
Standard Logic	1	4
RAMs	0	1
ASICs	8	17
Other	1	2
Optoelectronics	448	375
LEDs	264	212
Optocouplers/Isolators (GaAs content only)	104	79
Lasers	27	23
Detectors	15	18
Photovoltaic Cells	30	23
Integrated Opto Devices	8	20
Other Discretes	75	87
SS Transistors	30	35
Power Transistors	45	52

Note: Totals may not add due to rounding.

Source: Dataquest
January 1987

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Table A-3

WESTERN EUROPEAN GaAs MERCHANT SHIPMENTS BY TECHNOLOGY
(Millions of Dollars)

Category	1984	1985
Analog ICs	1	2
MMIC Amps	1	1
ASICs	0	1
Other	0	0
Digital ICs	1	2
Standard Logic	0	0
RAMs	0	0
ASICs	0	1
Other	1	1
Optoelectronics	126	143
LEDs	94	107
Optocouplers/Isolators (GaAs content only)	20	22
Lasers	2	3
Detectors	10	11
Photovoltaic Cells	N/A	N/A
Integrated Opto Devices	0	0
Other Discretes	9	10
SS Transistors	5	6
Power Transistors	4	4

Note: Totals may not add due to rounding.
N/A = Not Available

Source: Dataquest
January 1987

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Table A-4

JAPANESE GaAs MERCHANT SHIPMENTS BY TECHNOLOGY
(Millions of Dollars)

Category	1984	1985
Analog ICs	0	0 (All Captive)
MMIC Amps	0	0
ASICs	0	0
Other	0	0
Digital ICs	-	0 (All Captive)
Standard Logic	-	0
RAMs	-	0
ASICs	-	0
Other	-	0
Optoelectronics	661	721
LEDs	413	398
Optocouplers/Isolators	164	168
Lasers	84	155
Detectors	-	0
Photovoltaic Cells	-	-
Integrated Opto Devices	-	-
Other Discretes	46	80
SS Transistors	38	68
Power Transistors	0	4
Hall Elements	8	8

Note: Totals may not add due to rounding.

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Table A-5

JAPANESE GaAs MERCHANT SHIPMENTS BY TECHNOLOGY
(Billions of Yen)

Category	1984	1985
Analog ICs		
MMIC Amps	0	0
ASICs	0	0
Other	0	0
Digital ICs		
Standard Logic	-	0
RAMs	-	0
ASICs	-	0
Optoelectronics	157	172
LEDs	98	95
Lasers	20	37
Detectors	-	0
Photovoltaic Cells	-	-
Optocouplers/Isolators	39	40
Integrated Opto Devices	-	-
Other Discretes	11	19
SS Transistors	9	16
Power Transistors	0	1
Hall Elements	2	2

Note: Totals may not add due to rounding.

Source: Dataquest
January 1987

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Table A-6

WORLDWIDE GaAs MERCHANT CONSUMPTION FORECAST BY TECHNOLOGY
(Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR(%)
Analog ICs	46	80	117	173	237	331	448	551	42.6
Digital ICs	11	26	51	99	187	337	506	657	79.4
Discrete Opto	1,152	1,089	1,361	1,602	1,811	1,866	2,136	2,367	10.8
Integrated Opto	8	20	28	43	67	104	162	267	65.1
Microwave Discrete	122	156	210	273	341	410	450	529	23.3
Total	1,339	1,371	1,767	2,190	2,643	3,048	3,702	4,371	18.4

Totals may not add due to rounding

Assumptions:

Sustained materials, quality improvements and open-market availability of DF wafers.

No predatory pricing by major suppliers.

Successful MIMIC program funded in excess of $300M over 5 years.

Source: Dataquest
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Table A-7

WORLDWIDE GaAs CONSUMPTION BY END USE
(Millions of Dollars)

Application	1984	1985
Military/Government Satcom, ECM, EW, Radar, Surveillance, DSP		
Communications Fiber Optics--Long Lines and LANs, Lasers, Microwave Links, Cellular Radio, Commercial Satcom, TVRO		
Data Processing Supercomputers, Superminis, Peripherals	Data to be supplied 4/87	
Instrumentation		
Automotive		
Consumer		

Note: Totals may not add due to rounding.

Source: Dataquest
January 1987

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Table A-8

U.S. GaAs CONSUMPTION BY END USE
(Millions of Dollars)

Application	1984	1985
Military/Government		
Satcom, ECM, EW, Radar, Surveillance, DSP	152	155
Communications		
Fiber Optics--Long Lines and LANs, Lasers, Microwave Links, Cellular Radio, Commercial Satcom, TVRO	239	245
Data Processing		
Supercomputers, Superminis, Peripherals	139	107
Instrumentation	53	54
Automotive	20	18
Consumer	60	54

Note: Totals may not add due to rounding.

Source: Dataquest
January 1987

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Table A-9

WESTERN EUROPEAN GaAs CONSUMPTION BY END USE
(Millions of Dollars)

Application	1984	1985
Military/Government		
Satcom, ECM, EW, Radar, Surveillance, DSP	96	113
Communications		
Fiber Optics--Long Lines and LANs, Lasers, Microwave Links, Cellular Radio, Commercial Satcom, TVRO	75	86
Data Processing		
Supercomputers, Superminis, Peripherals	N/A	N/A
Instrumentation	45	50
Automotive	7	7
Consumer	23	25

Note: Totals may not add due to rounding.
N/A = Not Available

Source: Dataquest
January 1987

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Table A-10

JAPANESE GaAs CONSUMPTION BY END USE
(Millions of Dollars)

Application	1984	1985
Military/Government		
Satcom, ECM, EW, Radar, Surveillance, DSP	0	0
Communications		
Fiber Optics--Long Lines and LANs, Lasers, Microwave Links, Cellular Radio, Commercial Satcom, TVRO	88	143
Data Processing		
Supercomputers, Superminis, Peripherals	72	71
Instrumentation	143	143
Automotive	34	33
Consumer	231	260
Total	568	650

Note: Totals may not add due to rounding.

Source: Dataquest
January 1987

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Table A-11

JAPANESE GaAs CONSUMPTION BY END USE
(Billions of Yen)

Application	1984	1985
Military/Government		
Satcom, ECM, EW, Radar, Surveillance, DSP	0	0
Communications		
Fiber Optics--Long Lines and LANs, Lasers, Microwave Links, Cellular Radio, Commercial Satcom, TVRO	21	34
Data Processing		
Supercomputers, Superminis, Peripherals	17	17
Instrumentation	34	34
Automotive	8	8
Consumer	55	62
Total	135	155

Source: Dataquest
January 1987

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Table A-12

GaAs SHIPMENTS BY REGION
(Millions of Dollars)

Region	1984	1985
North America	575	559
Western Europe	137	167
Asia	707	801
ROW	0	0
Total	1,419	1,527

Note: Totals may not add due to rounding.

Table A-13

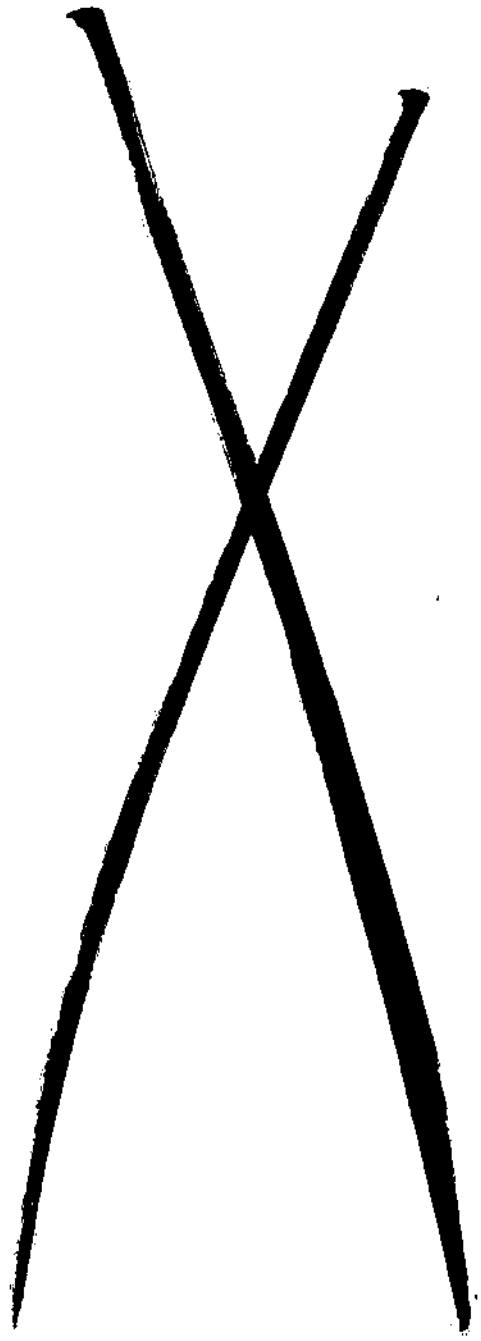
GaAs CONSUMPTION BY REGION
(Millions of Dollars)

Region	1984	1985
North America	663	635
Western Europe	246	281
West Germany	89	100
France	84	98
United Kingdom	60	66
ROE	13	17
Asia (Japan)	568	650
ROW	0	0
Total	1,477	1,566

Note: Totals may not add due to rounding.

Source: Dataquest
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APPENDIX B--MARKET SHARE DATA

INTRODUCTION

Appendix B consists of a set of detailed tables that estimate GaAs semiconductor industry market share data for 1984 and 1985. This analysis provides insights into semiconductor markets and reinforces estimates of consumption, production, and company revenues that were made using other data. A list of Appendix B tables detailing the type of data, years, and units is as follows:

Table Number	Type of Data	Calendar Years	Units
B-1	Market Share Estimates	1984-1985	Dollars
B-2	Market Share Estimates	1984-1985	Dollars
B-3	Market Share Estimates	1984-1985	Pounds
B-4	Market Share Estimates	1984-1985	French Francs
B-5	Market Share Estimates	1984-1985	Deutsche Marks
B-6	Market Share Estimates	1984-1985	Dollars
B-7	Market Share Estimates	1984-1985	Yen

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Power Devices

The difference between low-power and high-power transistors is set at the 1-watt power-handling capability.

DATA SOURCES

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CONSISTENCY

One of the key objectives in preparing these estimates is to achieve consistency among the various data elements that constitute the forecast and the historical data base. To ensure the accuracy and consistency of the estimates, we have compared the value of directly obtained data elements with values obtained by indirect means, wherever possible.

ACCURACY

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NEED FOR CAREFUL INTERPRETATION

Despite the care taken in gathering and analyzing the available data and in attempting to categorize those data in a meaningful way, careful attention must be paid to the definitions and assumptions used herein when interpreting the estimates presented in these tables. Various companies, government agencies, and trade associations may use slightly different definitions of product categories and regional groupings, or they may include different companies in their summaries. These differences should be kept in mind when making comparisons between these data and those provided by others.

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Table B-1

WORLDWIDE MARKET SHARE ESTIMATES--SALES BY U.S. GaAs MANUFACTURERS
(Millions of Dollars)

Company	1984 Share	1985 Share
Adams Russell	5	10
Alpha Industries	7	11
Avantek	12	17
Dexcel (Gould)	6	8
GE	28	20
GI Opto Division	51	40
GigaBit Logic	1	7
Harris Microwave	2	4
Honeywell	27	22
HP	152	139
Hughes	5	9
M/A-COM	21	29
Microwave Monolithics	1	3
MicroWave Technology Inc.	1	3
Motorola	19	21
Narda	10	15
Pacific Monolithics	0	7
Rockwell	2	8
Spectra Diode Labs	3	5
Teledyne	4	5
Texas Instruments	50	39
TriQuint	0	7
TRW	64	46
Others	92	65
Total	563	540

Note: Totals may not add due to rounding.

Source: Dataquest
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Table B-2

MARKET SHARE ESTIMATES--WESTERN EUROPEAN GaAs SUPPLIERS
(Millions of Dollars)

Company	1984 Share	1985 Share
Isocom	11	15
Litronix*	N/A	N/A
Microwave Semiconductor*	N/A	N/A
Philips	18	25
Plessey Three-Five	3	3
Siemens	70	75
Thomson CSF	2	3
Others	33	46
Total	137	167

N/A = Not available separately
*Included in Siemens data
Note: Totals may not add due to rounding.

Table B-3

MARKET SHARE ESTIMATES--WESTERN EUROPEAN GaAs SUPPLIERS
(Millions of £)

Company	1984 Share	1985 Share
Isocom	8	12
Litronix*	N/A	N/A
Microwave Semiconductor*	N/A	N/A
Philips	13	19
Plessey Three-Five	2	2
Siemens	52	58
Thomson CSF	2	2
Others	25	36
Total	102	129

N/A = Not available separately
*Included in Siemens data
Note: Totals may not add due to rounding.

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Table B-4

MARKET SHARE ESTIMATES--WESTERN EUROPEAN GaAs SUPPLIERS
(Millions of FFr)

Company	1984 Share	1985 Share
Isocom	31	44
Litronix*	N/A	N/A
Microwave Semiconductor*	N/A	N/A
Philips	51	73
Plessey Three-Five	8	9
Siemens	179	220
Thomson CSF	6	9
Others	94	135
Total	369	490

*Not available separately; included in Siemens data
Note: Totals may not add due to rounding.

Table B-5

MARKET SHARE DATA--WESTERN EUROPEAN GaAs SUPPLIERS
(Millions of DM)

Company	1984 Share	1985 Share
Isocom	96	134
Litronix*	N/A	N/A
Microwave Semiconductor*	N/A	N/A
Philips	157	224
Plessey Three-Five	26	27
Siemens	612	673
Thomson CSF	17	27
Others	288	413
Total	1,196	1,498

*Not available separately; included in Siemens data
Note: Totals may not add due to rounding.

Source: Dataquest
January 1987

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Table B-6

MARKET SHARE ESTIMATES--JAPANESE GaAs SUPPLIERS
(Millions of Dollars)

Company	1984 Share	1985 Share
ABM Semiconductor		
California Eastern Labs (NEC)		
Fujitsu		
Hitachi		
KDD (ITT Japan)		
Matsushita		
Mitsubishi		
NEC	Data to be supplied 4/87	
NTT		
Oki Electric		
Sharp		
Sony		
Stanley		
Toshiba		
Others		
Total	707	801

Note: Totals may not add due to rounding.

Table B-7

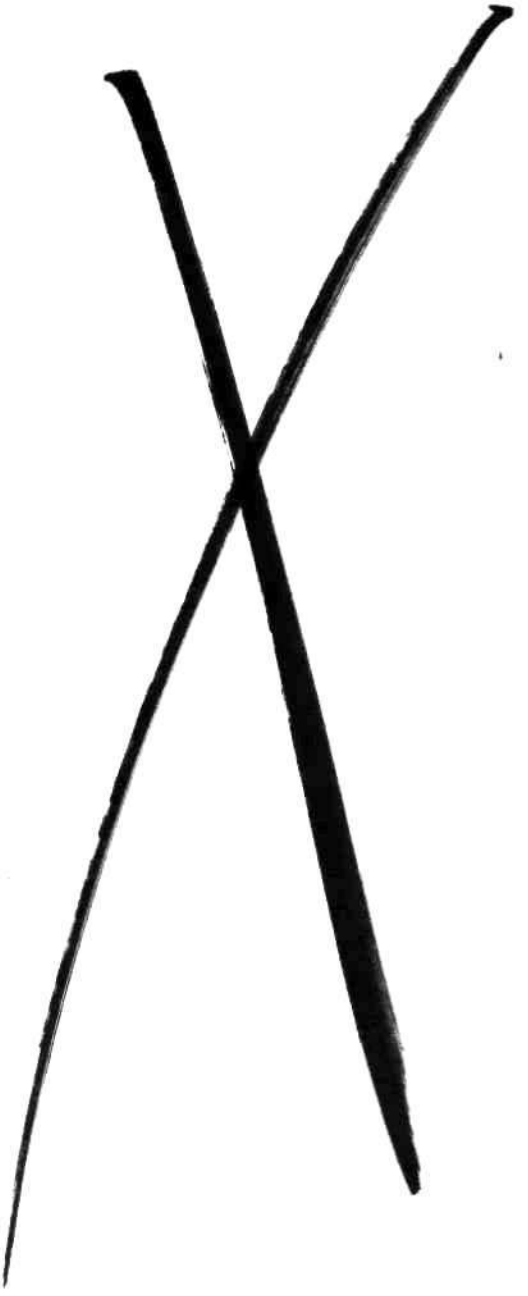
MARKET SHARE ESTIMATES--JAPANESE GaAs SUPPLIERS
(Millions of Yen)

Company	1984 Share	1985 Share
ABM Semiconductor		
California Eastern Labs (NEC)		
Fujitsu		
Hitachi		
KDD (ITT Japan)		
Matsushita		
Mitsubishi		
NEC	Data to be supplied 4/87	
NTT		
Oki Electric		
Sharp		
Sony		
Stanley		
Toshiba		
Others		
Total		

Note: Totals may not add due to rounding.

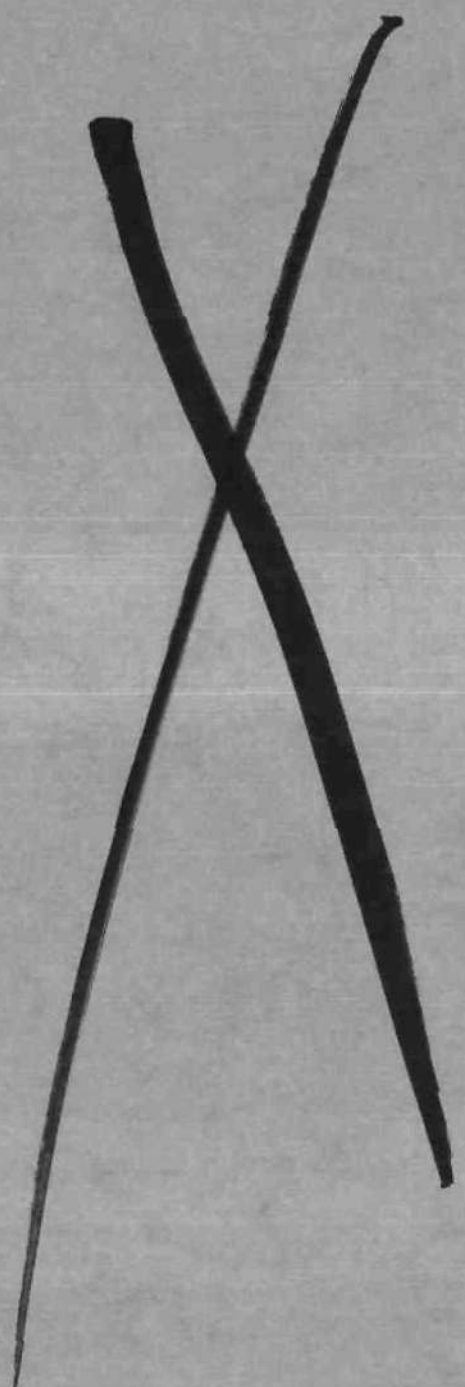
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APPENDIXES C, D, AND E NOT USED AT THIS TIME.

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Foundries

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GaAs foundry activity is intensifying, as commercial usages of digICs and MMICs gain market momentum. The lineup of players is changing, and new services are entering the market. Significant improvements in responsiveness occurred in 1990, as production rates increased and yield enhancements were made.

Fifteen GaAs foundries serve the free-world merchant marketplace. Thomson-CSF, which already has a foundry for French government contract work, is expected to join the ranks in the near future. Japan's candidates include at least four of the major silicon suppliers, a situation very different from that in the United States. Since early 1987, processes have advanced below 0.5μ at several facilities to support microwave performance demands.

The GaAs industry clearly has an abundant capacity to support VLSI-density digital and microwave analog custom and semicustom IC production. Substantial advancement in yields and level of service has been noted since 1987. Commercially viable products are increasingly evident in the many multiproject wafer and semicustom activities now under way throughout this industry. The infrastructure is rapidly evolving to provide improved CAD tools and other necessary support.

This section summarizes the major announced GaAs foundry services and facilities. Table 1 shows the capabilities by company. Tables 2 and 4 provide the early 1991 locations, telephone numbers, and foundry contacts by company. Additional data on services and costs are in Tables 3 and 5. The text provides further details about each company's capabilities. (At press time, the merger of GigaBit Logic into TriQuint was in progress. In November 1989, Fujitsu announced that it will second-source Vitesse's "Fury" series of gate arrays. Fujitsu's foundry plans were not available at press time.)

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Table 1

Merchant Market GaAs Foundries

Company	Process	Product	Comments
Adams-Russell	See text		
ANADIGICS	0.5µ D-MESFET	MMICs, digICs	Multiproject wafers
Avantek	0.5µ MESFET	MMICs	150,000-square-foot facility
COMSAT Labs	0.25µ MESFET and HEMT	MMICs	To 90 GHz+
Fujitsu	E/D MESFET and HEMT	MMICS,dig-ICs	Building $200 million facility
GAIN	See text		
GigaBit Logic	See text		
Harris Micro	1µ, 0.5µ MESFET	MMICs, digICs	Cell library
Honeywell	See text		
ITT GTC	0.4µ, 0.5µ D-, E-/D-MESFET	MMICs, digICs	Superior temperature test capacity
M/A-COM	0.8µ, 0.5µ, 0.25µ	MMICs	Acquired Adams-Russell
MSC	See text		
Plessey Three-Five	0.7µ D-MESFET	MMICs	Emphasis on quality control
Raytheon	0.5µ, 0.25µ D-MESFET	MMICs	Start-up in 1989
Rockwell	D-MESFET, HEMT	DigICs	250 3-inch wafers/ shift/ week
Sanders	0.5µ, 0.25µ	MMICs	To 40+ GHz
Tachonics	See text		
TI MMCD	0.5µ D-MESFET	MMICs	Three process profiles
TriQuint	1µ, 0.7µ, 0.5µ E-/ D-MESFET	DigICs, MMICs	Multiproject wafers
Varian	0.25µ HEMT	MMICs	To 40 GHz
Vitesse Semi	Scaled E-/D-MESFET	DigICs	Technology exchange with AMD, Fujitsu

Source: Aztek Associates

Analog/Linear GaAs Foundries

Microwave, millimeter wave, and other analog functions represent a continuing opportunity for many GaAs foundries. Because unique specifications are usually imposed by each customer and each application, and because the NRE costs are significant, the responsive foundry has an opportunity to support repeat business. Most foundries are continuing to develop and implement ASIC capabilities in response to specific market needs.

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Increasing availability of 3-inch and 4-inch MOCVD and MBE wafers with improved defect densities, coupled with enhanced modeling of GaAs functions on relatively inexpensive workstations, has caused a rapid migration toward monolithic ASIC solutions to multifunctional microwave design problems. As is the case in silicon technology, GaAs ASICs often provide the most cost-effective approach for both customer and supplier.

Several companies offer GaAs ASIC support via foundry services. Major MMIC ASIC foundries, locations, and contacts are summarized in Table 2, and the capabilities of these foundries are listed in Table 3.

Table 2

Analog/Linear GaAs Foundry Contacts

Company/Location	Phone	Foundry Contact
ANADIGICS Warren, NJ	(201) 668-5000	Javed Patel Director, marketing and sales
Avantek Santa Clara, CA	(408) 727-0700	Peter Manno Vice president, marketing and sales
COMSAT Labs Clarksburg, MD	(301) 428-4000	Dr. Ho Chung Huang Executive director, micro division
Ford Microelectronics Colorado Springs, CO	See text	
Harris Milpitas, CA	(408) 433-2222	Jim Klug Program director
ITT GTC Roanoke, VA	(703) 563-3912	Joe Grzyb Project manager
M/A-COM Lowell, MA	(508) 453-3100	Robert Tingley Director, marketing and sales
Plessey Three-Five Towcester, United Kingdom	(0327) 51871	Jim Arnold Applications executive
Sanders Nashua, NH	(603) 885-1054	Dr. Paul Hoff Technical director, advanced devices
TI MMCD Dallas, TX	(214) 995-6462	Steve Lazar Foundry services manager
TriQuint Beaverton, OR	(503) 644-3535	Dennis Powers Vice president, marketing and sales
Varian Associates Santa Clara, CA	(408) 562-2834	Michael Kopec III-V sales manager

Source: Dataquest (February 1991)

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Table 3

Analog/Linear GaAs Foundry Capabilities

Company	Wafer Size (Inches)	Capacity (Starts/Wk.)	Turnaround Time (Weeks)	Services	Approximate NRE Costs ($K)
ANADIGICS	3	200	8	Training	15 to 50
Avantek	2, 3	270	NA	Die bank	40/1st wafer, 10/ each additional
COMSAT Labs	2, 3	25	16	GaAs MESFET and HEMT processes	NA
Harris	2, 3	100	14	100% visuals	25 to 100
ITT GTC	3	100	9	Ion implant	60
M/A-COM	2, 3	NA	NA	NA	See text
Plessey Three-Five	2, 3	100	8-12	Strict QC	48 plus 6.5/wafer
Raytheon	3	NA	NA	NA	NA
Sanders	2, 3	50-125	14	RF probing	90/4 wafers, plus mask charges
TI MMCD	3	60	12	e-beam	70
TriQuint	3, 4	600	10	Multiproject	50 to 90
Varian Associates	2, 3	NA	16	e-beam, HEMT	40 first wafer, 15 next 10 wafers

NA = Not available
Source: Dataquest (February 1991)

GaAs DigIC Foundries

Similar to integrated circuits in the GaAs analog/linear world, GaAs application-specific digital integrated circuits (ASIC digICs) offer a relatively attractive means of evolving system designs from silicon to GaAs. Several companies, including recent start-ups, have mounted substantial foundry programs to support GaAs ASICs. Table 4 lists locations and contacts for merchant market foundries in the United States and in Western Europe offering GaAs digIC services in early 1991.

TriQuint and others are marketing multiuser prototype wafer programs that allow several customers to design devices according to the respective suppliers' ground rules and receive the first prototype devices from wafers fabricated during a single run. To accomplish this, the vendor assigns standardized reticle areas (e.g., 80 mils x 80 mils) for chip locations so that several customers' chips can be interspersed on the same wafer. This represents a major breakthrough in economies of scale in developing GaAs devices. Cost reduction for the user can be as much as 80 percent per wafer run.

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Table 4
GaAs DigIC Foundry Contacts

Company/Locations	Phone	Foundry Contact
ANADIGICS Warren, NJ	(201) 668-5000	Javed Patel Director, marketing and sales
GigaBit Logic CA	See text	
Harris Milpitas, CA	(408) 433-2222	Jim Klug Program director
Honeywell Minneapolis, MN	(612) 887-4341	David Lamb Program manager
ITT GTC Roanoke, VA	(703) 563-3912	Joe Grzyb Project manager
Plessey Three-Five Towcester, United Kingdom	(0327) 51871	Jim Arnold Applications executive
Rockwell Newbury Park, CA	(805) 375-1237	Deepak Mehrotra Marketing director
TriQuint Beaverton, OR	(503) 644-3535	Dennis Powers Vice president, marketing and sales
Vitesse Semi Camarillo, CA	(805) 388-3700	Tom Dugan Marketing director

Source: Dataquest (February 1991)

GigaBit Logic experienced particularly impressive foundry yields on the CRAY-3 GaAs ASIC program. Yields of the cell-based MSI-density chips have continued to advance well beyond 50 percent for more than two years. As a result, the CRAY-4 machine is expected to advance to E/D gate arrays or CBICs of at least a 2,000-gate density.

Table 5 summarizes digIC foundry data including wafer sizes, plant capacities, turnaround times, services, and representative NRE charges.

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Table 5

GaAs DigIC Foundry Capabilities

Company	Wafer Size (Inches)	Capacity (Starts/Wk.)	Turnaround Time (Weeks)	Special Services	NRE Costs ($K)
ANADIGICS	3	200	8	Training	15 to 50
ITT GTC	3	100	9	Ion implant	60
Plessey Three-Five	2, 3	100	8-12	Strict QC	48, plus 6.5/ wafer
Rockwell	3, 4	250/shift	NA		NA
TriQuint	3, 4	600	6-10	Multiproject wafers	50 to 90
Vitesse	3, 4	NA	3-8	Fujitsu, Thomson-CSF are alternate sources	25 to 125

NA = Not available
Source: Dataquest (February 1991)

Companies That Supply Foundry Services

The following companies offer foundry services in one or more aspects of GaAs technology.

Adams-Russell

In June 1989, M/A-COM made an offer to acquire Adams-Russell. The Adams-Russell foundry operation was merged with M/A-COM in 1990.

ANADIGICS

ANADIGICS offers GaAsIC (a trademark of ANADIGICS) foundry services. The process is 0.5μ gate length D-MESFET with 24-GHz f_T standard transistors. ANADIGICS' design tools include the following trademarked services and support: AISPICE design software, AIGRAPH layout, and AICHECK verification programs. Examples of microwave circuits that can be designed using the company's tools and processing are: wideband, power, and low-noise amplifiers; limiters, buffers, and mixers; and switches, VCOs, and phase shifters. Linear and digital circuit examples include: transimpedance amplifiers, MUX/DEMUX circuits, laser drivers, A/Ds and D/As, dividers, and ECL-compatible logic.

Capacity of ANADIGICS' 6,400-square-foot, Class 100 clean room is approximately 200 3-inch wafers per week. Wafer probe equipment is rated to 40 GHz; final testing is rated at DC to 26.5 GHz (rf) and 4 Gbps (digital). High-speed linear testing includes automatic on-wafer laser trimming. In addition to wafer fab, dicing, packaging, and screening, ANADIGICS offers backside

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processing including thinning metallization and via holes. Packaging includes DIPs, LCCs, flat-packs, and proprietary metal-ceramic packages to 20 GHz.

Avantek

Avantek recently expanded its 150,000-square-foot facilities to include a 3-inch GaAs wafer fab. Process is state-of-the-art 0.5µ GaAs MESFET. Foundry charges are $40,000 for the first wafer, which includes design rule package and engineering services, and $10,000 each for additional wafers (minimum lot size is five wafers).

COMSAT Labs

COMSAT Labs became a GaAs foundry in 1987. Capacity at press time was approximately 25 wafers per week, limited by personnel, not facilities. The company offers custom GaAs MMIC capability based on MESFET and HEMT technology with an operating frequency of more than 90 GHz. NRE charges are negotiable.

Ford Microelectronics, Inc.

Ford Microelectronics, Inc., operated a 12,000-square-foot GaAs facility at Colorado Springs, Colorado, with a 3-inch capacity of 500 wafers per week. However, Ford withdrew from the merchant market in 1989. The foundry was closed permanently on December 31, 1990.

GAIN Electronics Corporation

GAIN Electronics Corporation discontinued its operations in November 1988.

GigaBit Logic (GBL)

In 1990, a significant part of GBL's foundry operations were moved to Cray Research's facility in Colorado Springs, Colorado. At press time, the merger of GBL and TriQuint was under way, leaving the future of the GBL foundry in Newbury Park, California, uncertain.

Harris Microwave Semiconductor, Inc.

In April 1987, Harris Microwave Semiconductor, Inc., announced the availability of a library of GaAs standard cells for semicustom designs. The process is Harris' proprietary DIGI-2, 1µ MESFET using two-layer metal; t_{pd} is typically 280ps/cell at 10 to 40mW/cell ps. I/Os consume 11 to 88mW each and may be ECL, TTL, CMOS, and GaAs compatible. The cells range in complexity from two-input NAND gates to a two-bit full adder. In 1989, Harris de-emphasized GaAs digital ICs.

Harris' CAD/CAE tools are a modification of tools developed by Silicon Design Automation for the ASIC business. Other tools include a logic simulator, developed by SIMUCAD, and place-and-route software. The system is UNIX-based and runs on the Harris MCX-3, Sun 3/160, Apollo, Masscomp, and other workstations.

Honeywell

During a 1986 reorganization of Honeywell operations, the company consolidated its GaAs activities into the corporate R&D center at Minneapolis, Minnesota. New opportunities are being addressed on a case-by-case basis. The Richardson, Texas, GaAs facility was transferred to the control of the Opto Division of Honeywell as a part of the 1986 reorganization.

ITT GTC

ITT's Roanoke, Virginia, GaAs Technology Center (GTC) offers MMIC and high-speed digital IC foundry support on a limited basis for military and commercial applications. Foundry charges are approximately $60,000 depending on design complexity and other factors.

M/A-COM

M/A-COM has one of the largest GaAs foundry production facilities available, exceeding 90,000 square feet. The company primarily supports MMIC designs and offers processing to 0.8μ, 0.5μ, and 0.25μ design rules. Wafer runs processed to 0.8μ fab cost $25,000; processing to 0.5μ rules costs $30,000 per run. Mask charges usually involve 9 to 14 levels at $1,200 per level. Special testing and other services are negotiable.

In June 1989, M/A-COM acquired Adams-Russell, and the Adams-Russell foundry was merged with M/A-COM's operation.

MSC

Siemens sold its subsidiary, Microwave Semiconductor Corporation (MSC), in the fourth quarter of 1988. Foundry operations were discontinued at that time.

Plessey Three-Five

Plessey's Three-Five Group offers its F1 foundry process based on D-MESFETs with 0.9μ nominal gate length. A 0.7μ process is also available. Available circuit elements include FETs, diodes, resistors, capacitors, and inductors. NRE costs are $48,000 plus $6,500 per wafer. Plessey prefers projects that require at least two to five wafer fab runs per year, dependent upon product complexity.

Raytheon

Raytheon has constructed a major foundry facility at its corporate research center, with more than 30,000 square feet of fab area. Initial focus is on 0.5 and 0.25μ processes for custom MMICs. Capacity came on-line in 1989. The company is expected to enter the merchant market in the near future.

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Rockwell

Rockwell's Microelectronics Research and Development Center (MRDC) pioneered the development of GaAs materials and ICs. Its 41,000-square-foot Newbury Park facility near Thousand Oaks, California, is equipped to produce 250 3-inch wafers per week per shift. Foundry operations started in August 1985, initially supporting D-MESFET designs including LSI density chips. Subsequently, Rockwell developed etched E/D MESFET and HBT processes. The E/D process allows production of gate arrays to 50,000-gate density. The HBT production process is based on transistors with f_T of 70 GHz. Calma and Daisy Chipmaster systems are in place; additional design tools are added as needed. Foundry charges are negotiable.

Sanders Associates (Lockheed)

Sanders Associates, owned by Lockheed, offers 0.5 and 0.25µ MESFET MMIC foundry services at its Nashua, New Hampshire, facility. The company has a 3-inch fab capacity of more than 50 wafer starts per week.

Tachonics

A subsidiary of Grumman, Tachonics operated a GaAs IC standard product and foundry facility in Plainsboro, New Jersey, with initial capacity of 300 3-inch wafer starts per week. However, the company ceased foundry operations late in 1989.

Texas Instruments MMCD

In April 1987, Texas Instruments announced availability of MMIC foundry services at its Microwave Military Components Division (MMCD). The division has an 8,000-square-foot fab that runs three process profiles on 3-inch wafers. The 0.5-micron processes are each optimized with special characteristics, such as low noise high gain or high power intermediate gain. Texas Instruments offers a training course to familiarize designers with design runs, process parameters, and circuit examples. NRE costs are approximately $70,000, depending upon design and process.

TriQuint

TriQuint offers its foundry customers Q-chip, multiproject chip, full-custom, and ASIC services. Full-custom charges for customer-designed chips range from $42,000 for a 1-micron D-MESFET design to $60,000 for a 1-micron E/D design. These charges include design manual, maskmaking, and first prototype wafer run. ASIC charges for TriQuint designs to customer specifications are negotiable and range from approximately $50,000 to $90,000 per design.

The company charges $55,000 for the first 5 to 10 Q-chip samples, including design manual, standard cells on Daisy equipment, and evaluation board. Multiproject wafer cost is $9,900 for MSI-density design samples.

TriQuint periodically offers multiproject chip design courses in Portland, Oregon. The courses are led by more than a dozen of TriQuint's expert staff members, who have combined engineering experience of more than 200 years. The microwave design course typically consists of lectures on design logistics, GaAs processing, circuit models and SPICE modeling, chip design, packaging,

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testing, and reliability. The digital design course is similar, focusing on E/D processing, digital IC design, and standard cells. Informal design consulting is included in each course. TriQuint offers each of the attendees the opportunity to successfully specify, design, and evaluate samples of a custom state-of-the-art GaAs IC.

At press time, the merger of TriQuint and GigaBit Logic into TriQuint Semicoductor, Inc., was under way. The combined company is the world's largest GaAs IC producer.

Varian Associates

Varian Associates began offering foundry services at its Santa Clara, California, facility in 1987. The company provides processing of 0.25μ HEMT devices on 2-inch and 3-inch wafers. NRE charges are approximately $40,000 including the first wafer, plus $15,000 for the next 10 wafers.

Vitesse Semiconductor Corporation

Vitesse's facilities in Camarillo, California, include an E/D foundry. The company has demonstrated production capability in such standard products as the VE29GO1, a GaAs equivalent of the popular silicon 2901 4-bit microprocessor slice, and in ASIC gate arrays to 15,000-gate density. Vitesse's foundry has implemented a proprietary process called VEGA (*V*itesse *E*-D *GaA*s), a scaled, enhancement/depletion-mode self-aligned, nine-mask process featuring three levels of interconnects and subloop gate delays. Figure 1 illustrates a typical Vitesse and customer relationship and flow chart for a typical foundry project.

Vitesse has a one-time setup charge of $25,000 or more per design for a typical nine-layer chip. V-SPICE software, rule-check software, and a design guide cost $5,000. Engineering consultation costs $100 per hour. Processing cost for the first five wafers is approximately $6,000 per wafer; charges for more than five wafers are negotiable.

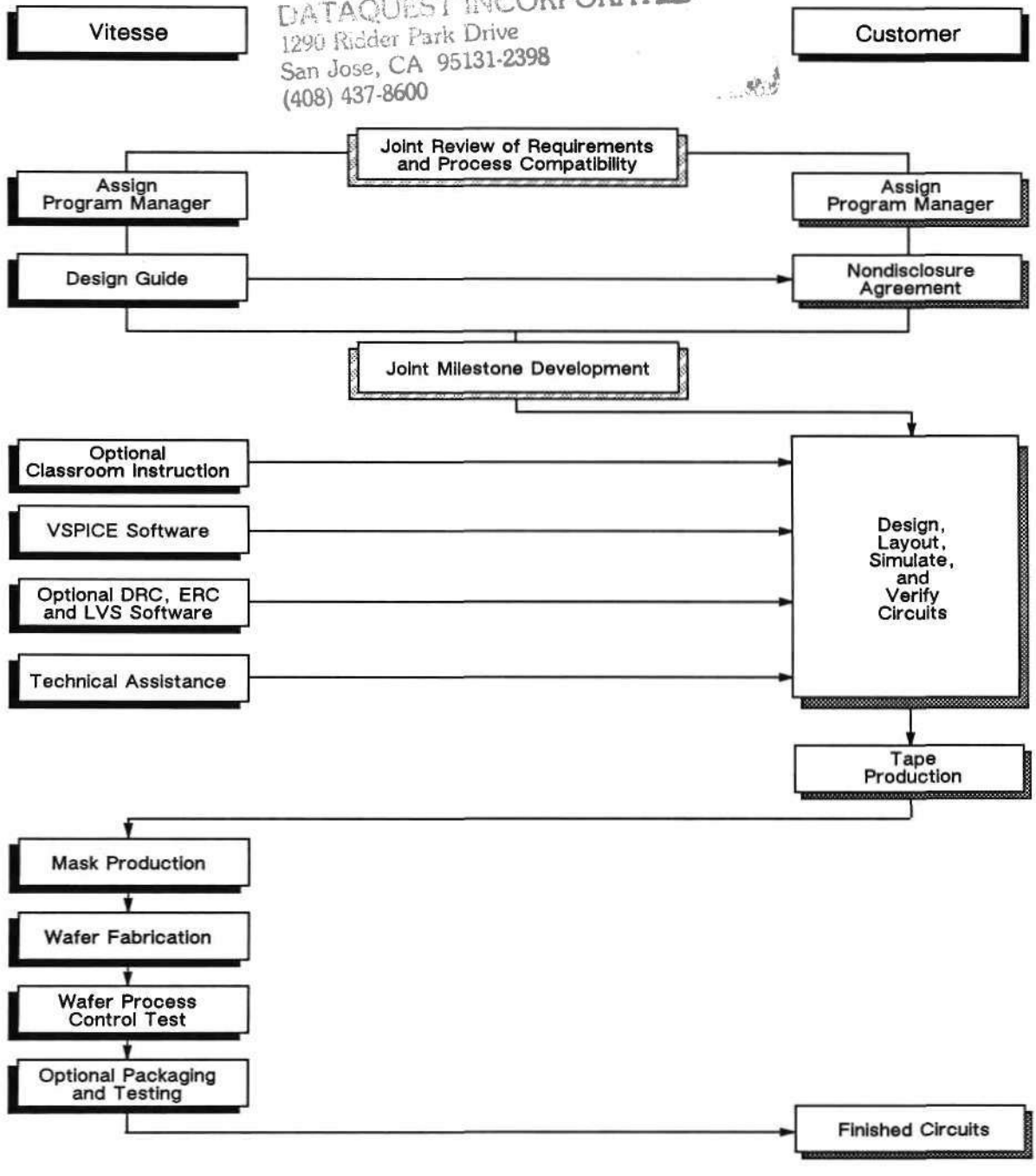
Vitesse has technology exchange agreements with AMD, Fujitsu, Thomson-CSF, and TRW.

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Figure 1

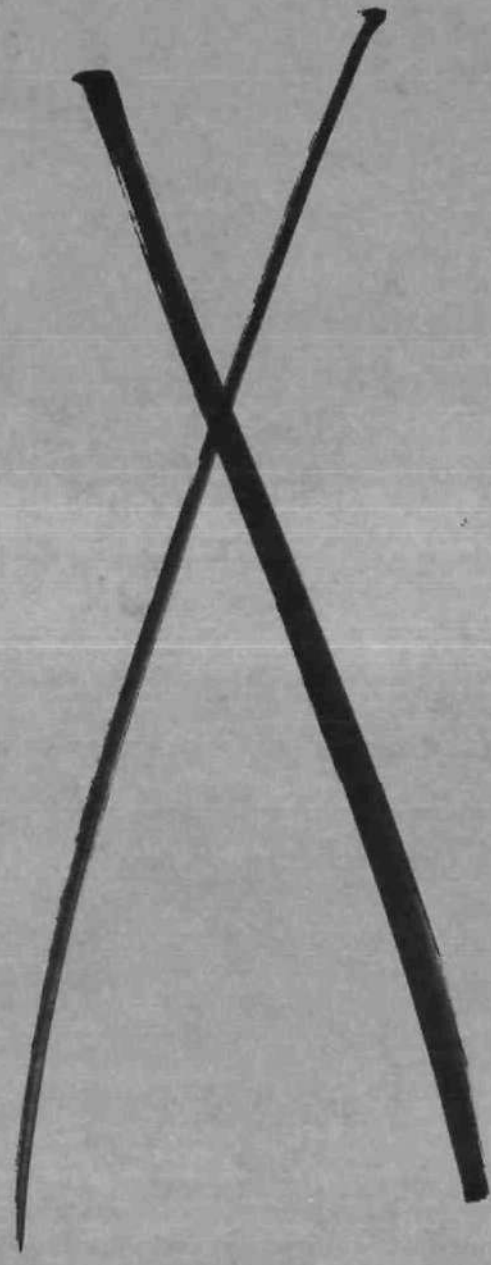
Foundry-Customer Interface and Project Flow

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Source: Vitesse Semiconductors

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GaAs Semiconductor Packaging

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INTRODUCTION

GaAs device packaging requirements usually are more stringent than those of all but the highest-performance silicon devices. The most effective methods of packaging GaAs chips include appropriate consideration of the systems (applications) constraints and requirements. For this reason, hybrid-type packages have been used extensively in the past, especially for analog and linear microwave and millimeter wave ICs. Important considerations and major factors affecting GaAs device packaging include the following:

- Package lead and bond impedances, including inductance
- Mechanical strength (GaAs chips may be more brittle than silicon chips)
- Thermal matching of package and die (similar coefficients of expansion)
- Shielding (opaqueness to electrical, photonic, and other radiation)
- Compatibility with silicon package form factors to allow mixing of GaAs and silicon devices in systems at reasonable cost
- Subsystem and system interconnections such as fiber-optic cable and 50-ohm terminated coaxial cables
- Other factors normally considered in silicon device packaging

The roles of silicon and metal are changing in the move toward photonic and photonic-electronic systems. Silicon, an electrical insulator, is an excellent conductor of photons. Metals such a gallium and indium now constitute part of IC substrates in compound semiconductors. This role reversal between the functions of metal and silicon in electronic systems has made a major impact in device packaging considerations and will have a greater impact in the decade ahead.

IMPEDANCE

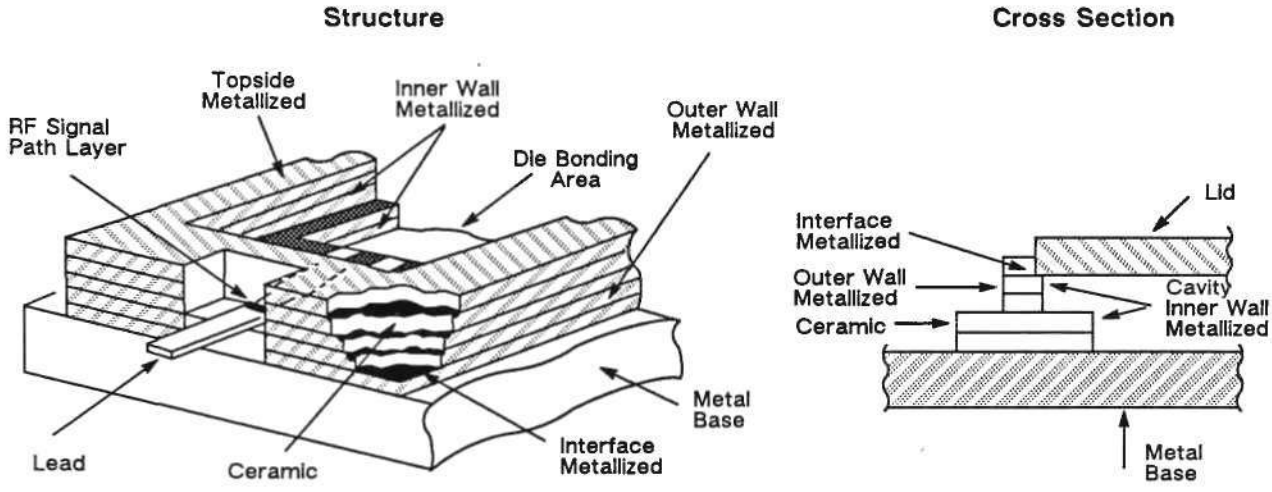
The loading impedance presented to output signals is particularly important at frequencies of more than 10 GHz. Small values of inductance in the range of 10 millihenries can induce oscillations resulting in logic faults in digital systems and major errors in analog systems. A package pin becomes an R-L-C filter at GHz frequencies. Thus, the user must exercise the same caution as in other RF design situations, and the chip supplier must consider the RF impedance characteristics of the packages to be used for the product line.

In November 1988, NTT reported development of a ceramic package for MMIC applications with operating frequencies to 30 GHz. The package has microstrip I/Os designed for 50-ohm impedance, each having insertion loss of less than 0.5dB up to 33 GHz and complementary I/O isolation of more than 30dB. Figure 1 shows the construction of the NTT package.

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Figure 1

Structure of Ceramic Package For 30-GHz Operation



Source: Dataquest (June 1991)

MECHANICAL STRENGTH AND THERMAL MATCHING

GaAs IC substrates are more brittle than silicon substrates of the same thickness. Thus, mechanical strength of the packaging method, including the bonding material, is important. Because the coefficient of thermal expansion of GaAs is different from that of silicon, GaAs IC package design should include adequate consideration of thermal characteristics of the various materials involved.

A study by Ball Aerospace generated and analyzed fracture data on large, thin (100mm^2 x 0.15mm) GaAs chips for prediction of safe stress limits during processing, packaging, environmental, and dynamic loading conditions. The study reached the following conclusions:

- Chip strength-to-fracture is relatively high when wafer and chip processing reduces or eliminates the number and size of edge, surface, and bulk flaws.
- Fracture strength characterization of GaAs chips allows prediction of safe stress limits, permitting reliable packaging to be designed.
- Elimination of edge flaws and surface flaws can result in a three to four times increase in resistance to uniaxial loads.
- Elimination of surface flaws can result in a 6- to 11-time increase in resistance to biaxial loads.
- Reducing etch pit flaws (dislocation density) increases fracture strength under biaxial loading.

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- Four times the increase in chip area reduces resistance to uniaxial loads by two times.
- As mean fracture strength increases, the variance (dispersion of values) also increases.

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SHIELDING

Because RF energy is radiated by any high-speed circuit, whether implemented in silicon or compound semiconductor technology, appropriate attention to shielding is needed for most GaAs applications. This negates the use of plastic packages for many applications, resulting in the additional cost of packages utilizing metal cladding or some other form of shielding.

FORM FACTOR

Convenient packages for many digital functions are the leaded and leadless ceramic chip carriers. These have proven adequate for the present generation of digital devices and for many analog GaAs chip types.

Pin-grid array packages, popular for many CMOS and some ECL functions, exhibit lead impedance problems at the higher frequencies of operation of many GaAs ICs. The problems are similar to those experienced in some silicon BiCMOS and ECL LSI/VLSI applications, where ECL100K-type interface signals are not easily terminated or shielded.

Because some GaAs devices perform optoelectronic functions, a unique package form factor may be required to allow radiating light, interfacing with fiber-optic cable, or receiving radiated energy. For simple LED diodes, this may be accomplished with a suitable transparent encapsulant. For laser transmitters, a precision-made coupling is required. Cost reduction of couplings is critical in automative applications.

Some fiber-optic transmitters and receivers are packaged in DIP-like structures, having electrical leads compatible with conventional 100-mil spacing on 0.3-inch centers. A threaded coupling is provided at one end of the package for connection with the fiber cable.

TriQuint Semiconductor supplies a family of GaAs IC packages, the MLC series. The family uses cofired ceramic technology to support pin counts to 196 pins and edge transit time of 100ps or less. Both digital and analog packages are included in the MLC family.

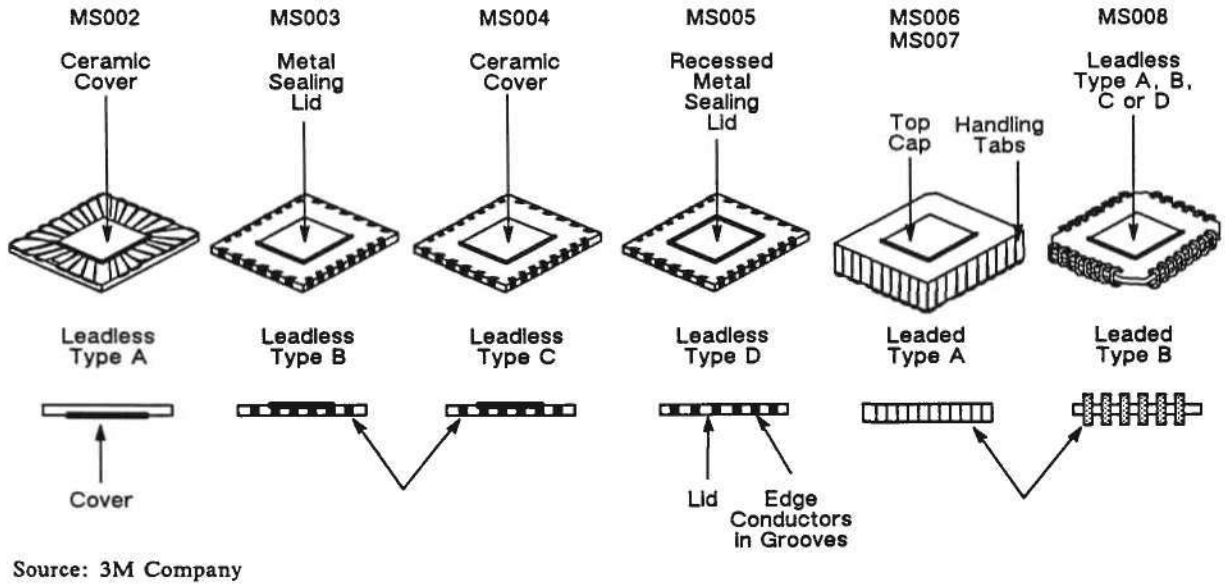
Examples of JEDEC-approved chip carrier packages currently used in the GaAs industry are given in Figure 2. This is not an exhaustive set, but is representative of products offered by 3M Company and other suppliers.

Figure 3 illustrates examples of package types used for microwave and millimeter wave analog/linear GaAs ICs. In some situations, connectorized packages such as the one on the right in Figure 3 are used to maximize interconnected signal integrity.

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Figure 2

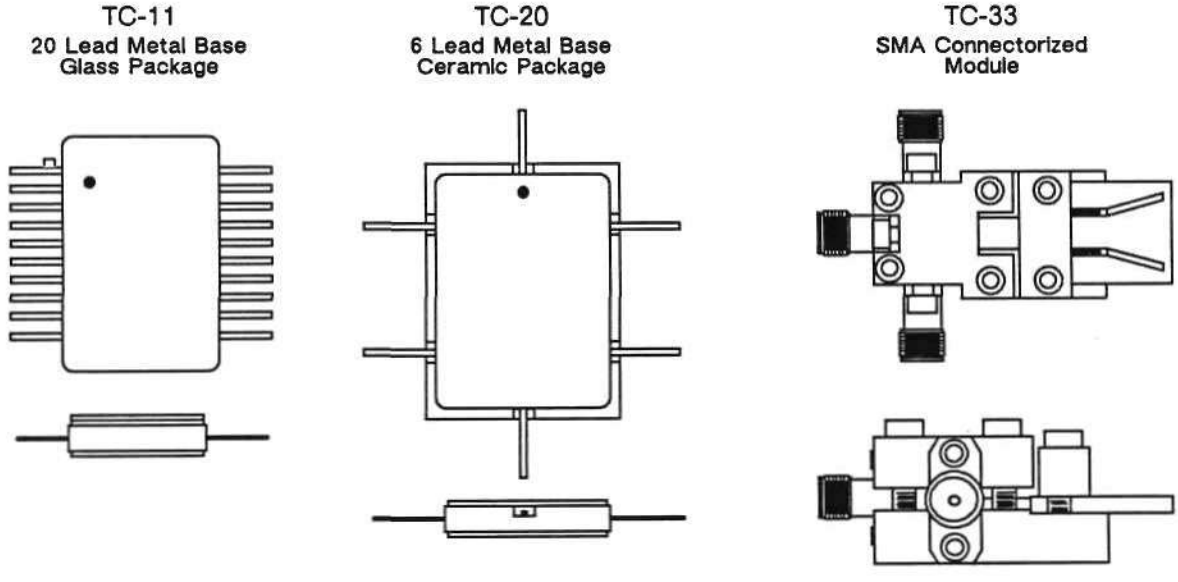
Examples of GaAs Chip Carriers



Source: 3M Company

Figure 3

Microwave and Millimeter-Wave GaAs IC Package Examples



Source: Tachonics Corporation

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OTHER CONSIDERATIONS

Radiation protection is another aspect of shielding. Although GaAs devices have demonstrated radiation tolerance superior to that of silicon devices, some environments may require additional radiation shielding.

For devices used in military applications, protection against nuclear radiation may be a requirement. In some space applications, protection against certain forms of cosmic radiation may be essential, whereas the same equipment may function on earth without special protection because of atmospheric shielding. The same precautions apply to silicon circuits and are not unique requirements of compound semiconductors.

PACKAGE SUPPLIERS

Table 1 is a representative list of companies now supplying or believed to be capable of supplying ceramic and other types of packages for GaAs chips. Many of these companies supply piece parts, such as lead frames, as well as partially assembled packages. All of the companies shown also are believed to be suppliers of silicon IC packages and package piece parts.

Table 1

GaAs Package Suppliers

Company	Location
Alcoa Electronic Products	San Diego, California
AMP Inc.	Harrisburg, Pennsylvania
ASPE Inc.	Fairchild, New Jersey
AVX Ceramics Corporation	Myrtle Beach, South Carolina
Airpax Corporation	Cambridge, Maryland
Augat Inc.	Attelboro, Massachusetts
Barry & Associates	Los Altos, California
Bourns Inc.	Riverside, California
Brush Wellman Inc.	Cleveland, Ohio
Burndy Inc.	Norwalk, Connecticut
Cabot Spectrum	San Diego, California
CTS Corporation	Elkhart, Indiana
Ceradyne Inc.	Santa Ana, California
Circuit Assembly Corporation	Irvine, California
Coors/Ceramics	Golden, Colorado
Dage Limited	Great Britain
Dande Plastics Inc.	Somerville, New Jersey
Demetron Inc.	Union City, California
Diacon Inc.	San Diego, California
Emerson & Cuming Inc.	Billerica, Massachusetts
GE Ceramics, Inc.	Chattanooga, Tennessee
General Ceramics	Anaheim, California

(Continued)

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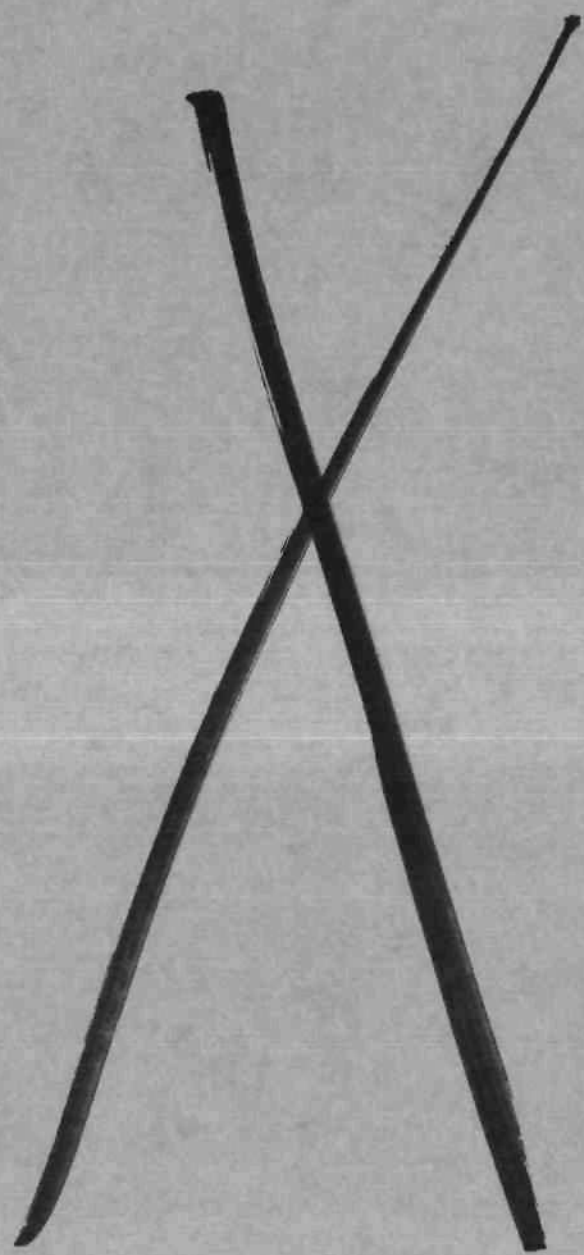
Table 1 (Continued)

GaAs Package Suppliers

Company	Location
Gibson-Egan Co.	Duarte, California
W.G. Heraeus GmbH	West Germany
Hermetic Seal	Rosemead, California
Hestia Technologies	Santa Clara, California
Hoechst Ceramtec NA Inc.	Providence, Rhode Island
Hoechst Informations-Technik	West Germany
Interamics	San Diego, California
Keramont Corporation	Tucson, Arizona
Kras Corporation	Fairless Hills, Pennsylvania
Kyocera International Inc.	San Diego, California
3M Company	Saint Paul, Minnesota
M/A-COM Semiconductor Products	Burlington, Massachusetts
Microelectronic Packaging Inc.	Scottsdale, Arizona
NTK Technical Ceramics	Nagoya, Japan
Naramics	Nagoya, Japan
National Beryllia Corporation	Haskall, New Jersey
Rosenthal Technik NA Inc.	Providence, Rhode Island
SCI	Santa Clara, California
Shinko Electric America Inc.	Santa Clara, California
Spec Industries Inc.	San Marcos, California
Textool Products	Irving, Texas
TriQuint	Beaverton, Oregon
Vichem Corporation	Stanford, California
Wells Electronics Inc.	South Bend, Indiana

Source: Dataquest (June 1991)

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Glossary

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TERMS ENCOUNTERED IN GaAs LITERATURE

A. Ampere, a unit of electrical current

Å. Angstrom, or 10^{-10} meter

A/D. Analog to digital

AEM. Analytical electron microscopy

AES. Auger electron spectroscopy, a method used for surface analysis and depth profiling of semiconductor structures

AGC. Automatic gain control

Ag/Fe. Silver/iron, used in magneto-electronic superlattice ICs

A-HJFET. Anisotype GaAs/InGaAs HFET, a type of transistor designed for digital logic applications

AI. Artificial intelligence

ALE. Atomic layer epitaxy

AlGaAs. Aluminum gallium arsenide

AlGaAsP. Aluminum gallium arsenide phosphide

AlGaSb. Aluminum gallium selenide

AlInAs. Aluminum indium arsenide

AlN. Aluminum nitride

ALU. Arithmetic logic unit

AM. 1. Amplitude modulation 2. Acoustic microscopy

amp. 1. Amplifier 2. Ampere, a unit of electrical current

AMS. Accelerator mass spectroscopy

AP. Atom probe

APD. 1. Avalanche photodiode 2. Antiphase domain

ARM. Atomic resolution microscope

ARROW. Antiresonant reflecting optical waveguide, a III-V geometry for coupling active gain or absorbing regions to low-loss passive materials, first demonstrated by AT&T Bell Labs prior to October 1986

As. Abbreviation for the element arsenic

AsH_3. Arsenic hydride or arsine, a poisonous gas

ASIC. Application-specific integrated circuit

ASMMIC. Application-specific MMIC, a technology developed by Ford

As_2O_3. An oxide of arsenic that is lethal to humans at 0.1 gram dosage

As_4O_6. An oxide of arsenic that is lethal to humans at 0.1 gram dosage

Au. The chemical symbol for the element gold

AuNiGe. Gold-nickel-germanium, the most frequently used contact-metal alloy in GaAs chip structures

BEEM. Ballistic electron emission microscopy

BH. Buried heterojunction or heterostructure

BiCFET. Bipolar inversion channel FET, a form of transistor having no neutral base, invented by Bell Labs.

BiFET. Another acronym for BiCFET (see BiCFET)

BFL. Buffered FET logic

BSE. Back-scattered electrons; an analysis methodology based on imaging

BWO. Backward-wave oscillator

C. 1. Celsius 2. Coulomb, a unit of electrical charge

CAGR. Compound annual growth rate

C band. The frequency band of 4 to 6 GHz

c_o. Symbol for the speed of light (which is 3 x 10^8 meters per second, or 30cm/ns, or 300u/ps in free space)

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CBE. Chemical-beam epitaxy

cc. Cubic centimeter

CCD. Charge-coupled device, one type of optoelectronic device

CCFL. Capacitor-coupled FET logic

CD. 1. Compact disc, a storage medium for digitized optical data 2. Critical dimension

cd. Symbol for the element cadmium

CD-ROM. Compact disc read-only memory

CdMnTe. Cadmium manganese telluride, one type of II-VI compound

CdS. Symbol for cadmium sulphide; a II-VI compound used in the fabrication of some types of lasers

CdSe. Cadmium selenide, one type of II-VI compound

CdTe. Cadmium telluride, a II-VI compound

CERDIP. Ceramic dual in-line package

CGCCD. Capacitive-gate charge-coupled device, a type of OEIC

C-HFET. Complementary heterostructure FET, a low-power form of GaAs logic, believed first reported by IBM

CHINT. Charge-injection transistor, a type of transistor having source, drain, and collector terminals

CL. Cathodoluminescence, an analysis methodology based on imaging

CMOS. Complementary metal oxide semiconductor

C/N. Carrier-to-noise ratio (expressed in decibels)

CPA. Charged particle activation analysis

cps. Cycles per second

CPU. Central processing unit

CPW. Coplanar waveguide

CSBH. Channeled-substrate buried heterostructure

CTE. Charge transfer efficiency

CTS. Current transient spectroscopy, an analysis methodology

$CuInSe_2$. Copper indium selenide, a material used in a type of solar cell

CVD. Chemical vapor deposition

CW. 1. Continuous wave 2. Carrier wave

D/A. Digital to analog

DBHET. Double-base, hot-electron transistor

dBm. The decibel referenced to 1 milliwatt

DBR. Distributed Bragg reflector, a type of DSM laser

DBRT. Double-barrier resonant tunneling

DBS. Direct-broadcast satellite

DBT. Double-barrier transistor

DCBPH. Double-channel planar buried heterostructure, a type of laser reported by Philips in 1986

DCD. Double-crystal diffractometry, a method of measuring lattice strain to detect damage in a material sample

DCFL. Direct-coupled FET logic

DCT. See DCXRT

DCXRT. Double-crystal X-ray topography, an analysis methodology utilizing imaging

DF. Defect-free

D-FET. Depletion-mode FET

DFB. Distributed feedback, a type of DSM laser

DFI. Dynamic fault imaging, a device analysis methodology

DGF. Dynamic gradient freeze, a method for growing InP crystals developed by Bell Labs

DH. Double heterojunction

DHBT. Double-heterostructure bipolar transistor

DHLD. Double-heterostructure laser diode

DigIC. Acronym for digital integrated circuit; a circuit that processes information in discrete steps, usually binary

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DLTS. Deep-level transient spectrography

D-MISFET. Depletion mode metal-insulator-semiconductor FET

DOES. Double-heterostructure optoelectronic switch, coined by AT&T

DQW. Double-quantum well

DRAM. Dynamic random access memory

DRFM. Digital RF memory

DSA. Delayed secondary avalanche

DSM. Dynamic single-mode

DSO. Digital-storage oscilloscope

DSP. Digital-signal processor

DSW. Direct step on wafer, a form of lithography

DUT. Device under test

dV/dt. The rate of change of voltage with respect to time

DW-LED. Dual-wavelength LED

EBIC. Electron-beam-induced current, an analysis methodology

ECL. Emitter-coupled logic

ECM. Electronic countermeasures

ECR-CVD. Electron cyclotron resonance chemical vapor deposition

ECR-MBE. Electron cyclotron resonance plasma-excited MBE, a method for selective growth of GaAs.

E/D. Enhancement/depletion, a circuit form using complementary devices for reduced static power consumption

E-DMT. Enhancement mode doped channel heterostructure MISFET, a type of AlGaAs/GaAs transistor first reported by NEC Microelectronic Research Laboratories in 1987

EDX. Energy dispersive X-ray, an analysis methodology

E-FET. Enhancement-mode FET

EFRW. Etched facet ridge waveguide, a type of structure that may be used to confine photons in OEICs

Eight 9s. Refers to a purity level of at least 99.999999 percent

E-HEMT. Enhancement-mode HEMT

E-JFET. Enhancement-mode JFET

EL. Electroluminescent

ELED. Edge-emitting LED

ELS. Energy loss spectroscopy, a method of analysis

EMBH. Etched-mesa buried heterostructure, a type of semiconductor laser

EMI. Electromagnetic interference

EMP. 1. Electromagnetic pulse 2. Electron microprobe

ENFET. See E-FET

E/O. Electro-optic

EPD. Etch pit density

Er. The symbol for the element erbium

Er-doped. Erbium-doped

ERMA. Extended red multialkaline

ErPAs. Erbium phosphoric arsenide, used to form metal layers on GaAs

ESCA. Electron spectroscopy chemical analysis

ESD. Electrostatic discharge

ESR. Electron spin resonance, a method for measuring displacement of atoms in materials

etalon. An interferometer-type of optical computing device in which the narrow space between mirrors is filled with a material having intensity-dependent optical properties; more properly referred to as a nonlinear Fabry-Perot etalon

EXAFS. Extended X-ray absorption, fine structure (analysis method)

f. Prefix meaning femto or 10^{-15}

FBL. Fly-by-light

FBM. Failure bit map, an analysis tool used for quality improvement in the design and manufacture of RAM chips

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fC. Femtocoulomb or 10^{-15} coulomb, a unit of electrical charge

FDDI. 1. Fiber-optic distributed data interface 2. Fiber-optic digital data interface

FDM. Frequency division multiplexing

FEC. Fully encapsulated Czochralski, a method of growing GaAs crystals in which the lower part of the drawn crystal is submerged in the melt

FEM. Field-emission microscope, an analysis method

FET. Field-effect transistor

fF. Femtofarad or 10^{-15} farads, a unit of capacitance

FI. Fan-in

FIB. Focused ion beam, a maskless ion-implantation methodology

FIM. Field ion microscope, an analysis method involving imaging

FIST. Focused ion-stripe transistor, first reported by Hughes Research Laboratory, Malibu, CA, in 1987

FM. Frequency modulation

FME. Flow-rate modulation epitaxy (a modification of MOCVD)

FO. 1. Fiber optic 2. Fan-out

fs. Femtosecond or 10^{-15} second

FSK. Frequency-shift keying

f_T. Cutoff frequency

FTIR. Fourier transform infrared, a type of spectroscopic analysis

g. Gram

G. Giga, or 10^9 or one billion

Ga. The symbol for the element gallium

GA. Abbreviation for gate array

GaAs. Gallium arsenide, a III-V compound allowing the mass production of circuits having frequency response, speed-power product, temperature range, and radiation-resistance characteristics superior to those of silicon

GaAs/InP. Epitaxial GaAs layer on indium phosphide wafer

GaAsP. Gallium arsenide phosphide

GaInAsP. Gallium indium arsenide phosphide, a III-V compound

GaInP. Gallium indium phosphide

GaP. Gallium phosphide

GaAs-on-Si. Epitaxial GaAs layer on silicon wafer

GaAs/Si. See GaAs-on-Si

GaInAs. Gallium indium arsenide

GaSb. Gallium antimonide, a III-V compound

Gbps. Gigabits per second

GEO. Geosynchronous (geostationary) earth orbit, an orbit located approximately 22,000 miles above the earth's equator

Gflops. Billions of floating-point operations per second

GHz. GigaHertz or 10^9 cycles per second

GRINSCH. Graded index seperate confinement heterojunction, a type of laser

GSI. Gigascale integration, or more than 10^9 devices per die

GSMBE. Gas source molecular-beam epitaxy

HB. Horizontal Bridgman, a method of growing GaAs crystals resulting in a "D " shape and relatively high level of impurities compared with LEC

HBT. Heterojunction bipolar transistor

HDTV. High-definition television

HEMT. High-electron mobility transistor; also referred to as SDHT

HeNe. Helium neon, a type of gas laser

HFET. Heterostructure FET

HGF. Horizontal gradient freeze, one of the earliest methods of GaAs crystallization

HME/D. High-margin E/D, a GaAs process developed by GigaBit Logic

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HJBT. See HBT

HIGFET. Heterostructure insulated gate FET

HI²L. Heterojunction integrated injection logic

HGF. Horizontal gradient freeze

HPLEC. Refers to the high-pressure LEC method of crystal formation

HPT. Heterojunction phototransistor

HREM. High-resolution electron microscopy

HRIT. High-resolution infrared tomography

HRLED. High-radiance LED

HRTEM. High-resolution transient electron microscopy

HSTL. Heterojunction Schottky transistor logic

HWE. Hot-wall epitaxy

Hz. Symbol for hertz or cycles per second

IC. If you don't recognize this one, you're in *BIG* trouble!

ICDL. Inverted common drain logic, a form of GaAs logic

IF. Intermediate frequency

III-V. Denotes a compound composed of elements from groups three and five of the periodic table of elements

IILD. Impurity-induced layer disordering

II-VI. Denotes a compound composed of elements from groups two and six of the periodic table, having a large direct bandgap relative to that of silicon

ILD. Injection laser diode

IMMA. Ion microprobe mass analysis

IMPATT. Impact avalanche and transit time

In. Symbol for the element indium

InAlAs. Indium aluminum arsenide

InGaAs. Indium gallium arsenide, a III-V compound

InGaP. Indium gallium phosphide

InP. Indium phosphide, a III-V compound

InP-on-Si. Indium phosphide epitaxial layer on silicon wafer

InSb. Indium antimonide

InSe. Indium selenide

IR. Denotes infrared frequencies, those at or just below the low end of the visible spectrum

ISDN. Integrated services digital network, a system architecture that facilitates combining voice and data services into the same channels of communication

ISS. Ion scattering spectroscopy, a method used for surface analysis and depth profiling of semiconductor structures

JFET. Junction FET

k. Kilo or one thousand

K. 1. 2^{10} or 1024 2. Kelvin, a temperature scale 3. Kilo

K band. The frequency spectrum from 10.9 to 36 GHz

KHz. Kilohertz or one thousand cycles per second

Ku band. 1. The frequency range from 12 to 18 GHz, a radar frequency band 2. The frequency range from 11 to 14 GHz, a communications frequency band

LAN. Local area network

LANG. Scanning Lang X-ray topography

laser. Light amplification by stimulated emission of radiation

LBIC. Light-beam induced current (e.g., in a photocell)

LCC. Leadless chip carrier

LCCC. Leadless ceramic chip carrier

LCVD. Laser-induced chemical vapor deposition

LD. Laser diode

LDD. Lightly doped drain

LEC. Liquid-encapsulated Czochralski, a method of growing compound semiconductor crystals

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LED. Light-emitting diode

LEED. Low-energy electron diffraction, an analysis method for identifying compounds

LEK. Liquid-encapsulated Kyropoulus

LEO. Linear electro-optic (effect)

LET. Linear energy transfer

lidar. Laser radar, which operates near 800nm wavelength

LIMA. Laser ionization mass analysis, a method for identifying elements

LN. Low noise

LNA. Low-noise amplifier

LNC. Low-noise converter, an antenna-mounted package containing an LNA and a downconverter

LOC. Large optical cavity

LPE. Liquid phase epitaxy

LPFL. Low-power FET logic

LPVPE. Low-pressure vapor phase epitaxy

LSI. Large-scale integration

LSSL. Lateral-surface superlattice, a type of MODFET that exhibits negative negative differential resistance, developed by MIT

m. Milli- or one-thousandth

M. Mega or one million

mA. Milliampere (one thousandth of an ampere)

MBE. Molecular beam epitaxy

MCC. Microwave chip carrier

MCM. Microwave Common Module, a development program partly funded by the U.K.'s Ministry of Defense and supported by Ferranti, M/A-COM, MEDL, and Plessey

MD-CCD. Modulation-doped heterostructure CCD

MESFET. Metal electrode semiconductor FET

MHz. Megahertz or one million cycles per second

MIBE. Molecular beam/ion beam epitaxy, a method of forming thin layers of material on a substrate

MIC. Microwave IC

mil. One one-thousandth of an inch, or 25.4 microns

MIM. Metal-insulator-metal

MIMIC. Monolithic millimeter wave/ microwave IC

mips. Millions of instructions per second

MISFET. Metal insulator semiconductor FET

MLEC. Magnetic LEC

mm. Millimeter, one one-thousandth of a meter

MMIC. Monolithic MIC

MOCVD. Metal-organic CVD, a term that is interchangeable with MOVPE, OMCVD and OMVPE

MODFET. Modulation-doped FET

MoGeInW. A metal alloy (of molybdenum, germanium, indium and tungsten) with contact characteristics superior to AuNiGe for forming contacts on-chip

MOMBE. Metal-organic MBE

mops. Millions of operations per second

MOVPE. Metal-organic VPE, a term that is interchangeable with MOCVD, OMCVD, and OMVPE

MQW. Multiple-quantum well

MSM-PD. Metal-semiconductor-metal photodiode

mV. Millivolt, a unit of electrical potential

mW. Milliwatt

MW. Multiple wavelength, usually referring to a light source

n. 1. Negative 2. Nano or 10^{-9} 3. Neutron

NAA. Neutron-activation analysis, a method of identifying elements

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NaS. Sodium sulfide

NDF. Near defect-free

NDR. Negative differential resistance

NiAl. Nickel aluminum

nm. Nanometer or 10^{-9} meter

NRA. Nuclear reaction analysis, a method used for surface analysis of semiconductor structures

NRE. Nonrecurring engineering

ns. Nanosecond or 10^{-9} second

OAS. Optically activated switch

OEIC. Optoelectronic integrated circuit

OGST. Opposed gate-source transistor

OM. 1. Organometallic 2. Optical microscope

OMCVD. Organometallic CVD, a term that is interchangeable with MOCVD, MOVPE, and OMVPE

OMVPE. Organometallic vapor phase epitaxy, interchangeable with MOCVD, MOVPE, and OMCVD

op. Operational

OPFET. Optically sensitive FET

OSI. Open-systems interconnection, a family of standards for information movement and management

OTDR. Optical time-domain reflectometer

p. 1. Positive 2. Pico, a prefix meaning 10^{-12}

P. 1. Symbol for the element phosphorus 2. Photochemical

p-BC. P-type buried crescent, a type of diode developed by TRW, Inc.

PBN. Pyrolytic boron nitride

PbS. Lead sulfide, a compound used in some types of solar cells

PBT. Permeable base transistor

pC. Pico-coulomb, a unit of electrical charge

PCE. Photoconductive circuit element

PCSS. Photoconductive semiconductor switch

PDBT. Planar-doped barrier transistor

PE. 1. Plasma enhanced 2. Plasma etched

PECVD. Plasma etched chemical vapor deposition

pF. Picofarad, a unit of capacitance

pH. Picohenry, a unit of inductance

PHBT. Photosensitive heterojunction bipolar transistor

PIC. Photonic integrated circuit, a monolithic integration of optical active devices with other optical components such as waveguides

PIN. 1. positive intrinsic negative 2. p-type intrinsic n-type

PINR. Proton-induced nuclear reaction, an analysis method for identifying elements

PIXE. Particle-induced X-ray emission, an analysis methodology

PL. Photoluminescence

PLD. Programmable logic device

PLE. Photoluminescence excitation, a form of spectroscopy used to measure quantum well width

PMMA. Polymethylmethacrylate, a plastic with properties that make it an acceptable material for optical fiber in certain applications

PROM. Programmable read-only memory

ps. Picosecond, or 10^{-12} second

PSK. Phase-shift keying

PTR. Photo-thermal-radiation, a type of microscope for measuring microdefects in, for example, GaAs wafers

QPSK. Quadriture PSK

QSS. Quasisteady state

QTS. Quantum-charge transient spectroscopy, an analysis methodology

QW. Quantum well

QWEST. Quantum-well envelope state transition, a type of optical computing device invented by Dr. Lawrence C. West

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QWET. Quantum-well emission transistor, a type having source, gate, and collector terminals

QWH. Quantum-well heterostructure

QWITT. Quantum-well injection transit time; a type of optoelectronic device proposed for operation to 300GHz, first reported by UCLA

QWW. Quantum well wire, a type of structure used for interconnections in photonic ICs

rad. Unit of radiation dosage equal to 0.01 joules/kg

radar. Radio detection and ranging

RAM. Random access memory

RBS. Rutherford backscattering spectroscopy, a method used for surface analysis and depth profiling of semiconductor structures

rf. Radio frequency

RFI. Radio-frequency interference

RHEED. Reflection high-energy-electron diffraction

RHIC. Radiation-hardened IC

RIE. Reactive ion etch

RIS. Resonance ionization spectroscopy

RISC. Reduced-instruction-set computer, one type of digital system architecture

RM-CW. Randomly modulated continuous wave

RTA. Rapid thermal annealing, a method for reducing implant damage to a semiconductor structure

RTBT. Resonant tunneling bipolar transistor

RTD. Resonant tunneling diode

RTT. Resonant tunneling transistor

SAG. Self-aligned gate

SAM. 1. Surface-to-air missile 2. Scanning auger microprobe 3. Scanning acoustic microscope

SATCOM. Satellite communications

Sb. Symbol for the element antimony

SCFL. Source-coupled FET logic

SCH. Separate-confinement heterostructure, a type of semiconductor laser

SDFL. Schottky diode FET logic

SDH. Synchronous Digital Hierarchy, called SONET (Synchronous Optical Network) in North America, an application for GaAs ICs

ISDHT. Selectively doped heterostructure transistor, invented by Dr. Raymond Dingle, et. al., at Bell Labs; also referred to as HEMT or TEGFET

SEAM. Scanning electron acoustic microscope

SEED. Self-electro-optical-effect device; an optical switch, invented by David Miller of AT&T

SEM. Scanning electron microscope

SEU. Single-event upset, a radiation-sensitive property of logic circuits

Seven 9s. Refers to a purity level of at least 99.99999 percent

Si. Symbol for the element silicon

SiF_3. Silicon fluoride

SIMS. Secondary ion mass spectroscopy, a method used for surface analysis and depth profiling of semiconductor structures

SLAM. Scanning laser acoustic microscope

SLD. Superliminescent laser diode

SLED. Surface-emitting LED

SLM. Single longitudinal mode, another name for a DSM laser

SNMS. Sputtered neutral mass spectroscopy

SPDT. Single-pole double-throw, a type of switching circuit

SQW. Single-quantum well

SRAM. Static RAM

$SrTiO_3$. A type of compound semiconductor used in oxygen sensor ICs

SSMS. Spark-source mass spectrometry, a method used for characterizing InP and other crystals

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S²DHT. Superlattice SDHET

STEM. Scanning transmission electron microscope

STM. Scanning tunneling microscope

SWIR. Short-wave infrared, the 1.55-1.73um frequency band

t. Symbol for time

T. Tera, a prefix meaning 10^{12} or one trillion

t_{aa}. Address access time, one measure of memory device performance

TDH. Thermally dependent Hall (effect)

TDM. Time division multiplexing

TED. Transferred electron device

TEGFET. Two-dimensional electron gas FET (see SDHT)

TELD. Transferred-electron logic device

TEM. Transmission electron microscope

THETA. Tunneling hot-electron transfer amplifier

THz. Terahertz or 10^{12} hertz

TiPt. Titanium platinum

TiPtAu. Titanium platinum gold

TJS. Transverse junction stripe

TMGa. Trimethyl gallium

TMR. Triple modular redundancy, a design methodology useful for increasing the reliability of hardware (sometimes used in chips designed for spacecraft)

t_{pd}. Propagation delay time, a measure of logic circuit performance

T/R. Transmit/receive; may refer to a MMIC or MIMIC radar module

TTL. Transistor-transistor logic

TVRO. Television receive-only

TWM. Thermal-wave microscopy

2DEG. Two-dimensional electron gas

2DHG. Two-dimensional hole gas

UFL. Unbuffered FET logic

UHF. Ultrahigh frequency

UHV. Ultrahigh vacuum

ULSI. Ultralarge scale integration, or 10^7 to 109 devices per chip

UV. Ultraviolet, the upper end of the visible and near-visible frequency spectrum

V. Volt, a unit of electrical potential

VB. Vertical Bridgman, a method of growing III-V crystals

VCE. Vacuum chemical epitaxy; developed by Chevron Research Company, Richmond, California, for use in fabricating solar cells

VCO. Voltage-controlled oscillator

VFET. Vertical FET

VGF. Vertical gradient freeze, a method for growing III-V crystals

VHF. Very high frequency

VHSIC. Very high-speed integrated circuit

VLE. Vapor levitation epitaxy; a process for growing thin layers of InGaAs, invented by Herb Cox of Bellcore and patented by AT&T

VLSI. Very large-scale integration

VPE. Vapor phase epitaxy, a method for forming thin layers of material such as GaAlAs on a wafer

VSAT. Very small aperture terminal

VSTEP. Vertical-to-surface transmission electrophotonic, a type of compound semiconductor device structure

W. 1. The chemical symbol for the element tungsten 2. Watt, a unit of power

WDX. Wavelength dispersive X-ray, a materials analysis methodology

WORM. Write-once, read-many; a type of optical storage

WSi. Tungsten silicide

XPS. X-ray photoelectron spectrography

X-ray. A band of high-energy radiation ranging in wavelength from 1nm (soft X-ray) to 1 angstrom (hard X-ray)

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XRD. X-ray diffraction, a method for measuring and studying materials characteristics

XRF. X-ray fluorescence, a method of elemental analysis

XRT. X-ray topography, an analytical methodology involving imaging

YIG. Yttrium indium garnet; may refer to a sphere used to electronically tune oscillators and other circuits

Z. Symbol for impedance, which consists of resistive, capacitive, and inductive components

Zn. Symbol for the element zinc

ZnCdSe. Zinc cadmium selenide, a II-VI compound used to fabricate 620nm wavelength lasers

ZnSe. Zinc selenide

ZnTe. Zinc telluride

μ. 1. Micron or micrometer or 10^{-6} meter 2. Micro (prefix), meaning "10-6" 3. Micro (prefix), meaning very small

μA. Microampere or one millionth of an ampere

μH. Microhenry or 10^{-6} henries, a unit of inductance

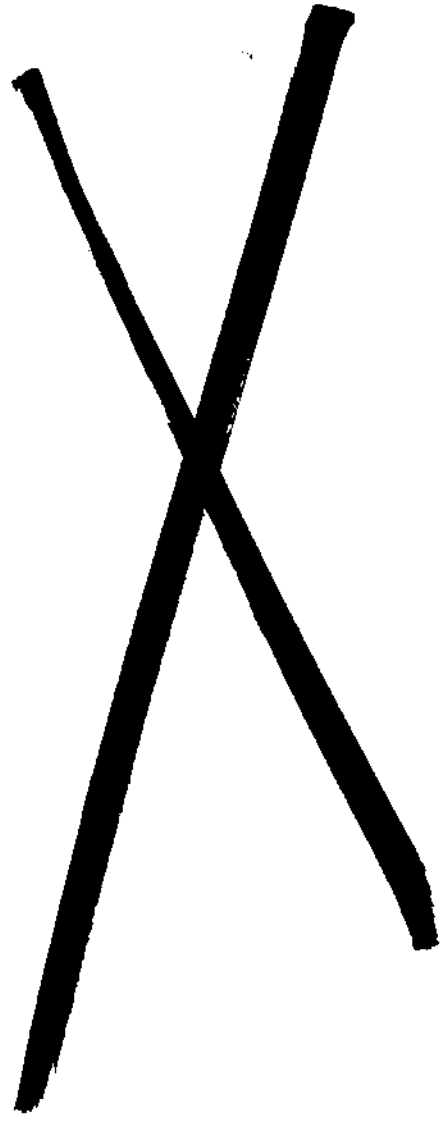
μm. Micron (see μ) literally, micrometer

μP. Microprocessor

μV. Microvolt

μW. Microwatt or 10^{-6} watt

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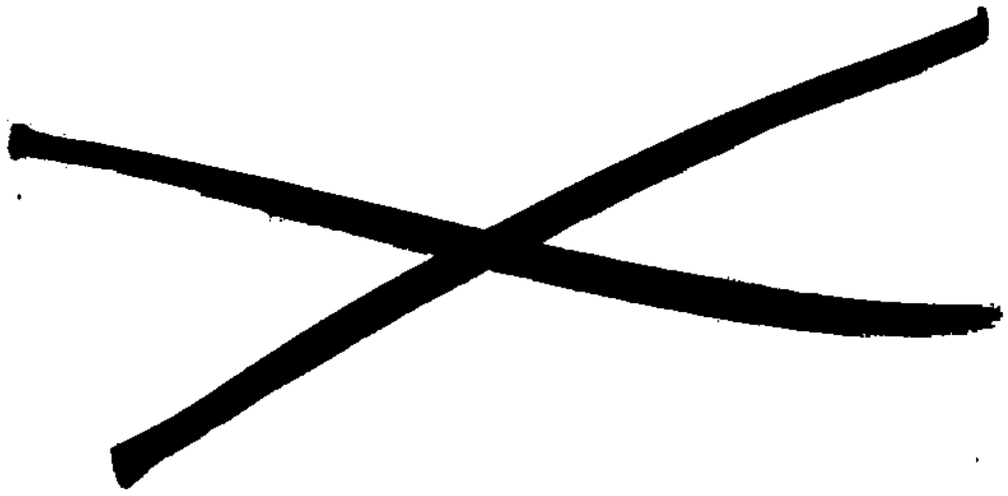
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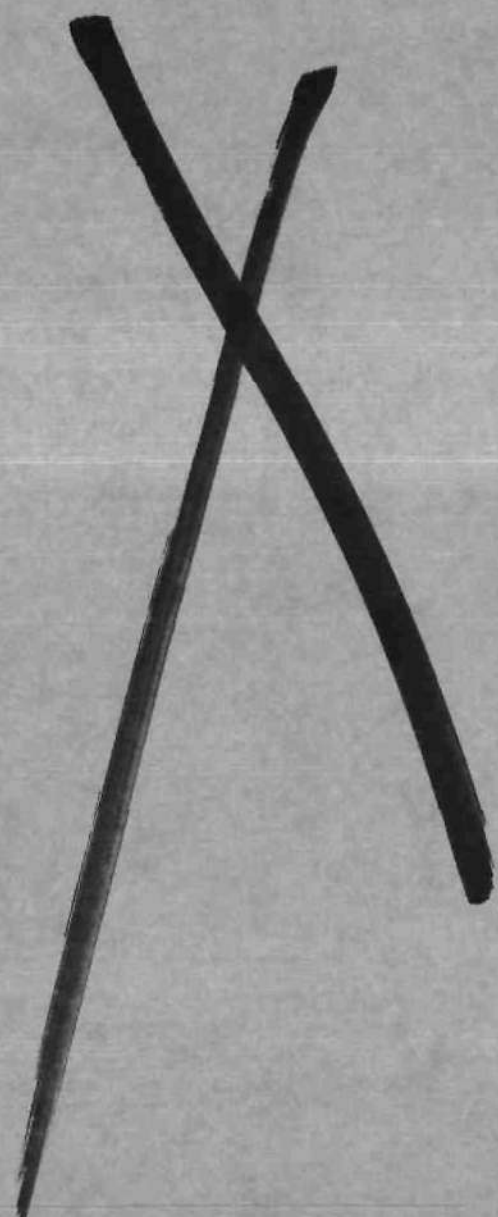
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ASEC	Asian Sources Electronics Components
BW	Business Week
CT	Corporate Times
DEMPA DIGEST	Dempa Digest
EB	Electronic Business
EBN	Electronic Buyers News
ECN	Electronic Component News
ED	Electronic Design
EDN	EDN
EET	Electronic Engineering Times
ELEC WEEK	Electronics Week
EN	Electronics News
EP	Electronic Products
ET	Electronics Times
FORD	Ford-Press Release
HARRIS	Harris-Press Release
HONEYWELL	Honeywell-Press Release
HT	High Technology
ICM	Integrated Circuits Magazine
IEEE	IEEE
IEEE C&D	IEEE Circuits & Devices Magazine
IEEE SPECTRUM	IEEE Spectrum
JEE	Journal of Electronic Engineering
JEJ	Japan Economic Journal
MATER RESCH	Materials Research-Press Release
MICROWAVE JOURNAL	Microwave Journal
MITSUBISHI	Mitsubishi-Press Release
MMT	Microelectronic Manufacturing & Test
NEC	NEC-Press Release
PB	Predi-Briefs
PHILIPS	Philips-Press Release
SJMN	San Jose Mercury News
SST	Solid State Technology
VLSI DESIGN	VLSI Design
WSJ	Wall Street Journal

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Research Newsletter

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ASIAN GaAs ACTIVITIES IN 1987

SUMMARY

This research study, the second annual report of its type, examines many Asian organizations' activities in GaAs and other III-V compound semiconductors in 1987. The report focuses on R&D, product developments, applications, pricing, production volumes, shipment data, and related business actions.

More than 50 Asian companies and other organizations and several U.S. and European companies are referenced in this newsletter. Their activities in III-V and other compound semiconductors range from research through product sales of materials, devices, subsystems, and end-use equipment. Applications of compound semiconductors described herein are diverse, from chips costing $0.69 that are used in consumer products to laser chips selling for more than $200.00 each that are used in fiber-optic and satellite applications. Brief discussions of some of China's and Japan's activities in space are included.

1987 CHRONOLOGY AND DISCUSSION

The major compound semiconductor activities by Asian companies in 1987 are listed by month in the sections below.

January

- NTT has developed a 4-GHz wideband GaAs limiting amplifier IC with phase-shift deviation less than five degrees for use in radar receivers and in optical and space communications systems.

- NTT licensed GAIN Electronics of Branchburg, New Jersey, to build GaAs chips with NTT's SAINT (self-aligned implanted n+ transistor) process. The first product application was a 2ns 4K SRAM.

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- MITI and the Optoelectronic Industry and Technology Development Association of Japan outlined a plan to standardize 33 items of opto telecom products. Standardized items will carry the designation "JIS" (Japanese Industrial Standard). The objective is enhanced compatibility of components for fiber-optic systems.

- Prices of consumer-product-grade (CD and video disk player) LED lasers declined sharply in recent months. In Tokyo, wholesale prices for large users ranged from ¥850 to ¥950 ($5.25 to $5.86) per unit for 780nm lasers, a 5.3 percent decline in two months. Leading-edge pricing was at ¥800 ($4.94). Severe competition and resultant price erosion was anticipated throughout the year as production volumes increased. Sharp Corporation increased laser production six times since April 1986.

- Fuji Electric (Japan) and Siemens A.G. (West Germany) strengthened their relationship with an agreement to exchange hardware and technology in the areas of factory automation, semiconductors, sensors, and telecommunications.

- Stanley Electric began to supply Nissan Motor Co. with LED high-mounted brake lights for the 1987 Z-model sports cars. This is the first use of LEDs for exterior illuminators on automobiles. The initial shipment rate was 6,000 units per month. Stanley intends to pursue other auto makers worldwide, including the big three U.S. companies.

- Fujitsu marketed the FMM100FG, a SSI GaAs frequency divider for applications to 4.2 GHz. The intended applications are prescaling and frequency synthesis.

- Japan launched its MOS-1 Marine Observation Satellite. Instrumentation on board includes a radiometer using a 2,048-element CCD integrated circuit.

- NEC offered a family of discrete power GaAs FETs called the NEZ series, featuring linear output power of 37.5 dBm over the range of C through Ku band frequencies. NEC claims the devices are space-qualified.

- A line of low-noise AlGaAs/GaAs microwave discrete high-electron-mobility transistors (HEMTs) became available from Sony and features a maximum noise figure of 1.0dB at 12 GHz. The HEMTs are fabricated by metal oxide chemical vapor deposition (MOCVD) and are intended for C band through Ka band satellite and other communications applications. Designated 2SK878-1, -2, and -3, sample prices were ¥10,000, ¥8,000, and ¥6,000 ($65.79, $52.63, and $39.47) respectively.

- Japan's National Space Development Agency (NASDA) forecast expenditures of $3.6 billion by the newly formed Space Station Integrated Project Center (SSIPC). The work force is estimated at 300 engineers and is expected to exceed 500 engineers by 1992.

- Space activities in Japan included development of the 4,400–lb. ETS–6 (sixth engineering test satellite). Toshiba, NEC, and Mitsubishi are responsible for overall system design/assembly, command/communications, and solar arrays/power, respectively. Approximate awards to the three companies were: Toshiba ($100 million), NEC ($75 million), and Mitsubishi ($75 million). NASDA apportioned the awards to maintain the technical staff at each of the Japanese satellite hardware suppliers.

- February 5 was set by Japan Institute of Astronautical Sciences for launch of the 925–lb. Astro–C spacecraft into a 320–mile orbit aboard a Nissan Motor Co. MU–3S–2 launch vehicle. Sensors on board included X–ray detection circuitry.

- Japan Technical Research Development Institute began to plan a portable antiaircraft missile using a visible image infrared homing mechanism. The missile is intended for use by its ground and air forces starting in 1990. Dataquest believes the device will require state–of–the–art military–range semiconductors.

February

- Toshiba planned to present a paper describing its development of a GaAs 6K gate array, at the ISSCC in New York, NY, USA, Feb. 25–27, 1987. Toshiba's chip features 284 ps gate delay at 1 mW per gate. Other ISSCC papers included a GaAs 1 ns 4K SRAM by Mitsubishi that dissipates 1.6 W, and a GaAs 16K SRAM by Hitachi.

- Mitsui strengthened its position in semiconductors with the formation of VM Technology Corporation, a joint venture with ASCII Corporation. VM Technology is to develop a virtual MPU for use in automobiles, word processors, copiers, and other products. Annual sales for 1989 are targeted at ¥5 billion ($31 million). (Note that Mitsui is a major backer of GAIN Electronics, a GaAs startup in Somerville, New Jersey.)

- Niigata Engineering Co. and Machine Technology Inc. (MTI) of the United States agreed to establish a joint venture to produce and market semiconductor manufacturing equipment. Initial capitalization was at ¥100 million to ¥200 million ($617,000 to $1,230,000). Operation started in Tokyo in March 1987. The 1990 sales target is ¥5 billion ($31 million).

- Hitachi announced the development of a high–speed logic circuit for telecom and imaging applications using sidewall contact structure (SICOS) technology. Propagation delay is 63ps per gate. The company also announced a low–power complementary version.

- Matsushita Electric Industrial Co., Ltd., reported its development of a 415nm–wavelength (blue–light) laser by coupling an 830nm laser with a second–harmonic generator (SHG) device. The device allows compression of optical storage area by a factor of four. Matsushita integrated the two components on a single chip for use in higher–density optical disk equipment; shipments started in second quarter 1987.

- Matsushita began marketing a standard cell library of analog cells early in 1987. The library includes A/D and D/A converters, op amps, comparators, and switches.

- NEC Corporation Microelectronics Laboratory announced completion of a lithography machine capable of drawing 0.25u patterns over a 20mm-square area.

- Hitachi Electronics Engineering Company, Ltd., began booking orders for its LS-5000 wafer surface tester, capable of inspecting haze and slipline defects at 0.16u accuracy. Pricing was ¥28 million to ¥30 million ($173,000 to $185,000). The first-year sales target was 70 to 80 units.

- Nippon Kogaku K.K. began marketing an X-ray lithography machine with 0.5u resolution over the exposure range of 29mm x 29mm. The equipment is adaptable to 3- to 6-inch wafers. Nippon Kogaku's sales target for the first year was five units, each of which is priced at ¥250 million ($1.54 million).

- Osaka University's laser nuclear fusion research center reported developing an X-ray exposure system capable of drawing 0.1u features. The research group plans to miniaturize the equipment for practical use.

- Hitachi and the Optoelectronics Joint Research Laboratory announced the development of a high-speed FET using lanthanum hexafluoride (LaF_6). The breakthrough is aimed toward development of GaAs VLSIs; LaF_6 could make dramatic increases in the level of integration possible. Hitachi plans to manufacture a compound semiconductor 256K SRAM based on LaF_6 FET technology.

- ERTI, the Korean Electronics & Telecommunications Institute, planned to proceed with 38 R&D projects with a budget of W45 billion ($52 million). These include several fiber-optic projects.

March

- Samsung Semiconductor and Telecom (Korea) announced a plan to develop GaAs chips for use in next-generation systems. Raw materials are to be developed by Goldstar Cable and Samsung in Korea.

- Matsushita announced production of GaAs gate arrays slated for mid-1987. The 200- to 1,000-gate devices feature 280ps gate delays and 1.5mW-per-gate power consumption. Initial pricing was ¥50 ($0.32) per gate.

- Toshiba began manufacturing a GaAs multiplexer that operates at a 2-GHz throughput rate. The logic IC contains approximately 700 elements. The company will make the device commercially available at a later date.

- Japan's opto industry production as reported by OEITDA grew 22 percent during the preceeding year. Data for fiscal years 1985 and 1986 (ending March 1987) are shown in Table 1.

Table 1

Japan Opto Industry Production
(Billions of Yen)

	FY 1985	FY 1986
Components	¥302.1	¥ 369.5
LEDs	134.7	159.3
Photodetectors	23.9	29.3
Photocouplers	32.5	39.2
Solar Cells	10.5	12.0
Fiber-Optic Cable	54.1	67.2
Other	46.4	62.4
Optical Equipment	446.7	543.2
Optical Applied Systems	99.1	126.9
Total	¥847.9	¥1,039.6

Source: OEITDA

- NEC introduced two photointerrupter products in molded resin packages. The PS4601 and PS4602 were initially priced at ¥40 and ¥45 ($0.26 and $0.29), respectively, in quantities of 50,000. Production started at 400,000 units per month and was increased to 800,000 units per month in October 1987.

- NEC reported operating a 678nm (visible) AlGaInP laser continuously for 3,000 hours at room temperature, claiming a record for this type of device.

April

- The Electrotechnical Laboratory of the Industrial Science and Technology Agency of Japan reported development of a superlattice Hall-effect device with sensitivity equivalent to that of InSb devices. The structure consists of AlGaAs and GaAs on GaAs substrate, and features 12V output at a magnetic field strength of 10,000 gauss. Nippondenso Co. is performing application studies.

- Korea's Goldstar Cable Co. and KAIST jointly developed a process for growing GaAs crystals. The companies plan shipments of GaAs wafers to semiconductor suppliers in 1988.

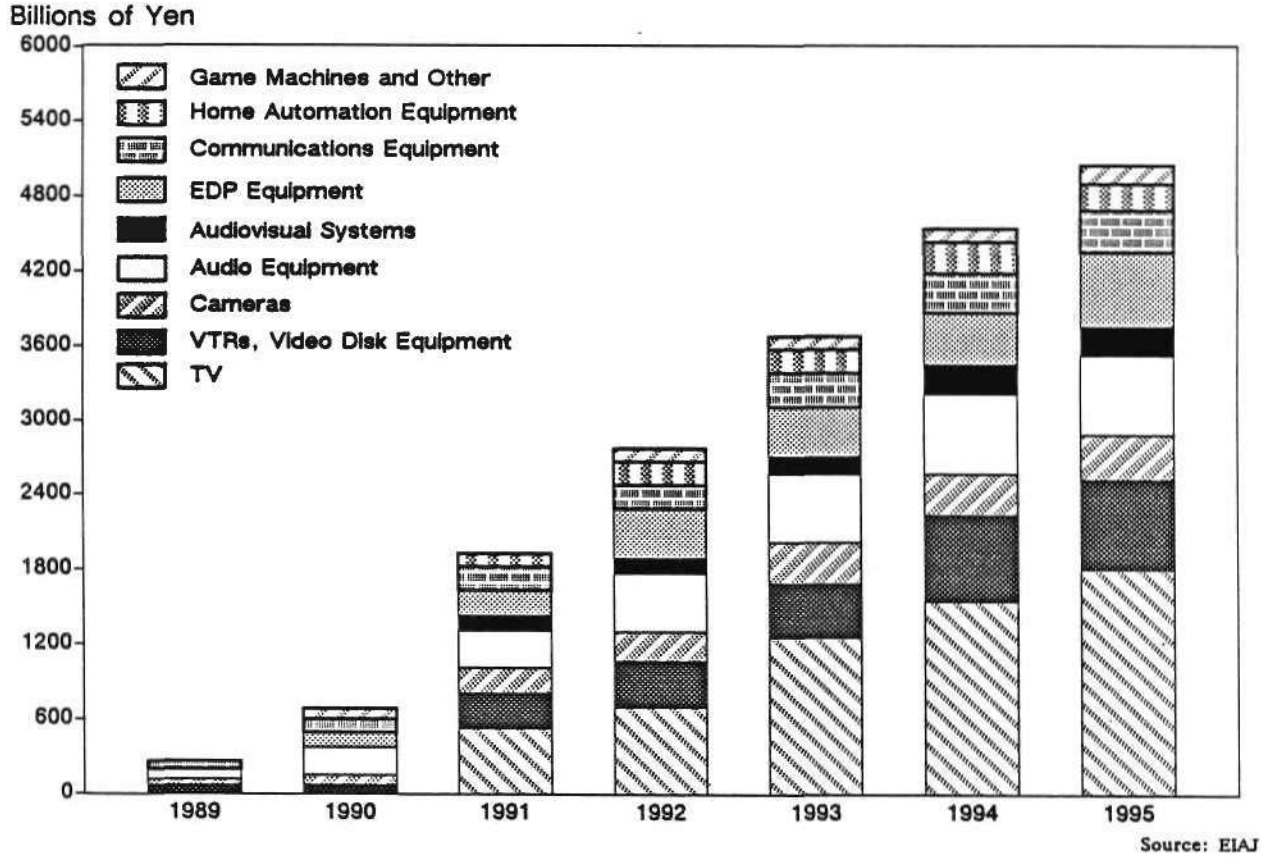
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- Matsushita reported a materials breakthrough for making blue LEDs four times brighter than those currently available. This was accomplished by mixing selenium, zinc, and chlorine to achieve resistance of 0.003 ohms per centimeter, one-tenth of that previously attainable.

- Electronic Industries Association of Japan (EIAJ) compiled a forecast of domestic consumer electronics through 1995. During the next 10 years, 129 new products are expected, including automatic translation machines. Figure 1 gives the details.

Figure 1

Japanese Consumer Electronics Production Forecast (Billions of Yen)



May

- NEC began sampling five types of GaAs digital ICs (digICs) in Japan. The devices are ECL-compatible and guaranteed for operation to 2 GHz. Table 2 shows sample pricing.

Table 2

NEC GaAs DigICs

Part Number	Function	Price (Yen)	Price ($)
UPG703B	4-stage counter	¥40,000	$287.77
UPG704B	4:1 mux	¥54,000	$388.49
UPG705B	1:4 demux	¥54,000	$388.49
UPG706B	Decision circuit	¥38,000	$273.38
UPG707B	Laser driver	¥38,000	$273.38

Source: Dataquest
December 1987

- Toyota bought 8.1 percent (2 million shares) of Hamamatsu Photonics K.K., an optoelectronics company, for ¥3.8 billion ($26.6 million), assuring Toyota of a strong position in optoelectronics technology.

- Sharp Corporation reported success in forming AlGaAs superlattice lasers by MBE. The company has fabricated MQW lasers with threshold current density of 145 amps per square centimeter, stripe width of 817nm, quantum well width of 45 angstroms (15-molecule layers) and 490u resonance length.

- Toshiba exported 10 CVD units to Siemens and 1 to Korea. The company planned to export epitaxial equipment and EB writing equipment in the near future.

- IBM's new System 2 has featured as an option an optical disk memory based on a Matsushita drive and media subassembly. The write-once unit incorporates a GaAs 20mW laser diode.

- Sanyo has developed a read-write-erase laser for application in erasable optical disk hardware such as read-mostly memories for EDP systems. The chip uses three monitor diodes to control the read, write, and erase beams.

- NEC began marketing its new NE202 low-noise GaAs HEMTs in the United States via California Eastern Labs. The devices are available in chip and package form, and feature 1.0dB noise figure at 12 GHz with 12dB associated gain.

- NEC announced development of GaAs-on-InP heterostructures and successful testing of long-wavelength (1300nm to 1550nm) OEICs.

- The Japanese Defense Agency reported its fiscal 1986 (ending March 1987) procurement figures. The data is shown in Table 3.

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Table 3

Japanese Defense Agency Procurement in Fiscal Year 1986

Ranking FY '86	Ranking FY '85	Company	Amount (Billions of Yen)	Percent Change from FY 1985
1	1	Mitsubishi Heavy Industries Ltd.	¥291.4	16.2%
2	2	Kawasaki Heavy Ind. Co., Ltd.	¥144.8	17.5%
3	3	Mitsubishi Electric Corp.	¥ 81.3	(23.2%)
4	5	IHI	¥ 78.2	13.3%
5	4	Toshiba Corp.	¥ 67.4	(8.0%)
6	6	NEC Corp.	¥ 48.5	19.9%
7	7	Japan Steel Works	¥ 22.2	(22.3%)
8	10	Fuji Heavy Ind. Co., Ltd.	¥ 18.2	2.9%
9	9	Hitachi Shipbuilding and Engineering	¥ 18.2	(15.8%)
10	-	Mitsubishi Corp.	¥ 17.0	-

Source: The Japan Economic Journal

- Sony's SLD300 series AlGaAs/GaAs lasers are now marketed in the U.S. The diodes feature a selection of CW power from 100mW to 1W. Packaging options are 9mm or TO-3 headers; wavelength options range from 770nm to 840nm.

June

- Fujitsu Laboratories, Ltd., has built and operated a GaAs HEMT 16-bit multiplier, achieving 4.1ns multiplication time at room temperature. The multiplier was constructed on a 4,000-gate array chip.

- Semiconductor laser prices experienced increasing pressure due to sluggish demand from CD-player makers. Volume pricing for 870nm lasers dropped to ¥500 ($3.57), a 30 percent decrease in six months. Mitsubishi reduced production by 33 percent to 400,000 lasers per month.

- At a press interview, NEC Corporation officials announced that the company would establish a compound semiconductor wafer fabrication facility within NEC Kansai, Ltd. The plant started production within 90 days of the announcement. Its first year production target is ¥10 billion to ¥15 billion ($69 million to $104 million).

- Three important high-tech exhibitions are held each May in Japan: BIOTEX, High-Tech Materials Exhibition, and Business Show. Each of these attracted approximately 100,000 attendees. Current Japanese government-sponsored projects featured at the shows are summarized in Table 4.

Table 4

Current Japanese Government-Sponsored New Materials R&D Projects

Theme	Private Organization	National Institute
Fine Ceramic	Engineering Research Association for High-Performance Ceramics (15 companies)	Government Industry Research Institute, Nagoya Government Industry Research Institute, Osaka National Institute on Research Organic Materials Machinery Engineering Lab
High Molecular Membrane for New Separation Technology	Research Association for Basic Polymer Technology (15 companies)	National Chemical Lab for Industry Research Institute for Polymers and Technology Industrial Products Research Institute
Molecular Materials	Research Association for Basic Polymer Technology (5 companies)	Electric Technology Lab Research Institute For Polymers and Technology
High-Performance Plastics	Research Association for Basic Polymer Technology (5 companies)	Research Institute for Polymers and Technology
Advanced Array with Controlled Crystalline Structure	Research and Development Institute of Materials and Composites for Future Industries (7 companies)	National Research Institute for Materials National Research Institute for Machines Government Industry Research Institute, Nagoya
Advance Composite Materials	Research and Development Institute of Materials and Composites for Future Industries	Government Industry Research, Osaka National Research Institute for Machines Research Institute for Polymers and Technology

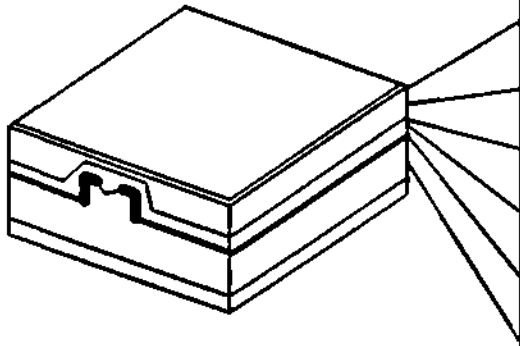
Source: Dataquest
December 1987

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- Matsushita described its GaAlAs laser designed for optical disk storage applications. It has 50mW output at 780nm wavelength, which allows increasing information storage density by a factor of 1.5 to 2.0, compared with 830nm-laser capability. The company plans to market the laser by early 1988. The structure of the laser is shown in Figure 2.

Figure 2

Matsushita's 780nm GaAlAs Laser



	High-Output Shortwave Laser	
n-GaAs	3 μm	Contact layer
n-GaAlAs	7 μm	Cladding layer
p-GaAlAs	0.04 μm	Active layer
p-GaAlAs	0.2 μm	Cladding layer
n-GaAs	2.5 μm	Block layer
p-GaAs	80 μm	Substrate

Source: Matsushita Electric Industrial Co. Ltd.

July

- According to the Japan Manufacturers' Society of Compound Semiconductor Materials (JAMS-CS), Japanese production of compound substrates totaled ¥17B ($116 million), flat for the third consecutive year. GaAs accounted for 49 percent, GaP for 42 percent, and all others, 9 percent.

- The Electrotechnical Laboratory of MITI's Agency of Industrial Science and Technology and Sumitomo Electric Industries announced that they would jointly construct a small synchrotron using superconductor technology. The machine is expected to be the world's smallest, at a diameter of 4 meters and weight of 20 tons. The laboratory plans to produce synchrotrons in volume for semiconductor makers.

- Sortec Corporation announced that it would develop synchrotron orbital radiation (SOR) equipment for use in high-resolution processing of ICs for Hitachi, Mitsubishi, Sumitomo, and Toshiba at a plant in Tsukuba. The project will cost ¥14.3B ($98 million).

- Sumitomo started building SOR equipment that will be set up in the company's opto technology research building in Tanashi, Tokyo, by April 1988. Production cost of the equipment will range from ¥1B to ¥2B ($6.8 million to 13.7 million).

- Sharp Corporation outlined a plan to increase opto device production, which includes photocouplers and interruptors, from the current rate of 40 million per month to 60 million per month. Opto devices accounted for 80 percent of Sharp's semiconductor usage, or $106 million in 1986 and $117 million in 1987.

- NTT is converting Japan's microwave long-haul telephone and television circuits to digital microwave, to be completed by the year 2000. Japan's systems today are 80 percent analog, particularly 4-, 5-, and 6-GHz bands using FDM/FM. The links between Japan and Okinawa were digitized in 1984. Table 5 provides some data on Japan's primary digital microwave systems.

Table 5

Japan's Primary Digital Microwave Systems

Frequency GHz	Capacity Per Channel Mb/s	Channel Spacing MHz	Repeater Spacing km	Modulation Method	Transmitter Power dBm
2.1-2.3	3	1.25	25	PSK	21
2.1-2.3	32	7	50	QAM	23
3.6-4.2	200	40	50	QAM	26
4.4-5.0	200	40	50	QAM	26
10.7-11.7	100	40	25	PSK	30
10.7-11.7	12.5	1.25	15	QAM	26
10.7-11.7	12.5	5	15	PSK	26
14.4-15.2	100	40	8	PSK	23
17.7-21.2	400	160	6	PSK	26

Source: Dataquest
December 1987

- Korean Semiconductor Research Association (KSRA) announced plans for six joint projects in addition to its 4Mb DRAM effort. These include GaAs ICs, standard cell ICs, compound materials, epoxy molding, and others, with a total budget of W8.6 billion ($10 million).

August

- Japan has been accelerating the process of "hollowing out" by relocating many semiconductor production facilities overseas. Compound semiconductor manufacturers in countries other than Japan should be aware of the potential competitive threat posed by these moves. Table 6 identifies Japanese overseas semiconductor plants.

Table 6

Japanese Semiconductor Makers' Overseas Plants

Company	Plant Name	Location	Year Established	Fab	Assy	Test
NEC	NEC Electronics USA	Mountain View, California	1979	-	X	X
		Roseville, California	1984	X	X	X
	NEC Ireland	Ireland	1976	-	X	X
	NEC Semiconductor U.K.	Livingston, U.K.	1982	X	X	X
	NEC Malaysia	Malaysia	1974	-	X	X
	NEC Singapore	Singapore	1976	-	X	X
Hitachi	Hitachi Semiconductor	Irving, Texas	1987	X	X	X
	Hitachi Semiconductor	West Germany	1980	-	X	X
	Hitachi Semiconductor	Malaysia	1972	-	X	X
Toshiba	Toshiba Semiconductor	Sunnyvale, California	1980	-	X	X
	Toshiba Semiconductor GmbH	West Germany	1983	-	X	X
	Toshiba Electronics Malaysia	Malaysia	1974	-	X	X
	Industrial Mexican Toshiba	Mexico	1966	-	X	X
Fujitsu	Fujitsu Microelectronics	San Diego, California	1980	-	X	X
	Fujitsu Microelectronics Ireland	Ireland	1981	-	X	X
	Fujitsu Microelectronics Asia	Malaysia	1986	-	X	X
Matsushita Electric	Matsushita Electric Singapore Plant	Singapore	1988	-	X	X
Mitsubishi	Mitsubishi Semiconductor USA	Durham, North Carolina	1985	-	X	X
Sanyo	Korea Tokyo Silicon	Korea		-	X	X
	Taiwan Tokyo Semiconductor	Taiwan		-	X	X
	Shenzhen Sanyo Semiconductor	China		-	X	X
Oki	Oki Semiconductor	Sunnyvale, California	1984	-	X	X

Source: Dataquest December 1987

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- Sharp Corporation announced the development of a 780nm wavelength semiconductor laser with 5mW maximum output. The device features an operating temperature range of -30 to +85 degrees Celsius. The company has serialized the device into four types—the LT022HC/WC (standard size) and the LT022HS/WS (small size)—and put them on the domestic market. Sample prices are ¥1,500 ($10.00) to ¥1,700 ($11.33) each. Production is targeted at 200,000 units per month.

- Matsushita Electric Industrial's Semiconductor Research Center reported the development of new superlattice manufacturing technology based on MOCVD. Early in 1988, the company plans to commercialize a II–VI compound semiconductor optical wave guide implemented in the new technology.

- A Chinese spacecraft was launched August 5 to obtain data on processing semiconductor materials in space. Tests during the five-day mission included smelting and recrystallization of alloys and semiconductor materials.

September

- NEC began marketing in the United States—via California Eastern Laboratories—eight GaAs digICs designed for DSP applications at or above 2 GHz (see Table 7). All are packaged in hermetic ceramic DIP.

Table 7

NEC GaAs DigICs

Part Number	Function	Clock Rate	Comments
UPG501B	Divide by 4	5 GHz	For 100 pieces, price each $105
UPG502B	Divide by 2	5 GHz	For 100 pieces, price each $95
UPG504B	Divide by 2	10 GHz	
UPG703B	4-stage counter	2 GHz	ECL-compatible
UPG704B	4:1 mux	2 GHz	ECL-compatible
UPG705B	1:4 demux	2 GHz	ECL-compatible
UPG706B	Decision circuit	4 GHz	Rise/fall times 100ps
UPG707B	Laser driver	2 GHz	Rise/fall times 150ps

Source: Dataquest
December 1987

- Listed as new participants in the Korean GaAs semiconductor industry were Goldstar Cable, Hanil Textile, and Samsung Corning; considered as possible newcomers were Asia Cement and Hanryo Development (photomasks), Korea Pilot (hybrids), Pochul (wafers and leadframes), and Koryo Systems.

- Fujitsu outlined plans for a new IC factory in Gresham, Oregon, that will initially specialize in ASIC fab, assembly, and test.

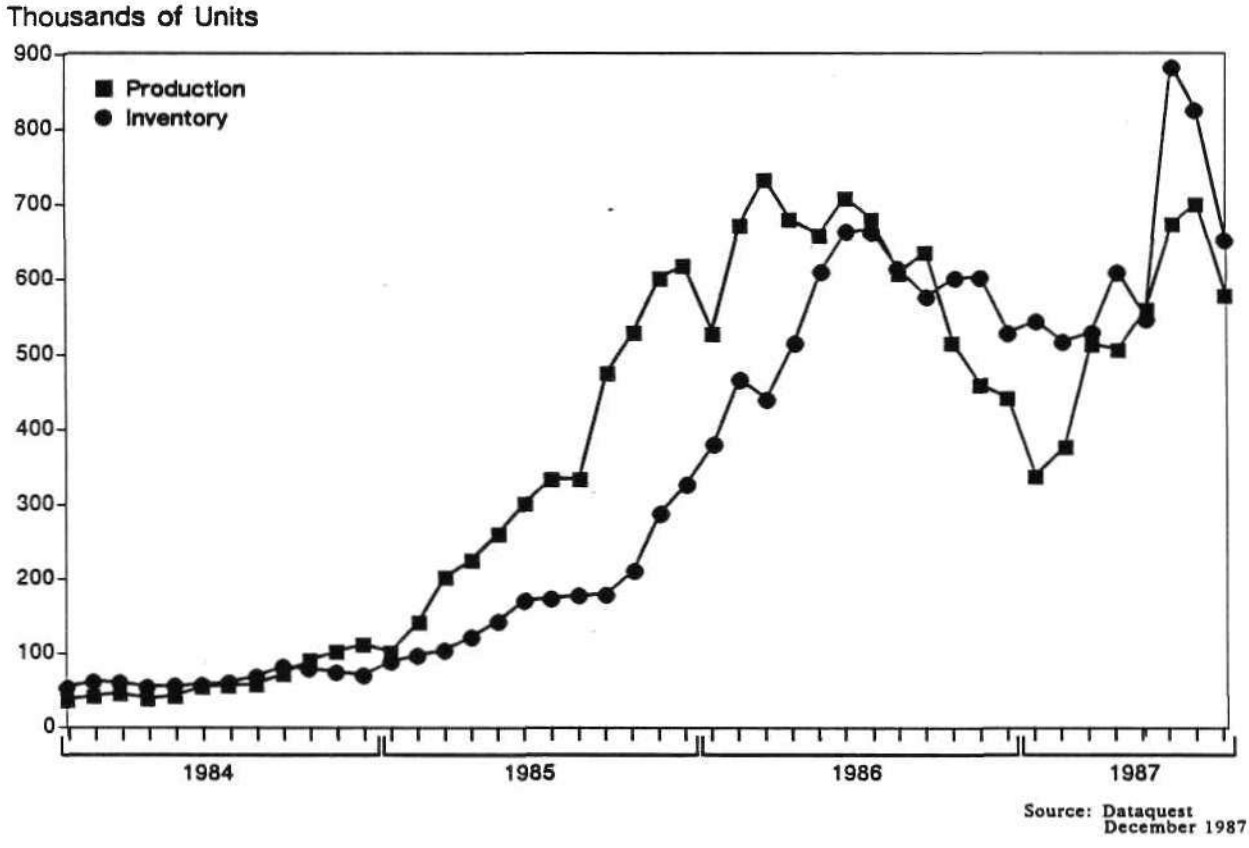
- NTT reported operating a GaAs/InGaAs heterojunction bipolar transistor (HBT) at 5.5ps delay time at room temperature, claiming a world speed record for such a device.

- Japan's ETS–5 Engineering Test Satellite was launched August 27 and achieved geosynchronous orbit on August 30. The satellite accomplished a large–scale test of the influence of space radiation on 64K CMOS SRAMs and GaAs devices. Its large semiconductor solar arrays were opened a half–day earlier than planned due to a high–temperature problem. The ETS–5 was also intended to demonstrate mobile satellite communications with ships and aircraft.

- Japan's production of CD players recovered gradually in mid–1987. Production was expected to exceed 10 million units in 1987, up 25 percent from 1985. Figure 3 plots Japanese CD player production and inventory.

Figure 3

Japanese Digital Audio Disk Player
Production and Inventory



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October

- NTT developed an X-ray stepper capable of 0.2u feature-size IC production. Processing speed is 20 six-inch wafers per hour.

- NEC succeeded in forming 0.2u features using SOR, and claims it can achieve 0.1u geometries with this technology. NEC plans to use SOR in production of ICs by 1990.

- A low-voltage 4Kx4 GaAs SRAM is being developed by Mitsubishi's LSI R&D Laboratory in Itami, Hyogo, under the MITI Scientific Computing Systems Program. Test devices, using 1.0u E/D DCFL self-aligned-gate MESFET process and dual-layer metal, were operated at 1.0V power supply voltage, t_{aa} of 11ns max and P_D of 1.0W. The 5.79 x 4.73 mm^2 die incorporates four blocks of 128x32 memory cells, each 31.5 x 24 um^2.

- A 6,000-gate GaAs gate array was built by Toshiba VLSI Research Center at Saiwai-ku, Kawasaki, as part of MITI's Scientific Computing Systems Program. The array used a conventional SCFL structure to implement 232 rows by 26 columns of cells. A test structure with serial-parallel-serial registers occupying 80 percent of the die consumed 952mW when operated at an 850-MHz data rate. Die size is 8 x 8 mm^2.

- Under the MITI Scientific Computing Systems Program, Hitachi's Central Research Lab, Kokubunji, Tokyo, fabricated and tested ECL-compatible GaAs 1K and 4K E/D DCFL SRAMs. The chips have an access time spread of less than 1ns and max t_{aa} of 3ns, and use conventional SCFL interface structures for improved noise margin.

- Mitsubishi LSI R&D Laboratory, Hyogo, built a 0.5u-gate GaAs SAG-MESFET with cut-off frequency (f_T) of 42 GHz. The process has silicon-tungsten/titanium/gold gate electrodes and gold-germanium/nickel/gold ohmic electrodes at source and drain. The company developed the process to extend microwave monolithic (MMIC) performance.

- Hitachi Central Research Lab (CRL), Tokyo, has fabricated a family of three optoelectronic ICs (OEICs). The circuits include a 4-GHz laser driver, a 2.4-GHz preamp, and a 2.4-GHz gain-controllable amplifier implemented with 0.7u-gate GaAs SAG MESFET processing. Hitachi plans to refine GaAs ICs to achieve at least 10GHz optical transmit/receive rates.

- NEC Microelectronics Research Labs, Kawasaki, has developed a CML SSI logic family using AlGaAs/GaAs HBTs formed by MBE. The structures consist of 0.15u emitters, 0.1u bases, and 0.5u collectors formed by a self-aligned fabrication process; f_T of 50 GHz has been achieved. A 17-stage ring oscillator was operated at t_{pd} of 12.3ps per stage.

- Matsushita Semiconductor Research Center, Osaka, has performed testing of 0.3u-gate GaAs FETs with gain of 9.5dB at 12 GHz. The process implements self-aligned dummy-gate MESFETs. The devices were developed for use in MMICs.

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- Matsushita Electronic Research Laboratory (ERL), Osaka, has demonstrated a high-CMRR (common mode rejection ratio) GaAs op amp with CMRR (common mode rejection ratio) of 63dB at unity-gain frequency of 150 MHz.

- Matsushita ERL has also built a GaAs four-stage wideband MMIC amplifier. The chip operates at more than 2 GHz. Gate lengths are 1u; 2u gate-source and 4u gate-drain spacings are used. Gain is relatively flat at 23 ± 0.5 dB over the operating frequency range of 0.2 GHz to 2.0 GHz.

- Oki Electric Industry Company Research Lab, Tokyo, is exploring the problem of "side-gating" in an effort to increase the density level achievable in GaAs LSI chips. Oki proposed using negatively biased p-regions between devices as an effective solution.

- Hitachi Central Research Lab, Tokyo, has built a GaAs 4K SRAM with 1ns access time. The process uses 0.7u gates, resulting in cells with 60 to 80 femto-Coulombs (fC) critical charge. The effort is supported by MITI's National R&D Program on Scientific Computing Systems.

- Fujitsu Laboratories (owned by Fujitsu, Ltd.) Atsugi, has implemented a 500ps address-access-time 1Kx4 SRAM using GaAs E/D DCFL HEMT processing with 0.5u gates. Chip power dissipation is 5.7W; die size is 2.8 x 3.6 mm^2. This effort is also being supported by MITI's National R&D Program on Scientific Computing Systems.

- NTT was the first company to report the demonstration of a GaAs ROM. The company's Electrical Communications Lab (Kanagawa) has developed an ECL-compatible GaAs 512x8 ROM. The chip has t_{aa} of 1.2ns; p_d is 3.75W. The ROM uses 0.5u-gate E/D DCFL technology.

- NEC Compound Semiconductor Devices Division, Kawasaki, produced a 5-GHz ECL-compatible master-slave flip-flop (FF) based on 0.8u SAG-MESFET process. The chip is intended for use in high-speed communications and instrumentation applications.

- NEC Corporation, Kanagawa, has developed a GaAs LSI 8 x 8 matrix switch for high-speed digital communications applications such as high-definition television (HDTV). The 3.1 x 4.1mm^2 die is packaged in 40-pin flatpack. The chip has 390 internal BFL gates and SCFL I/O buffers.

- Mitsubishi LSI R&D Lab, Hyogo, developed a lightly doped drain (LDD) SAGFET GaAs 128/129 prescaler that operates at 1 GHz, consuming 2mA at 5V (and therefore capable of battery operation). The circuit has been packaged in plastic with no observed degradation in reliability.

- Sony Research Center, Yokohama, has applied MOCVD technology (previously used for laser fabrication) to the construction of GaAs HEMTs with 0.5u gates. GaAs HBTs were also grown by MOCVD.

- Toshiba's VLSI Research Center (Kawasaki, Japan) has fabricated a 16:1/1:16 mux/demux chip set based on a 1.2u-gate GaAs DCFL MESFET process. The chips have ECL- and TTL-compatible I/Os, and operate at 1.4 GHz and 1.0 GHz, respectively.

- Shimazu Seisakusho began marketing 1300nm LED lasers priced at ¥30,000 ($209.79). The fiscal 1988 sales target is 10,000 units.

- Since NHK, the Japan Broadcasting Corporation, began 24-hour direct broadcast satellite (DBS) service in July, the demand for HEMTs for consumer products increased sharply. Fujitsu planned a large production boost by year end. NEC expanded HEMT production by 500 percent, and Sony increased its run rate from 10,000 per month to 100,000 per month. Mitsubishi, already producing 50,000 per month, was taking a cautious attitude.

November

- Fujitsu Laboratories, Atsugi, Japan, has been studying resonant tunneling transistors as a means of extending circuit-switching speeds beyond that of HEMT. Fujitsu researchers believe that future HEMTs will peak at 1ps transit time, and that 0.2u is the lowest practical gate length (limited by punch-through). The company has been examining both resonant hot-electron transistor (RHET) and resonant bipolar transistor (RBT) structures for possible use in future high-speed digital hardware.

- A high-speed computer in development at Fujitsu began to employ HEMT technology to implement extremely fast CPU operation. Completion is scheduled for 1990.

- Fujitsu has signed agreements in the United States and Australia to export HEMTs for use in radio telescopes. The Nobeyama Radio Observatory in Japan has used such chips since 1986 to study previously unobserved radio waves from space.

- Oki Electric Industry Co. Research Laboratory, Tokyo, has grown high-quality 4u-thick GaAs layers on (1-0-0) 50mm, 280u-thick silicon wafers, and has fabricated MESFETs, ring oscillators, power FETs and AlGaAs LEDs on the GaAs-on-Si substrates. Test results were similar to those for devices built on GaAs wafers. A company spokesperson expects Oki to manufacture monolithic ICs containing silicon ICs and optical devices for future products.

- Tokki Corporation, a factory automation house, began marketing its electron cyclotron resonance (ECR) plasma CVD machine. The technology was introduced from NTT. The machine is priced at priced at ¥40M to ¥100M ($280,000 to $690,000). Tokki plans to sell 5 to 10 units in the initial year.

- NTT has built and tested polymethylmenthacrylate (PMMA) fibers, demonstrating an attenuation loss limit near 35dB/km at 568nm wavelength. Using deuterium to replace hydrogen in the polymer, the attenuation loss was reduced to 9dB/km at 680nm wavelength, indicating a potential usage for plastic fibers in optical communications.

- Toyota Central R&D Laboratory, Aichi, has developed a negative differential resistance (NDR) device based on a 10-layer superlattice structure.

- Mitsubishi's LSI Research Center has developed a low-impedance gate GaAs FET with 42-GHz cutoff frequency for use in manufacturing MMICs, starting in 1988.

December

- Sumitomo claims it is the world leader in III–V semiconductor materials, offering doped and undoped polycrystal and single–crystal GaAs, GaP, InP, InSb, InAs, and GaSb ingots, substrates, and epitaxial wafers. Sumitomo has more than 200 customers, in more than 20 countries including Bulgaria, Poland, and the U.S.S.R.

- Matsushita's Wireless Research Laboratory has investigated a multiple self–aligned process for AlGaAs/GaAs HBTs. The process uses one mask for emitters, emitter contacts, emitter contact leads, buried collectors, base contacts, and base contact leads. HBTs with 1 x 20um^2 emitters, base islands of 4 x 20um^2, base contacts of 1.5 x 20um^2 and oxygen ion–implanted buried collectors demonstrated f_T of 54 GHz and f_{max} of 42 GHz. Base contact to emitter spacing was 0.25u. Process refinements are expected to increase the maximum gain available cutoff frequency to a value greater than 100 GHz.

- Sony and Philips have jointly developed data formats and other standards for CD–ROMs, including preliminary mixed–mode formats. These have been issued to licensees. The specifications contribute to lowering the cost of CD–ROM mastering, which will boost the market for players and hence for III–V lasers and sensors.

- Panasonic is offering a line of CD–ROM drives and optical disk players ranging in price from $895 to $3,995, and plans to announce a 5.25–inch WORM drive in the near future. All of the units use laser diodes in the read circuitry. Recording capacity of the 8–inch (200mm) TQ–FH224 unit is 24,000 frames of standard video resolution data (approximately 540 megabytes).

- Japan expects to launch its next H–1 booster on February 1, 1988. The mission is scheduled to carry the Mitsubishi CS–3A communications satellite into geosynchronous orbit.

DATAQUEST CONCLUSIONS

The field of GaAs and other III–V compound semiconductors is advancing rapidly every year; 1987 was no exception. Asian companies are very active in the application of GaAs technology to EDP, consumer, fiber–optic communications, and satellite hardware, and continue to refine the traditional LED display devices. There is increasing competition in the worldwide IC marketplace, particularly in MMICs and digICs, with new players entering the performance race. Dataquest expects this pace of activity to continue into the 1990s as Asian IC suppliers, pressured by declining profits in silicon devices, seek out niches in III–V markets.

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Research *Newsletter*

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GOMAC–87: "CHALLENGES FACING GOVERNMENT ELECTRONICS IN THE 1990s"

The 1987 Government Microcircuits Applications (GOMAC) conference was held in Orlando, Florida, on October 27 through 29, 1987. Approximately 1,000 attendees participated in 21 sessions on subjects ranging from IC design concepts to discontinued parts. Due to time constraints, parallel sessions were held, up to four at a time, making it necessary for those involved in defense programs to split up their delegations in order to attend as many sessions as possible. Exhibits of products, services, and capabilities of more than 30 companies were on display in an area adjoining the lecture halls. This newsletter discusses some highlights of this important conference.

VHSIC INSERTION

Progress in VHSIC insertion was reported by most of the participating companies. Many of the exhibits featured examples of VHSIC chips and their application to defense electronics systems. The presentations indicate that VHSIC technology has been applied to a wide range of hardware including ruggedized computers, imaging systems, digital signal processing (DSP) functions, and radar electronics.

SIGNAL PROCESSING

Applications of silicon or Si/GaAs IC technology to signal processing problems have been accomplished by numerous defense electronics suppliers. For example, TRW described its superchip family and presented data on its high–performance 6–bit analog–to–digital converter (ADC). The TRW ADC uses a GaAs front end to drive a silicon bipolar flash quantizer.

Bipolar Integrated Technology, Inc. (Beaverton, Oregon), presented a family of integer and floating–point DSP circuits based on its 2.0 silicon bipolar process. The company claims that the process offers the higher speeds of ECL at the VLSI functional density of CMOS.

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VTC (Bloomington, Minnesota) has developed a bipolar cell library of analog/digital cells for signal processing applications. The bipolar structures use complementary transistors with f_T of 6 GHz (NPNs) and 1 GHz (PNPs). The cell library is augmented with components for use in customization.

MIL-STD-1750A

Performance Semiconductor presented and displayed information on its 40-MHz VHSIC-class PACE 1750A system. The system is a CMOS three-chip set consisting of a central processor unit, a processor interface chip, and a memory management unit/combination support chip. The set provides system performance greater than 2 mips. Performance Semiconductor supports its PACE 1750A with a product line consisting of the world's fastest CMOS SRAMs, with chip densities ranging through 256Kx1.

Other companies presenting information on 1750A architectures and products included Allied Signal, General Electric, IBM, Loral, Texas Instruments, TRW, and UTMC.

GaAs SEMICONDUCTORS

GaAs has been applied to high-performance military electronics for several reasons, among which are frequency response and speed superior to silicon, and inherent radiation hardness. General Electric described innovations in using GaAs to implement radar transmit/receive modules.

Several companies, including AT&T, GAIN Electronics, Raytheon, TriQuint, and TRW, made presentations or displayed information about their progress in developing and producing GaAs ICs. AT&T is offering a 1-GHz divide-by-128/129 prescaler, the DG1096AX. The circuit is fabricated using GaAs E/D MESFET process and comes in 8-lead flatpack or DIP. The chip consumes less than 40mW and has TTL/MOS-compatible I/Os.

GAIN Electronics Corporation is marketing a family of gate arrays including its GFL6000. This product is a 5,776-gate array with 204 I/O buffers, 3W maximum power dissipation, and unloaded gate delays of 100ps. I/Os may be CMOS-, TTL-, or ECL-compatible. Package options include chip carriers and pin-grid arrays. The company is processing production orders for its gate arrays.

Raytheon offers GaAs IMPATT diodes for selected applications. The devices are specified to 60-GHz frequency and 10W output power, and to 44-GHz and 25W output. The devices are produced at the research division in Lexington, Massachusetts.

TriQuint is producing a 3,000-gate ASIC array called the TQ3000, which has 1,020 core cells and 64 I/Os. NRE charges are $80,000 including design manual and workstation software. The ASIC is supported by Daisy, Mentor, and Tek/CAE workstations.

TRW is developing microwave and millimeter wave ICs for communications and other defense applications. TRW, Honeywell, and General Dynamics compose one of the DOD teams developing this technology; TRW is the prime contractor for this team.

RELIABILITY AND FAULT TOLERANCE

The United States Air Force has launched a program called R&M 2000. In implementing this program, the Air Force Systems Command is challenging the electronics industry with specific goals, such as "double-R, half-M" (double the reliability and half the maintenance) and 2,000-hour MTBF for line-replaceable units (LRUs), to be met by defense contractors.

TRW summarized the historical development of fault diagnosis and presented fault-tolerant methodologies that lend themselves to present-day design activities. The discussion emphasized the need for increased focus on fault-tolerance in future designs.

Fault-tolerant software was the subject of a joint paper by Westinghouse, SRI International, and NASA. The authors described a distributed general-purpose, fault-tolerant operating system for use on VHSIC 1750A processors.

Intel reported close work between its Military Operation (Chandler, Arizona) and one of its major accounts to significantly reduce incoming VLSI reject rates. The company said it plans to extend the approach to other customers.

Lockheed described a design methodology for extending traditional fault-tolerant design techniques to analog functions. Included are techniques for self-test, self-diagnosis, and self-correction, previously used only in digital circuit design.

TESTABILITY

Honeywell made two presentations on VHSIC testability and maintainability. The first described a control function block to be included on-chip. The second described a standard design methodology for producing inherently testable systems on a consistent basis.

Teradyne has developed a tester calibration architecture for VHSIC modules. The company says the system calibration allows maintaining a maximum of $\pm$1.5ns skew at 40-MHz frequency across more than 400 pins.

Silicon Compiler Systems described the growing importance of integrating test development into the design process. The company's exhibit included a demonstration of its automatic test generation (ATG) system.

A joint presentation was made by VTC, Inc., and Control Data Corporation describing a rad-hard standard cell testability structure. Other companies presenting information on testability included Mitre, Unisys, and UTMC.

RADIATION HARDNESS

Two of the GOMAC sessions and more than a dozen papers were devoted to radiation hardness. LockHeed, M/A-COM, Motorola, VTC, and others made presentations on this subject.

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The UTMC exhibit included information on its UTB-R and UTD-R rad-hard gate array families and other rad-hard products. The UTMC products are designed to withstand these levels of radiation:

- Data sheet specification operation to $2x10^5$ rads (Si) total dose
- Functional to 10^6 rads (Si) total dose
- No upset of less than 10^9 rads (Si)/s dose rate
- Dose rate latch-up $>10^{10}$ rads (Si)/s
- Neutron fluency 10^{14} N/cm

DISCONTINUED PARTS

The life cycles of many commercial IC devices and families are shorter than those of most military electronics equipment. As the rate of technological change increases, discontinued parts generate a growing set of problems to defense contractors. Four organizations made presentations of methods useful in resolving some of these problems.

Honeywell, for example, has developed a replacement for many of the (DTL) functions that are no longer procurable. The replacement device is a 16-pin bipolar generic array. Another company, SAIC, has worked with DESC on an R&D program to develop TTL, LSTTL, ECL, linear, and other emulation devices for fabrication on a bipolar baseline process at a silicon foundry.

PACKAGING AND INTERCONNECTION

Kyocera Corporation, Kyoto, Japan, displayed state-of-the-art packages at its exhibit. The company claims world leadership in technical ceramics. One of the more exotic of Kyocera's products was a 1,700-pin grid array (PGA) of approximately 15-square inches.

Kyocera has steadily increased its account penetration in the United States and is a leading supplier to VHSIC chip houses. This raises an interesting issue regarding DOD's dependence on foreign suppliers.

Dow Corning Corporation has developed materials for implementing a novel hermetic package concept for improved chip reliability. The approach is called surface protected electronic circuits (SPEC) and involves applying multiple layers of polymeric materials directly to the circuits.

Honeywell discussed a package design that may in many instances solve the problem of having to tool separate packages to accommodate various chip designs and multiple chip suppliers. A joint paper by Interamics and Texas Instruments described a package development to support multiple VHSIC chips in a single ceramic module.

DATAQUEST CONCLUSIONS

Although much progress has been made in semiconductors for military applications, major challenges remain. The R&M 2000 initiative, requiring doubling of MTBFs and halving maintenance, is but one example.

Although great strides are being taken in domestic chip technology, it appears that the U.S. defense industry still relies heavily on a sole foreign source for large-volume production of IC packages. This is not new; the situation has existed for several years. Two questions remain:

- Is reliance on non-United States-based sources of electronic parts really a high-priority matter?
- If so, who in the industry or in Washington is responsible for working on the packaging issue, and what is the timetable for resolution?

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Research *Newsletter*

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ANOTHER APPLICATION FOR GALLIUM ARSENIDE: LOW–COST COLLISION–AVOIDANCE RADAR

SUMMARY

Low–cost collision–avoidance radar, a new application for gallium arsenide semiconductors, can significantly improve motor vehicle safety. One company, Vehicle Radar Safety Systems, Inc., is already producing a $900 unit, and development activity among other companies and major auto makers is intense.

We expect widespread use of this equipment on passenger automobiles by the mid– to late 1990s. We believe that this will create a high–frequency GaAs circuits market that will exceed today's military market.

This is another example of a new application for gallium arsenide that is emerging as designers become familiar with the unique properties of the material. Gallium arsenide devices originally were developed for high–speed supercomputing applications, but now designers are realizing that these devices can also be used for high–temperature, radiation hard, and ultrahigh frequency applications.

BACKGROUND

More than two years ago, companies such as Pacific Monolithics developed low–cost (less than $10) GaAs ICs for satellite downconverters in TVRO applications. This and similar efforts in discrete GaAs have resulted in production–worthy GaAs chips, which in turn have made possible low–cost Doppler radar units. By adding a nominal amount of DSP hardware, such units can provide collision–danger warning signals to the driver of an automobile or other vehicle. Functions such as a Gunn diode oscillator, power amplifier, mixer, receiver low–noise amplifier (LNA), filters and, if required, an A/D converter, are easily implemented with GaAs. Other functions in the unit, including DSP, can be built with silicon devices as can the filters and A/D converter (depending on operating frequency).

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DEVELOPMENT PROJECTS

The following paragraphs discuss the current collision-avoidance projects.

Battelle

Battelle has recently developed a millimeter-wave radar concept for vehicle collision-avoidance systems. The proposed system operates at a frequency between 35 and 95 GHz, has a beam-steerable antenna, uses FM/CW (frequency modulated, continuous wave) Doppler radar circuitry, and requires a 10Mb/second computer for DSP. Battelle estimates the prototype funding requirement at approximately $750,000.

Daimler-Benz

The European Prometheus project, launched in 1986 by Daimler-Benz, includes development of a collision-avoidance system. A spokesman for Daimler-Benz estimates that the Prometheus system could reduce European traffic casualties by a factor of two within 15 years. The project involves more than 15 European auto producers and at least 50 research organizations throughout Europe.

Nissan

Nissan Motor Corp. is developing a system using two pulse-Doppler transceivers and an on-board computer to detect danger conditions ahead. Progressive audible alarms will alert the driver as conditions change.

Ford

In the United States, the Ford Motor Company and GM/Hughes are working on collision-avoidance systems for vehicles. These companies had not announced availability dates for any such products as of press time.

DATAQUEST CONCLUSIONS

GaAs semiconductors have unique properties that lend themselves to heretofore unrealized applications. Automotive collision-avoidance radar is a prime illustration of innovation made possible by GaAs technology. Other examples are:

- Fiber-optic transceivers
- High-speed, high-resolution color-graphics mux/demux functions
- The Cray-3 supercomputer

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- Multi-GHz satellite communications links
- Hall-effect sensors for automotive brakes and other high-temperature environments
- Low-cost TVRO chips

Dataquest believes that the semiconductor industry has an exciting opportunity for growth in the emerging market for vehicular collision-avoidance radar. A major contribution to highway and street safety can be made by those manufacturers that excel in this marketplace.

Gene Miles

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Research Newsletter

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GaAs TEAMS, AGREEMENTS, PARTNERSHIPS, AND ACQUISITIONS

SUMMARY

A natural consequence of GaAs technology development in the United States is the increasing number of partnerships, agreements, mergers/acquisitions, joint ventures, and team efforts. This newsletter summarizes some of the major such actions in this industry.

MIMIC PROGRAM

The DOD MIMIC (millimeter-microwave IC) initiative represents a major effort to incorporate the advantages of compound semiconductors into a variety of military applications. These applications include:

- Ultrareliable radar for the U.S. Air Force ATF
- Shared-aperture radar for the U.S. Navy ATA
- MILSTAR network communications terminals
- Smart munitions
- Wideband jammers
- Antiradiation missiles
- Other "brilliant" weapons

The MIMIC program entered Phase 0 early in 1987 with the award of 12 major and 4 smaller contracts to prime contractors. Table 1 is a compilation of the responsible services, prime contractors, approximate amounts of awards, and team members involved in the major Phase 0 contracts. Additional awards went to Hittite Microwave ($500,000), Ball Aerospace ($497,000), E-Systems ($100,000), and Loral ($100,000). Funding for the remainder of the seven-year program recently was estimated at more than $530 million. Dataquest believes that Phase I of MIMIC will see some realignment of the participants, as the program becomes more competitive and the number of teams decreases.

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Table 1

MIMIC PHASE 0

Service	Army			
Prime Contractor	Eaton	ITT	Martin Marietta	TRW
Award ($K)	886	995	986	1,000
Team Members:				
Adams Russell				
Aerojet				
Airtron (Litton)				
Alpha Industries			X	
AT&T				
Avantek				
Cascade			X	
Cominco				
Compact Software				
Consilium				
Cornell University				
EEsof			X	
General Dynamics				X
General Electric				
Harris			X	
Honeywell				X
Lockheed				
M/A-COM				
Magnavox				
Motorola				
Norden (United Technologies)				
Pacific Monolithics		X		
Rockwell				
Singer				
Spectrum			X	
Teledyne Ryan				
Texas Instruments			X	
TriQuint				
Varian				
Watkins-Johnson		X		

(Continued)

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Table 1 (Continued)

MIMIC PHASE 0

Service	Navy			
Prime Contractor	Bendix	Ford	Raytheon/TI	Sandecs
Award ($K)	751	1,000	999	981
Team Members:				
Adams Russell				X
Aerojet			X	
Airtron (Litton)			X	
Alpha Industries				
AT&T				
Avantek				
Cascade				
Cominco				
Compact Software			X	
Consilium			X	
Cornell University				
EEsof				
General Dynamics			X	
General Electric				
Harris				
Honeywell				
Lockheed				X
M/A-COM		X		
Magnavox			X	
Motorola				X
Norden (United Technologies)			X	
Pacific Monolithics	X	X		
Rockwell				
Singer		X		
Spectrum				
Teledyne Ryan			X	
Texas Instruments				
TriQuint	X	X		
Varian				X
Watkins-Johnson				

(Continued)

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Table 1 (Continued)

MIMIC PHASE 0

Service	Air Force			
Prime Contractor	Harris	Hughes	UNISYS	Westinghouse
Award ($K)	748	998	953	989
Team Members:				
Adams Russell				
Aerojet				
Airtron (Litton)				
Alpha Industries			X	
AT&T		X		
Avantek				X
Cascade				
Cominco				X
Compact Software				
Consilium				
Cornell University	X			
EEsof	X			X
General Dynamics				
General Electric	X	X		
Harris		X		
Honeywell				
Lockheed				
M/A-COM				
Magnavox				
Motorola				
Norden (United Technologies)				
Pacific Monolithics				
Rockwell				X
Singer				
Spectrum				
Teledyne Ryan				
Texas Instruments				
TriQuint	X		X	X
Varian			X	
Watkins-Johnson				

Source: Dataquest
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Pacific Monolithics/TriQuint

TriQuint has performed well as Pacific Monolithics' primary foundry, supplying processed wafers to mutually acceptable specifications. Dataquest believes that this relationship led to some of the specific teaming on the DOD MIMIC program (see Table 1).

Pacific Monolithics/COMSAT LABS

In July 1987, Pacific Monolithics announced it had signed an exclusive agreement with COMSAT Laboratories of Clarksburg, Maryland, to develop and pursue products and markets for power and millimeter-wave MMICs, and to seek Phase I through III contracts under the DOD MIMIC program. Pacific will provide design and marketing skills; COMSAT will contribute 30-GHz MESFET foundry capability. The agreement is also intended as a vehicle for exploring additional business opportunities in monolithic and millimeter-wave devices.

Rockwell/IBM

Early in 1987, Rockwell International and IBM entered into an agreement for the cooperative development of high-speed digital and optoelectronic GaAs devices for future computers and telecommunications equipment. The program involves Rockwell's GaAs pilot line at Newbury Park, California; Rockwell development teams at Newbury Park and Thousand Oaks, California; and IBM development teams at East Fishkill, New York; and Yorktown Heights, New York. Dataquest believes that this agreement positions IBM to take a leadership role in GaAs digIC (digital integrated circuit) applications.

Cray/GigaBit

For about three years, Cray Research, Inc., has been working with GigaBit Logic, Inc., to develop a reliable source of GaAs devices for use in a Cray-3 computer. Early in 1987, Cray increased the amount of its order for GigaBit GaAs IC chips to be delivered in 1987 to $5.2 million. Dataquest believes that this agreement allows Cray to redirect its internal GaAs capability toward development of HEMT, E/D MESFET, or other high-speed technology. Cray Research participated in GigaBit Logic's round 3 financing in May 1987, along with Analog Devices, Inc., Digital Equipment Corporation, and others.

AMD/Vitesse

In 1986, AMD and Vitesse agreed to a technology exchange involving AMD's 2900 bit-slice family and Vitesse's E/D MESFET GaAs technology. The effort resulted in Vitesse's announcement of its 29G01, 29G10 and other GaAs bit-slice products late in 1986.

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GigaBit/Seattle Silicon

GigaBit and Seattle Silicon Corporation have developed a 4-bit ALU that is functionally equivalent to the 100181, a 100K ECL chip. Design engineering support was provided by the Washington Technology Center (WTC). The chip is 5.7 times faster than its silicon counterpart and consumes half the power.

GigaBit/Prisma Corporation

In July 1987, GigaBit and Prisma Corporation announced an agreement to produce a complete family of custom GaAs logic and memory digICs for use in Prisma's new family of real-time supercomputers. The machine architecture is based on a 32-bit RISC structure. Under the agreement, Prisma will design the ICs to GigaBit's newly released HME/D (high-margin enhancement/depletion) process, which is characterized by sub-100ps gate delays at power levels significantly lower than those of silicon ECL gates.

Ford/Vitesse

Ford Microelectronics, Colorado Springs, Colorado, and Vitesse Semiconductor Corporation, Camarillo, California, are establishing an E/D self-aligned gate GaAs IC alternate-source agreement and capability. Initially, the agreement includes custom and semicustom circuits, but it may be extended to standard products. Dataquest believes that Ford has successfully processed wafers containing gate array chips to mutually agreed-upon design rules.

Microwave Technology, Inc./Monolithic Microsystems, Inc.

In June 1987, Microwave Technology, Inc., Fremont, California, completed its acquisition of Monolithic Microsystems, Inc., of Santa Cruz, California. Under the agreement, Monolithic Microsystems will become a wholly owned subsidiary of Microwave Technology and will continue manufacturing at its present 8,200-square-foot facilities.

TRW/TriQuint

TRW Components International (a subsidiary of TRW, Inc.) and TriQuint have agreed to jointly supply GaAs devices for space applications. The companies are working together on procedures for producing Class S-level GaAs components. TriQuint will provide foundry support.

Ciba-Geigy/Spectra-Physics

In June 1987, it was reported that Ciba-Geigy had signed a definitive agreement to acquire Spectra-Physics for $266 million. A prior lawsuit seeking to enjoin Ciba-Geigy's initial (reportedly hostile) takeover offer

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was reported as being dismissed without prejudice by the Delaware Federal Court. Dataquest believes that this acquisition will strengthen Ciba-Geigy's ability to participate in the GaAs industry infrastructure.

California Micro Devices/Tachonics

A June 1987 announcement stated that California Micro Devices, Milpitas, California, has formed an alliance with Tachonics, Plainsboro, New Jersey, to produce a family of GaAs ASICs for military applications. Tachonics is a subsidiary of Grumman Aerospace Corporation of Bethpage, New York.

Amoco/Spectra Diode/Kodak/Litton Airtron

Amoco Laser Company, a wholly owned subsidiary of Amoco Corporation, has formed a strategic alliance with Eastman Kodak, the Airtron Division of Litton Industries, and Spectra Diode Labs to support Amoco's laser systems product line. Kodak provides production support, Litton Airtron supplies wafers, and Spectra Diode makes the semiconductor lasers. Amoco intends to use this alliance to pursue communications, projection TV, reprography, and other commercial and military applications.

Thorne-EMI/Varian

TEV is a United Kingdom-based joint venture of Thorne-EMI Electronics (United Kingdom) and Varian Associates (United States). The company supplies tubes for broadband EW and expendables for military applications. TEV also is developing 70 to 80mW 90-GHz oscillators for missile-seeking mortars (smart munitions). The company is focusing on applications in earth resources satellites and SARs (synthetic aperture radars).

DATAQUEST CONCLUSIONS

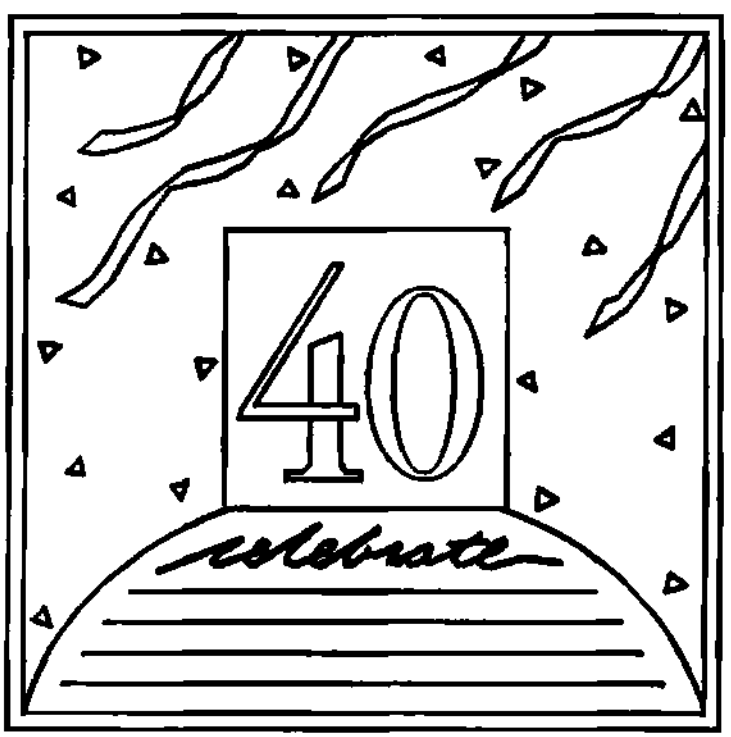
The interaction of GaAs industry participants is intensifying as this industry moves ahead, with national objectives as much a part of the scenario as they were in the silicon world 15 years ago. Interestingly, the majority of large computer houses have remained silent about their GaAs technology plans. The commercial marketplace now has IBM to consider, and one has to wonder how long IBM's competitors have left to refine their strategies and to take viable positions, either with GaAs merchant suppliers or by acquisition, or both.

Gene Miles

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Mark your calendars now!

Semiconductors' Midlife Crisis



1987 Semiconductor Industry Conference

October 18–21
The Pointe at Squaw Peak
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Research *Bulletin*

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FORD OFFERS E/D GaAs FOUNDRY SERVICES

Ford Microelectronics, Inc., has established a 12,000-square foot GaAs foundry at Colorado Springs, Colorado, the United States. This facility has a 3-inch capacity of 500 wafers per week. The clean room exceeds Class 10 criteria and reduces LSI/MSI density devices on a self-aligned E/D process. The circuits feature loaded gate delays of 150ps at 0.7mW per gate pd and a worst case noise margin of 300mV.

Ford offers proprietary SPICE-based circuit simulation software called GASSIM. Hermetic IC packaging capability includes a variety of standard packages. The fab site has both environmental screening and 100 percent burn-in capabilities. Electrical testing is performed on Sentry 21 and MegaTest's MegaOne VLSI testers. Table 1 delineates foundry charges at the new Ford Microelectronics facility.

Table 1

Ford Microelectronics, Inc.
FOUNDRY CHARGES

E/D Gate Array--1,000 Equivalent Gates	
NRE and 10 Prototypes	$75,000
Custom Foundry--E/D SAGFET	
Foundry Kit	$24,000
Engineering Consultation	$3,000
5-wafer minimum:	
First 25 wafers	$7,000 each
Next 25 wafers	$6,000 each
Next 50 wafers	$5,000 each
More than 100 wafers	Negotiable

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March 1987

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Ford Microelectronics is a full-service supplier of GaAs digital and analog standard, semicustom, and full-custom products. The company reportedly is establishing an E/D GaAs IC alternate source agreement and capability in conjunction with Vitesse Electronics Corporation of Camarillo, California.

Dataquest believes that adequate E/D foundry capacity is critical to the successful long-term application of GaAs technology to commercial digital hardware, and that Ford's capabilities will enhance the development and growth of this industry.

Gene Miles
Tom Wang

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Research Newsletter

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III-V MATERIALS--WHO'S ON FIRST?

Since our August 1986 newsletter on GaAs materials, the compound semiconductor materials situation has evolved into a new game. In most high-technology business areas, innovation never ceases, leading to gyrations in the competitive lineup. The III-V materials industry is no exception.

Recent developments that we consider worth watching include:

- GaAs on Si substrates
- Progress in NDF wafer manufacture
- New entrants and start-ups
- Increases in the price of gallium in Japan
- Innovations in InP manufacture

DATAQUEST ANALYSIS

Although Sumitomo Electric in Japan is the acknowledged leader in GaAs wafers with an estimated world market share of 50 percent, the competition is heating up with major expansions under way. For this newsletter, Dataquest identified 39 companies in the Free World marketplace that are involved in compound semiconductor materials manufacturing operations. These include 18 in the United States, 2 in Canada, 11 in Japan, 3 in West Germany, 2 in the United Kingdom, 2 in France, and 1 in Sweden. As we predicted earlier, materials companies are becoming increasingly aggressive in their attempts to establish a significant presence in this market.

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A key factor in the growth of the compound semiconductor industry is the ability to move into LSI and VLSI levels of integration. This movement is presently limited by the quality of substrate material. Although NTT announced development of a 16K SRAM in 1984, none of the device suppliers has been able to mass-produce the chip for the commercial market, at any price. Dataquest believes that recent laboratory work by Westinghouse and others on GaAs crystal growth has resolved the technical problems associated with VLSI from the standpoint of materials. Which company or companies will be first to benefit from this in the merchant market is not yet clear.

A promising alternative to GaAs substrates is the possible move to GaAs on silicon substrates, with pioneering work under way at start-up Kopin Corporation and other companies. Vertically integrated companies believed to be working in the field of GaAs on Si include AT&T Bell Laboratories, Ford, Fujitsu, GTE, HP, NEC, NTT, Oki, Texas Instruments, and Xerox. TI demonstrated a 1K SRAM implemented on a GaAs on Si substrate, in 1986. IBM's position in this area is not known, although it is believed to be heavily engaged in GaAs device and chip development, and has publicized its work on GaAs ballistic transistors. GaAs on Si, when perfected, will also significantly reduce wafer and, therefore, chip costs, bringing GaAs cost/performance at the system level much closer to that of Si ECL.

Table 1 summarizes the activities of merchant suppliers of GaAs and other compound semiconductor materials companies. It is arranged alphabetically and identifies the companies' corporate nationalities, major compound semiconductor products, methods of manufacture, wafer sizes, expansion plans, and other information that Dataquest believes is of value to its clients.

In addition to Kopin Corporation, the table shows other compound semiconductor materials start-up companies including Picogiga (France) and Preussag AG (West Germany). Dataquest expects 1987 to bring more new players to this field, as if it weren't crowded already.

Gene Miles
Peggy Wood

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Table 1

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Airtron	U.S.	GaAs undoped and Si-doped wafers	Growth method: LPLEC Firm is a division of Litton Industries 2", 2.5", and 3" wafers available
Bertram Labs	U.S.	GaAs wafers	Growth method: HB 2" GaAs wafers available
Boliden Finemet AB	Sweden	GaAs wafers	Growth method: HPLEC 2" and 3" GaAs wafers available
Cominco Electronic Materials	Canada	GaAs GaSb, InSb, InAs, CdTe, HgTe, and CdHgTe wafers	Growth methods: HPLEC, HB Completed expansion of LEC GaAs wafer plant in Trail, BC, Canada in 1985. Capacity 250K sq. in./year; 2", 3", and 4" wafers available
Commercial Crystal	U.S.	GaAs, GaP, InP wafers	Growth methods· LEC, HB 2" wafers available
Cryscon Technologies	U.S.	GaAs wafers	Growth method: LEC Subsidiary of Alcan Aluminum of Canada. Started shipping GaAs Q4/85. Cryscon supplies 2" and 3" GaAs wafers produced by LEC and electrodynamic gradient freeze (EFG) technique. Annual capacity approx. 2 million sq. in./year. Cryscon was for sale as of 10/22/86
Crystacomm Inc.	U.S.	InP crystals and wafers	Growth method: LEC 2.5" wafers available
Crystal Specialties	U.S.	GaAs wafers, MOULD epi reactors	CSI became subsidiary of Kollmorgen Co. in summer 1984. Wafer facility moved to Colorado Springs, CO, from Ephraim, UT, in Q3/86; reactor facility in Portland, OR
Dowa Mining	Japan	GaAs, InP wafers, poly InP, high purity In	Growth method: HB Research lab located in Akita
EMCORE	U.S.	GaAs epitaxial wafers (MOCVD epi reactors)	Start-up in New Jersey Founded in late 1984 2" and 3" wafers
Epitaxy	U.S.	Epi wafers, photodetectors	Start-up in Puncton, NJ, founded in 1984. Adding InGaAs layer onto InP wafers for photonics and other applications
Epitronics	U.S.	GaAs expitaxial wafers	MOCVD and LPE epi methods Subsidiary of Alcan Aluminum of Canada

(Continued)

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Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Furukawa Electric	Japan	GaAs, InP wafers, GaAs epi wafers	Growth method: LEC Wafers produced at Tokyo lab
GAIN Corporation	U.S.	GaAs epi wafers	Production expected in 1987
Galarix Corporation	U.S.	GaAs wafers, poly and single-crystal GaAs ingots	Growth method: HB Started in 1983 as research organization Marketing of GaAs materials primarily focused toward R&D facilities
Gallium Arsenide Substrates	U.S.	GaAs wafers, poly and single-crystal GaAs ingots	Using gradient freeze process with less than 1,000 dislocation defects/square cm Capitalized with $1 million in private funding
Hitachi Cable	Japan	GaAs, InP epi wafers, single-crystal GaAs ingots	Growth method: LEC Production of III-V materials at Takasago plant in Ibaraki. Investing ¥2 billion to expand two plants including epi plant at Kidaka
Hitachi Metals	Japan	Single-crystal GaAs ingots	Growth method: LEC Developing single-crystal undoped GaAs
ICI Wafer Technology	U.K.	GaAs, InP wafers, poly and single-crystal GaAs and InP ingots	Growth method: LEC ICI bought Cambridge Instruments' III-V operations in 1/85. 2" and 3" GaAs and 2" InP wafers available
Iwaki Handotai	Japan	GaAs wafers	Growth method: LEC 50-50 joint venture of Furukawa Mining/Shin-Etsu Handotai (SEH), founded 1982. Plant in Fukushima prefecture began 2" and 3" wafer production in June 1983. SEH began shipping 2" GaAs wafers to subsidiary, SEH America, from Iwaki Handotai June 1985. 3" wafers available in R&D quantities
Kopin Corporation	U.S.	GaAs-on-Si wafers	Start-up in Taunton, MA 3" and 4" wafers. Developing MOCVD epi process
M/A-COM Semiconductor Products	U.S.	GaAs and GaAs epi wafers	Growth method: LEC Merchant sales as well as captive consumption of GaAs wafers. Microwave Assoc. Ltd. is M/A-COM distributor in the United Kingdom
MCP Limited	U.K.	GaAs wafers	Located in Wembley, Middlesex, England

(Continued)

Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Metal-Specialties Inc.	U.S.	GaAs, GaP, GaSb InAs, InP, InSb wafers	Growth methods: LEC, HB
Meteaux Speciaux	France	InP ingots wafers	Growth method: LEC Plant located in Moutiers, France Production expected mid-1987
Mitsubishi Metal Corporation	Japan	GaAs wafers	Growth methods: LEC, HB Wafer plant located in Omiya, Saitama prefecture. Nissho Iwai Corp. is the U.K. distributor
Mitsubishi Monsanto Kasei (MMK)	Japan	GaAs, GaP wafers	Growth methods: LEC, HB Production system for 3" NDF GaAs wafers developed at Tsukuba plant. MMK spending ¥3 billion for expansion; plans to double sales by 1989. Planned capacity is 500 wafers/month. MMK using NTT's vertical magnetic CZ method to produce 3" wafers with 10 defects/ square cm. max. MEMC to sell MMK wafers in U.S. market
Morgan Semiconductor (division of Ethyl Corp.)	U.S.	GaAs wafers; GaAs epitaxial wafers	Growth methods: LEC, HB Started sampling LP LEC 3" GaAs wafers in 1984; med. pressure LEC 3" GaAs in September 1986. Shipment of 2" and 3" GaAs epi wafers began 4Q/1986
Nippon Mining	Japan	InP wafers, poly and single-crystal InP, single-crystal GaAs and CdTe ingots	Growth method: LEC First Japanese company to grow NDF 3" InP crystal material. Nimio (Cupertino, CA) is a Nippon Mining subsidiary; purpose is to promote sales of GaAs, InP, CdTe, other III-V and II-VI materials in the U.S. market
OMVPE Technologies	Canada	GaAs epitaxial wafers	Start-up located in St. Laurent, Quebec, Canada
Picogiga	France	GaAs epi wafers	Start-up with $4 million in private funding, located in Les Ulis (Orsay). Began operation in August 1986. 2" GaAs MBE wafers
Preussag AG	West Germany	GaAs wafers	New division of Preussag, located in Gossiar, West Germany. Spending $30 million+ to develop wafer capability. Preussag is a major mining interest and supplier of Ga material.

(Continued)

Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Raytheon	U.S.	GaAs epitaxial wafers	Growth methods: LEC, HB
Showa Denko	Japan	GaAs, GaP, InP wafers	Growth method: LEC First company in Japan to produce InP wafers by MLEC. Sampled reduced-defect GaAs wafers in summer 1985
Siemens Company, Inc. Opto Div. (Litronix)	U.S.	GaAs wafers	Growth method: HB Facility located in Cupertino, CA 1.6" to 3" wafers available
Spectrum Technology	U.S.	GaAs wafers	Growth method: HP and LP LEC Spectrum founded in 1982, acquired in Q2/1985 by NERCO Advanced Materials, Inc. (Portland, OR), a large mining interest
Spire Corporation	U.S.	GaAs epitaxial wafers and equipment	Located in Bedford, MA. MOCVD growth of III-V and II-VI compounds, including GaAs, AlGaAs, GaAsP, InP, ZnS, ZnSe on 2" and 3" substrates
Sumitomo Electric	Japan	GaAs, GaP, InP, InSb, InAs, GaSb wafers	Growth method: LEC, HB Largest III-V substrate supplier in the world; 50 percent share of GaAs market. Has capacity for 3,000 3" GaAs wafers/month. GaAs material produced in Itami City (north of Osaka), Hyogo prefecture
Sumitomo Metal Mining	Japan	GaAs, GaP and CdTe wafers	Growth method: LEC
United Epitaxial Technologies	U.S.	GaAs and AlGaAs epitaxial wafers	Start-up in Oregon; received approx. $5 million in first-round venture funding. Founded mid-1984. Working with Crystal Specialties to develop MOCVD equipment. 2" and 3" epi wafers
Wacker	West Germany	GaAs, GaP InP wafers	Growth methods: LEC, HB Shipping 2" and 3" epi wafers

Note: LPLEC = Low Pressure Liquid-Encapsulated Czochralski, HB = Horizontal Bridgeman, HPLEC = High Pressure Liquid-Encapsulated Czochralski, LEC = Liquid Encapsulated Czochralski, MOCUD = Metal Organic Chemical Vapor Desposition, LPE = Liquid Phase Epitaxy, MBE = Molecular Beam Epitaxy, MLEC = Magnetic Liquid-Encapsulated Czochralski

Source: Dataquest
March 1987

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Research Newsletter

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ASIAN GaAs ACTIVITIES IN 1986

SUMMARY

This research report examines many of the major Asian company activities in GaAs and other III-V compound semiconductors in 1986. The report focuses on R&D, product announcements, specifications, pricing, production volumes, shipment data, and related business actions.

Thirty-seven Asian companies are referenced in this newsletter. Their activities in III-V compound semiconductors range from research through product sales of materials, devices, subsystems, and end equipment. Applications of III-V devices discussed herein are diverse, from chips costing 69 cents for use in consumer products to laser chips selling for more than $3,000 each for use in telecommunications and satellite applications. Brief summaries of Japan's activities in space and China's major thrusts in optoelectronic telecommunications are included. The 37 Asian companies in this report are listed below. Those companies making product announcements are indicated by an asterisk (*).

Anam Industrial Co. Ltd.
Fujitsu Ltd.*
Gakei Electric Works Co. Ltd.
Hamamatsu Photonics K.K.
Hitachi Cable Ltd.*
Hitachi Ltd.*
Kawasaki
Kadenshi Corp.*
Kwang Han Electronic Co. Ltd.
Kyokuto Bomki Kaisha, Ltd.
Matsushita Electric Ind. Co. Ltd.*
Matsushita Electronics Corp.*
Mitsubishi Corp.
Mitsubishi Electric Corp.*
Mitsubishi Monsanto Chemical Ind. Ltd.*
NEC Corp.*
Nippon Gakki Co. Ltd.*
Nippon Kogaku K.K.
Nippon Telegraph & Telephone (NTT)
Nisshin Steel Co. Ltd.
Oki Electric Industry Co. Ltd.
RHD Inc.
Roha
Samsung Electronic Parts Co. Ltd.
Sanken Electric Co. Ltd.*
Sanyo Electric Co. Ltd.
Sharp Corp.*
Showa Arco Solar Inc.
Showa Arco Solar Far East
Showa Shell Sekiyu K.K.
Sony Corp.*
Stanley Electric Co. Ltd.*
Sumitomo Electric Industries Ltd.
Teksel Co. Ltd.
Tokyo Electron Ltd.
Toshiba Corp.*
Toyo Ink Manufacturing Co. Ltd.

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1986 CHRONOLOGY AND DISCUSSION

The major activities in GaAs and other III-V semiconductors by Asian companies in 1986, listed by month, are as follows:

January

- Fujitsu has developed an InGaAsP APD for 1.55μ optical communications applications, to be commercialized later this year. The device has a current multiply ratio 15 to 20 times greater than other APDs.

- Mitsubishi Electric Corporation's LSI Research Laboratory announced a 1-GHz GaAs prescaler IC comprised of 440 transistors on a 1.0 x 1.1mm^2 die. Production of the IC started later in 1986.

- The Chemical Compound Semiconductor Division of Hitachi Cable, Ltd., announced 1989 target sales of $59 million, catching up with Sumitoac Electric Industries. Hitachi began quantity production of MOCVD GaAs wafers in the spring of 1986. The company expects to increase its epi wafer sales from one-third to one-half of total sales by late 1987.

- Mitsubishi Monsanto Chemical Industries, Ltd., developed the first 100mm DF GaAs wafers using full-encapsulated Czochralski vertical magnetic-field methodology developed by NTT. The company was in production of 75mm DF GaAs wafers in 1986 and planned quantity production of 100mm wafers starting in 1987.

- Sharp Corporation exceeded a production volume of 800,000 semiconductor lasers/month; Mitsubishi planned to increase its laser production by 50 percent to 600,000 per month by mid-1986. Sony and Matsushita also planned large increases. These four companies supply lasers to the CD player market. NEC and Hitachi planned increased production to support the telecom equipment market.

February

- Matsushita Electric Industrial Co. Ltd.'s Semiconductor Research Center has developed a set of three GaAs optoelectronic ICs. The E-FET structure provides IC operation of 1.6 Gbps at P_d less than 500mW. Shipments started in mid-1986. The ICs are:

Function	FETs	Die Size	Sample Lot Prices
Multiplexer	378	1.3 x 1.9mm	$1,478.00 (¥300,000) each
Demultiplexer	495	1.5 x 1.9mm	$2,463.00 (¥500,000) each
Recognition Logic	96	0.9 x 1.15mm	$ 493.00 (¥100,000) each

- Mitsubishi Electric Corporation began marketing three GaAs MMIC products in January 1986, with the production target set at 20,000 per month. The products are:

Product	Frequency Range	Noise Index	Gain	Sample Price
MBF7002	0.90 to 1.6 GHz	2.5dB	17dB	$4.09 (¥830)
MBF7003	0.21 to 1.8 GHz	2.5dB	9dB	$3.45 (¥700)
MBF7004	0.20 to 1.8 GHz	3.0dB	9dB	$2.46 (¥500)

- Dataquest forecasted the following GaAs SRAM research papers by NTT: 64K density by early 1987 and 256K density by mid-1988. The mid-1984 paper on 16K GaAs SRAMs was six months ahead of Dataquest's forecast.

- Matsushita Electronics Corporation announced a GaAs wideband, low-loss, double-balanced mixer IC for operation from 50 MHz to 2 GHz. The product is priced at $1.58 (¥300) each; planned run rate (by April 1986) was 50,000 per month.

- NEC entered the GaAs digIC (digital IC) market and began shipments of three ECL-compatible SSI chips. The μPG700 master-slave D-type flip-flop, the μPG701 T-type FF, and the μPG702 3-input OR/NOR gate are priced at $252.63 (¥48,000) each. Planned run rate (by late 1986) was 5,000 per month.

- Hitachi has developed an InP optoelectronic amplifier IC containing an optical switch, four DFB Lasers, and a waveguide on a 1.6 x 1.0mm die. Hitachi expects this to lead to the development of optical exchange equipment and optical computers.

- Under MITI sponsorship, Mitsubishi's LSI Development Laboratory has attained 9.6 percent conversion efficiency on a 100-cm^2 amorphous solar cell.

March

- Sharp began marketing the LT300 small-signal FED for 69 cents (¥125) per unit in miniature molded package, with production slated initially for 110,000 per month. The dual-gate MESFET has a typical gain of 20dB and a noise figure of 1.4dB at 1GHz. Die size is 0.52 x 0.54mm; package size is 2.9 x 1.5 x 1.1mm.

- NEC has developed a 3,000-gate GaAs gate array using 1.4μ structures. The 7.5 x 7.4mm die contains about 36K transistors and diodes and dissipates 4.6mW per gate. Unloaded gate t_{pd} is 56ps; loaded with 2mm interconnect, the delay increases to 186ps.

- Mitsubishi started a fab line for telecommunications lasers at its Kitaitami Works, doubling the plant capacity for laser production. Plant production rate for lasers for CDs is 600,000 per month. Telecommunications lasers account for one-third of the company's semiconductor sales.

- Showa Shell Sekiyu K.K. planned to establish two joint ventures with Arco Solar Inc. to develop and sell amorphous solar cells. Capitalization is 75 percent by Showa Shell and 25 percent by Arco Solar. The companies are as follows:

  - Showa Arco Solar Inc., capitalized at $856,000 (¥154,000,000) and headquartered in Tokyo, will build a pilot plant for amorphous solar cells in Atsugi, Kanagawa Prefecture, in 1987.

  - Showa Arco Far East, to be established in Singapore, will take charge of all Far East sales except in Japan; the first year sales target is $5.6 million to $8.3 million (¥1 billion to ¥1.5 billion).

- Fujitsu has prototyped a 1,520-gate HEMT array and used it to test an 8-bit multiplier at 3.1ns t_{pd} when operated below 77 degrees Kelvin. The chip has an array of 76 x 20 cells and 72 I/Os.

April

- The Optoelectronic Industry and Technology Development Association of Japan has released production figures indicating huge growth in optoelectronics since 1980, as shown in Table 1.

- Matsushita introduced a GaAs laser nose canceller IC, the MEL5005, priced at $2.81 (¥500) each. Volume production was scheduled to start in June 1986 at 10,000 per month.

- Mitsubishi announced that it will begin marketing a 1.55μ-wavelength semiconductor laser in June 1986, priced at several hundred thousand yen per unit. The device functions to 115 degrees C and has a threshold current of approximately 10mA.

- Hitachi Cable Ltd. began sampling a high-powered linear LED array (LLA). The device was developed for optical printer applications and allows higher-speed operation than that of conventional serial scan beam printers.

- NEC announced an InP optoelectronic IC transceiver capable of 1.2 Gbps transfer speed with 1.2μ bandwidth. NEC plans to develop a production process and begin manufacturing the device within three years.

- Optoelectronics Joint Research Laboratory of Japan has developed a technology for InP single-crystal wafer production that reduces impurities by a factor of 10 and cuts production costs to less than one-tenth that of conventional methods.

Table 1

JAPANESE OPTOELECTRONIC PRODUCTION
(Millions of Dollars)

Products	1980	1983	1984	1985	CAGR 1980-1985
Optical Components	$345	$1,341	$1,549	$1,714	38%
Machines and Equipment	100	871	1,574	2,516	91%
Optical Fiber Systems	62	380	445	572	56%
Total	$507	$2,592	$3,568	$4,802	57%

Source: Optoelectronic Industry and Technology Development Association of Japan

May

- At the Applied Physics Society meeting, the Electrotechnical Laboratory of Japan's Agency of Industrial Science and Technology presented a paper on its GaAs IBT (inverted base bipolar transistor). The IBT is claimed to be faster than HEMT structures.

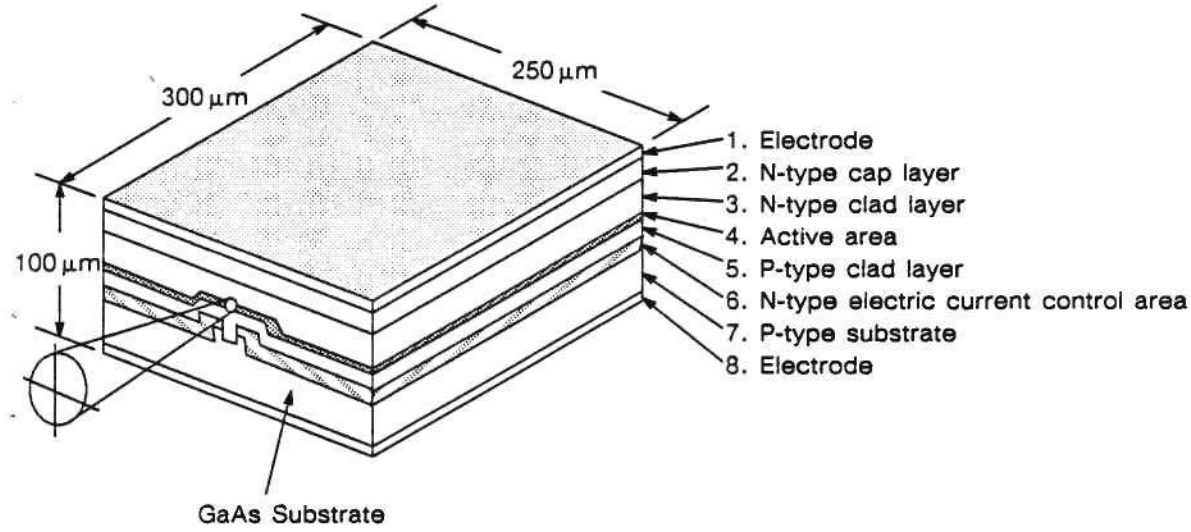
- Sony and Sharp announced an agreement on standardization of specifications for consumer equipment lasers. Under the agreement, both fires have developed miniaturized semiconductor lasers, one-fifth the volume and less than one-third the weight of existing lasers. Sharp is shipping its LT022MS at $13.89 (¥2,500) each, and Sony began sampling its SLD101U at the same price. Both companies planned volume production by October 1986 at rates of 200,000 per month.

- Matsushita achieved 280mW output in a GaAlAs laser by improving its BTRS (buried twin ridge substrate) structure. The company will produce the chip in volume as a 50mW device. A BTRS structure is shown in Figure 1.

- Tokyo Electron Ltd. and Mitsubishi's Development Laboratory have jointly developed an opto/plasma assist laser CVD machine using a high-output excimer laser together with an ultraviolet lamp and plasma. The machine can handle wafers up to 6 inches in diameter.

Figure 1

BTRS SEMICONDUCTOR LASER STRUCTURE



Source: Dataquest
February 1987

- RHD Inc. and Gakei Electric Works Co. have jointly developed an InP/GaAs crystal-pulling machine and will soon begin producing test wafers. The equipment will be marketed within two years. RHD is an R&D concern owned jointly by Nisshin Steel Co. Ltd., Toyo Ink Manufacturing Co. Ltd., and Mitsubishi Corporation. The three parent companies and RHD may establish a new company for the pulling equipment and wafers in the future.

- Japanese production of CD and VD players and video cameras grew substantially from 1984 through 1986. These items represent 11.3 percent of Japan's total consumer electronics production. Details are given in Table 2.

- Japanese production of visible-range (0.78μ wavelength) semiconductor lasers has grown rapidly to support the CD and VD player markets. Company plans to increase production still further are as follows:

  - Sharp--800,000 per month; increase to 1,200,000 per month
  - Mitsubishi--500,000 per month; increase to 600,000 per month
  - Matsushita--160,000 per month; increase to 500,000 per month
  - Sony--200,000 per month; increase to 400,000 per month

- Toshiba--100,000 per month; increase to 400,000 per month

- Rohm--Will begin volume production at 100,000 per month

• Oki Electric Industry Co. Ltd. completed installation of a production line in its Hachioji Factory for GaAs device production to support the car telephone market. Oki plans sample shipments of GaAs digICs (digital ICs) for telecommunications and instrumentation equipment markets by late 1986.

Table 2

JAPANESE CD PLAYER, VD PLAYER, VIDEO CAMERA PRODUCTION
(Millions of Yen, Thousands of Units)

	CD Player	VD Player	Video Camera	Total
1984				
Units	769	403	1,571	2,743
Value	¥ 45,586	¥47,697	¥154,891	¥248,174
Ratio to Total CE Equipment (%)	1.0%	1.0%	3.3%	5.3%
1985				
Units	4,133	503	2,574	7,210
Percent Change 1984 to 1985	437.8%	24.9%	63.9%	162.9%
Amount	¥150,872	¥54,166	¥352,430	¥557,468
Percent Change 1984 to 1985	231.0%	13.6%	127.5%	124.6%
Ratio to Total CE Equipment (%)	3.1%	1.1%	7.1%	11.3%
1986				
Units	18,000	900	3,300	22,200
Percent Change 1985 to 1986	93.6%	78.9%	28.2%	207.9%
Amount	¥220,000	¥85,500	¥430,000	¥735,500
Percent Change 1985 to 1986	45.8%	57.8%	22.0%	31.9%
Ratio to Total CE Equipment (%)	4.5%	1.7%	8.8%	15.0%

Source: Dempa Shimbun
Dataquest
May 1986

June

- Fujitsu, Sony, and Toshiba are marketing HEMTs for the satellite communications market. Other major suppliers are expected to create heavy sales competition. Sample pricing ranges from $294 to $882 (¥50,000 to ¥150,000) each.

- Stanley Electric Co. Ltd. has started shipment of an outdoor electric lamp incorporating LEDs. Power consumption is 0.3W to 0.6W, about one-thirtieth that of conventional lamps. Pricing is $2.88 (¥1,000) to $5.76 (¥2,000) each; production volume is targeted at 15,000 to 20,000 per month.

- Toshiba's new Super MLEC method of pulling GaAs crystals is claimed to increase productivity by 5 to 6 times that of existing processes.

- NEC's Otsuki Factory in Yamanashi Prefecture began producing optical communications devices such as optical data links, LEDs, receiver modules, and optoconnectors. First-year production by the five-story, 16,000-square-meter factory is targeted at $174 million (¥30 billion).

July

- Hitachi announced production of its HL1341A (1.3μ wavelength) and HL1541A (1.55μ wavelength) DFB laser diodes. Device pricing is $2,410 (¥400,000) and $3,012 (¥500,000), with production to start at 500 units per month in July and September, respectively. Volumes are slated to increase to 3,000 per month for the HL1341A and 1,000 per month for the HL1541A by March 1987.

- Matsushita Electronics Corporation introduced a GaAs op amp IC, claimed to be 100 times faster than Si op amps, for high-frequency applications including video amplifiers. Die size is 0,93 x 1.18mm; operating frequency ranges to 200 MHz. Sampling is scheduled for late 1986.

- Matsushita Electric Company's Semiconductor Research Center announced development of an SHG (second harmonic generation) device for 0.4μ wavelength operation. The niobic acid lithium crystal device will be combined with YA6 lasers and semiconductor lasers to implement practical hardware. Matsushita expects to start sampling within six months.

- Anam Industrial Co. Ltd. of the Republic of Korea exported $249.7 million between January and May 1986, up 46 percent from the same period in 1985, according to Korea's Electronic Times. Exports included $1.87 million in LEDs.

- Hamamatsu Photonics K.K. planned volume production of optical semiconductors for January 1987. Its new $12 million (¥2 billion), 7,900-square-meter plant was built exclusively for optosemiconductor production. Planned start day for operation was October 1986.

- Sharp shipped its 10,000,000th semiconductor laser in July 1986. The company has produced these devices since 1981 for CD and VD players, laser beam printers, and other applications.

- Hitachi announced two low-noise GaAs FETs, the 2SK779 and the 2SK780. Sampling started in August 1986.

Product	Noise Specification	Sample Price	10,000 PC. Price
2SK779	1.3dB	$124.24 (¥20,000)	$62.11 (¥10,000)
2SK780	1.6dB	$ 31.11 (¥ 5,000)	$15.53 (¥ 2,500)

- Matsushita Electronics Corporation and Matsushita Electric Industrial Co. Ltd.'s Wireless Research Laboratory jointly developed a GaAs RF amplifier for UHF frequency operation, the GN1030/1031. Volume pricing is $1.00 (¥150); production was planned to start later in 1986 at 50,000 per month.

- Sharp Corporation announced the development of a low-noise semiconductor laser and a laser driver IC, both of which operate from a single +5V power supply.

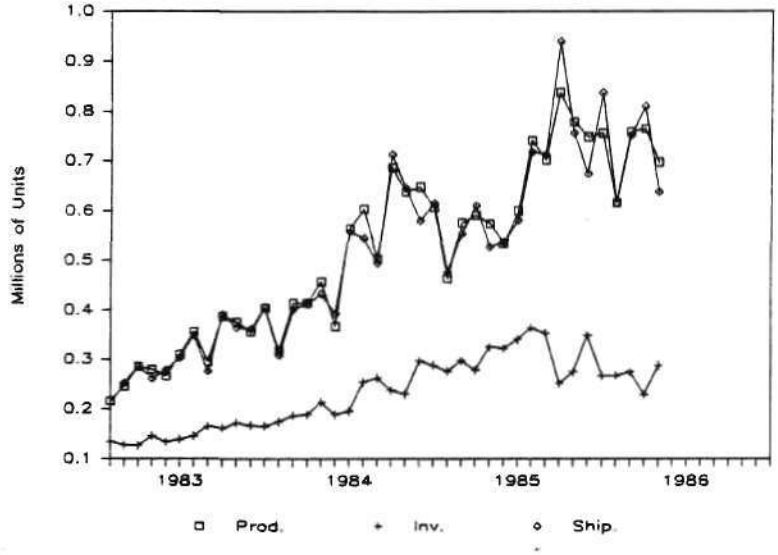
- Sanken Electric Co., Ltd., is now marketing a new series of contact-mounting LEDs. The devices are identified as the SEL3000 series. The company has also introduced an ultrahigh-brightness LED, the SEL1615. This LED product reportedly has achieved 1,000 millicandelas by employing GaAlAs.

- Japanese makers became increasingly concerned about excessive exports of compact disk players to the United States. Although the U.S. CD player market has been increasing, exports from Japan have exceeded the increase in demand. As a result, underselling the competition due to oversupply has started. Under the circumstances, Japanese makers might start controlling shipments to the United States. Because 40 percent of the CD players made in Japan are exported to the United States, oversupply in the U.S. market can greatly influence CD player production in Japan.

- The graph in Figure 2 shows Japanese production, inventory, and shipments of microwave ovens from January 1983 through April 1986.

Figure 2

JAPANESE PRODUCTION, INVENTORY, AND SHIPMENTS
OF MICROWAVE OVENS
(January 1983 through April 1986)



Source: Dataquest
February 1987

August

- Toshiba Corporation has developed an ultrasmall semiconductor laser that is compatible with standardized models built by Sharp Corporation and Sony Corporation. The laser features low noise through use of Toshiba's structure called the New ISSS (inner stripe square-channel substrate). Sample shipments will begin in September 1986 at a price of $15.82 (¥2,500) per unit. Other makers such as Hitachi Ltd., Matsushita Electronics Corporation, Mitsubishi Electric Corporation, and NEC Corporation also plan to manufacture standardized ultrasmall semiconductor lasers.

September

- Demand for compact disk player ICs continued to slow down. Among major makers, there is currently a move toward production control. Distributors expected orders received for September 1986 shipment to be 10 to 15 percent less than the record numbers reached in June and July 1986. CD player production had rapidly increased since the last half of 1985. Total production between January and May 1986 reached nearly 3.3 million units, about 80 percent of total production for the year 1985. The decline in demand for CD player ICs may indicate that CD player production has peaked.

- The Republic of Korea's Ministry of Trade and Industry has reported a national production plan for 116 items of electronic components. Eighty-four companies are participating in the project. Upon completion of the plan, we expect that national products will replace $472 million worth of imports and that the increase in exports will reach $309 million. Research and development costs for the project total W 137, which will be invested jointly by the government and the private companies. Major products included in the project are shown in Table 3.

- NEC Corporation announced that it started volume production of single-axis-mode, DFB (distributed feedback) lasers in September 1986. NEC is the second Japanese maker to start volume production of DFB lasers, following Hitachi Ltd. The lasers are the NDL5600 for the 1.3μ range, priced at $2,922 (¥450,000), and the NDL5650 for the 1.55μ range, priced at $3,571 (¥550,000). Initial run rate is 500 to 1,000 units per month, which are to be increased to 2,000 units in the first half of 1987.

- Teksel Co., Ltd., signed a sales agency contract with Anadigics Inc. of the United States and started selling GaAs ICs. Under the contract, Teksel markets the ADA25001, a superwideband amplifier, and the AOP1510, a superwideband operational amplifier. Prices are $246.10 (¥37,900) per unit (in 100-unit lots) for the ADA25001 and $80.52 (¥12,400) per unit for the AOP1510.

- Matsushita Electronics Corporation developed a new semiconductor laser called a monolithic 2-beam GaAlAs laser array, for read-write optical disk applications. The laser is capable of generating two kinds of laser optical output--one for writing and the other for reading--on a single chip. The new product makes it possible to produce compact optical pickups for disk systems.

- Matsushita Electronics Corporation prototyped an OEIC (optoelectronic integrated circuit). The device is a combination of an AlGaAs semiconductor laser with 30mW output and a high-frequency oscillator for laser noise reduction. Forty-four elements that include one semiconductor laser, 25 MESFETs, and 18 diodes are integrated onto a chip measuring 0.35 x 1.2mm. Laser noise has been reduced to negative 135dB. The new device will pave the way toward making small, high-performance optical disks. Matsushita expects to put the device to practical use within two years.

- Toshiba Corporation recently succeeded in exposing electronic circuits of 0.35μ line width on a silicon wafer by use of an excimer laser. The technology, which will enable the development of 64MB-class memories, will be put to practical use during 1987.

- NEC Corporation had developed a prototype InP FET for microwave/millimeter waveband width, succeeding in making a layer on InP substrate with ion implantation and, on that layer surface, forming a GaAlAs insulating gate using MBE. The new device, with 1μ gate features, has high-power gain of more than 83dB at 12 GHz. The company plans to commercialize a high-power, 30 GHz to 40 GHz device for satellites in 1987.

- Fujitsu Ltd. accomplished 20km nonrelay transmission at 600Mb per second, using an edge-emitting LED developed by the company. Fujitsu claims that this is a world's record in transmitting capacity in terms of distance and data volume. Using edge-emitting LEDs as light sources for optical communications can cut costs to one-tenth that of the existing method. The technical breakthrough is expected to accelerate the spread of optical communication to households.

Table 3

MAJOR DEVELOPMENTS OF CONSUMER PRODUCTS BY KOREAN COMPANIES

Product	Company	Application	R&D Period	R&D Expense	Capital Expense
IR LEDs	Kwang Han	Televisions	6/86 to 12/86	$250,000	$375,000
Display LEDs	Kwang Han	Copiers, calculators	6/86 to 12/86	N/A	N/A
Solar Cells	Samsung	Computers, watches	7/85 to 10/87	$140,000	$2 million

Source: Electronic Times (Korea)

October

- Hitachi Ltd. recently disclosed that it shipped a large quantity of semiconductor lasers, which will be used for transpacific and transatlantic optical submarine cables, to AT&T Corp. of the United States. Shipment volume is estimated to total 4,000 to 5,000 units at a value of several billion yen. AT&T will equip submerged repeaters with the lasers.

- Hitachi Ltd. has entered the photodiode merchant market by introducing 15 models of InGaAs PIN diodes. The new series, which is adaptable to long-distance optical communication systems, has detector sensitivity for 1.3μ and 1.55μ wavelengths. The 50-, 80-, 100-, and 300- models were placed on the market in September 1986. The price for 10-unit lots is $180.65 (¥28,000) per unit. The 3mm versions were shipped as samples beginning in September. Sample price is $1,290.32 (¥200,000) per unit.

- Kodenshi Corp. has developed a series of photo interrupters and has started sample shipment. The devices, dubbed the Photo Interrupter LC Series, have been developed by using a GaAs LED and adding a photo IC for the light-emitting diode. Model numbers are LG-0101, 0201, 0401, and 0501.

- NEC Corporation has developed a 1.55μ bandwidth, single-mode semiconductor laser. By using a new laser, transmission distance by quartz fiber without relay can be extended from the current 30 kilometers to 50 kilometers or longer. The company is continuing research on the laser so that it can be used commercially as soon as possible.

- Nippon Gakki Co., Ltd., has developed an 18-bit signal processing LSI for compact disk players. The new LSI DSP chip is capable of processing CD signals at 16 times higher resolution than the attainable with the conventional digital processing method. By using the LSI in a CD player, noise can be substantially reduced. The device will be adapted to high-grade CD players to be marketed in October 1986.

- China is expected to experience major transitions in its communications technology and facilities over the next two to three decades. These include:

  - Conversion of electromechanical exchanges to solid state

  - Conversion of analog audio and video links to digital, incorporating ISDM

  - Replacement of copper networks with fiber optics

  Each of these changes will generate tremendous demand for silicon and III-V semiconductor technologies. China expects to organize these conversions into separate programs governed by sequential five-year plans.

  The fiber-optic intercity links will use InGaAsP laser sources and InGaAs PIN diode/GaAs FED preamp detectors. Conversion of intracity (local office) nets will occur later. In China, fiber-optic LANs are now used for highway traffic surveys, factory monitors, and OA. Shallow-sea fiber-optic cable links are planned along China's coasts, across bays, and among islands. Deep-sea cable will not convert to fiber optics before the late 1990s.

  China's first use of fiber optics for interoffice trunks was in Shanghai in 1979. All equipment and cables were made in Shanghai for a 1.8km link operated at 8Mb using GaAs LED sources and PIN detectors. A field trial of a 50km, 140Mb digital link is now planned in Shanghai. The Railway Ministry and the Electric Power Ministry of China have already installed fiber-optic systems.

November

- Fujitsu Ltd. is marketing four models of GaAs prescaler ICs. Two of the new devices, dubbed the MB50104/50106, are fixed-ratio prescaler ICs for microwave telecommunications; the other two, the MB50201/50202, are variable types for portable mobile radio communications systems. Sample prices are:

  - MB50104--$96.77 (¥15,000) per unit
  - MB50106--$193.55 (¥30,000) per unit
  - MB50201--$32.26 (¥5,000) per unit
  - MB50202--$58.06 (¥9,000) per unit

  Volume production will begin in spring of 1987 at a rate of 50,000 to 60,000 units per month.

- Sanyo Electric Co., Ltd., had developed a high-efficiency GaAlAs semiconductor laser, using the MBE method. In the new laser, external differential quantum efficiency has been increased to 80 percent. Internal quantum efficiency is 95 percent. The company plans to commercialize the semiconductor laser by March 1987 for use in short-distance optical communications applications.

- Sharp Corporation developed a new VSIS-structure (V-channeled substrate inner strip) semiconductor laser. Threshold current of the new laser has been reduced to 25mA at the 780nm visible range, half that of the conventional model. Volume production is planned for 1987. The VSIS-structure semiconductor laser is Sharp's original product. Since its development in October 1981, the company has sold more than 10 million units.

- Matsushita Electric Corporation developed a new semiconductor laser process by using MOCVD. With the new process, which applies the self-alignment method to crystal growth, submicron light-emitting stripes can be formed easily. The company has already manufactured on an experimental basis a 1μ stripe GaAlAs laser, which has 15mA threshold current and 1.05 ellipticity. It plans to commercialize the 1μ laser for short-distance optical communication within two years.

December

- According to a report from the Korean Ministry of Science and Technology (MOST), Korea will develop new semiconductor materials such as polycrystalline materials, ceramics, fiber optics, and high-quality single-crystal silicon. The specific areas of focus are:

  - Silicon semiconductors
    - Large integration and high purification of single crystals
    - Improvement of silicon wafer process
  - Polycrystalline materials
    - Mass production technology for solar cells (i.e., amorphous silicon)
    - New material development
  - Semiconductors
    - GaAs single-crystal technology
    - Now semiconductor components
  - Fiber optics
    - Laser diodes
    - Fiber-optic components
  - Semiconductor sensors

- While Japan claims to have a zero military budget, it has amassed tremendous capabilities in aerospace hardware in recent years and has aggressive plans for the next decade. The aerospace program is expected to cause Japanese companies to focus on rad-hardened circuits because many of the spacecraft must pass through the Van Allen Belt. Table 4 details some of Japan's capabilities and plans in this area.

- The Ministry of International Trade and Industry (MITI) in cooperation with the Optoelectronics Industry and Technology Development Association framed a rough plan to standardize 33 items of opto telecommunication products. It will gradually designate the products as JIS (Japanese Industrial Standard) items from March so that compatibility of optical fibers, which connect components and perform other functions, will be increased.

Table 4

PLANNED JAPANESE SPACECRAFT
AND SATELLITE LAUNCHINGS

Launch Date	Type	Company	Payload (Pounds)	Orbit (Height)	Comments
8/1/86	EGP	Kawasaki	1,500	900 miles	Laser target; first H-I payload
Mid-1987	ETS-5	Mitsubishi	N/A	Geosync.	Mobile satcom with ships and planes
1/87	MOS-1	NEC	1,650	545 miles	Carrying CCDs and other multispectral detectors
Early 1988	CS-30	Mitsubishi	N/A	Geosync.	Third-generation; 6,000 voice channels plus K- and C-band transponders
Mid-1988	CS-3B	Mitsubishi	N/A	Geosync.	Sister to CS-3A
Mid-1989	GMS-4	NEC	N/A	Geosync.	Weather spacecraft; H-I launch vehicle
Mid-1989	GMS-5	NEC	N/A	Geosync.	$185 million development cost; 3-axis stabilized; H-I launch vehicle
Mid-1990	BS-3A	NEC	N/A	Geosync.	Color television--three channels
Mid-1991	BS-3B	NEC	N/A	Geosync.	Sister to BS-3A
N/A	ERS-1	NEC/Mitsubishi	3,000	N/A	To carry synthetic aperture radar, IR and visible sensors; electrically sequenced transmitters used for careful study of ground

(Continued)

Table 4 (Continued)

PLANNED JAPANESE SPACECRAFT
AND SATELLITE LAUNCHINGS

Launch Date	Type	Company	Payload (Pounds)	Orbit (Height)	Comments
81/92	ETS-6	Mitsubishi	N/A	N/A	First H-II payload
1994*	N/A	N/A	N/A	N/M	H-II payload; seismic detection
Mid-1990s	Venus Probe	N/A	N/A	N/M	H-II payload; magnetosphere probe

Geosync. = Geosynchronous orbit (approximately 22,000 miles above Earth's surface
N/M = Not Meaningful
N/A = Not Available

*Moon Probe

Source: AZTEK Associates

- Prices of semiconductor lasers to be used for CD players and video disks have declined sharply. In the case of 0.78μ lasers, the wholesale prices for large users in Tokyo are $5.25 to $5.86 (¥850 to ¥950) per unit, a 5.3 percent decline in two months. Some new makers' models are sold at $4.94 (¥800) per unit, with underselling competition expected to continue toward the end of the year as makers plan for production increases. Sharp Corporation's production capacity has increased six times since the beginning of this year.

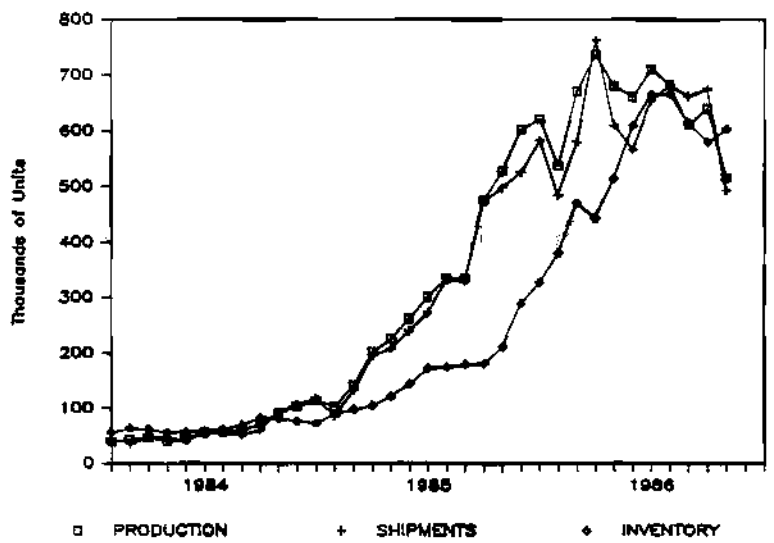
- Stanley Electric Co., Ltd., will supply Nissan Motor Co., Ltd., with LED high-mounted brake lights for the 1987 Fairlady 2, Nissan's sports car, marking the first time that LEDs will be used as automobile illuminators. Monthly shipments to Nissan are expected to be 6,000 units. Because of interest by automobile makers at home and abroad, including the big three U.S. companies, Stanley plans to expand its LED lamp market throughout the world.

- Stanley Electric Co., Ltd., and Kyokuto Bomki Kaisha, Ltd., have jointly established I.I. Stanley Inc. in Battle Creek, Michigan. The new company, capitalized at $1 million (60 percent by Stanley, 30 percent by Kyokuto, and 10 percent by Stanley Electric U.S.) will start production of LEDs and lighting apparatus in May 1987. Capital investment in the company is expected to total $10 million.

Dataquest estimated that semicondutor consumption for digital audio disk (DAD) players was around ¥3 billion ($18.52 million) per month in 1986. Since the production cost per unit was going down, semiconductor consumption tended to decrease also (see Figure 3).

Figure 3

JAPANESE DIGITAL AUDIO DISK PLAYERS PRODUCTION, SHIPMENTS, AND INVENTORY (January 1984 to October 1986)



Source: Dataquest February 1987

DATAQUEST CONCLUSIONS

The field of GaAs and other III-V compound semiconductors is advancing rapidly every year, and 1986 was no exception. Asian companies are very active in the application of GaAs technology to consumer products, fiber-optic communications, and satellite hardware, and they continue to refine the traditional LED display devices. There is increasing competition in the IC field, particularly in MMICs and digICs, with new players entering the marketplace. Dataquest expects this pace of activity to continue into the 1990s as IC suppliers, pressured by declining profits in Si, seek out niches in III-V markets.

Gene Miles

Dataquest
a company of The Dun & Bradstreet Corporation

Research Newsletter

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1987-03

GaAs TECHNOLOGY UPDATE

SUMMARY

The development activity in GaAs ICs in 1986 resulted in significant breakthroughs in materials, design techniques, and new products. There were more start-ups to aid the overall market growth, which exceeded 50 percent. The largest commercial contract for digital ICs (digICs) announced to date was awarded to GigaBit Logic by Cray Research, Inc. The year was not all rosy, however, as two participants were involved in staff reductions and a third withdrew from commercial activity.

Major product announcements expected in SRAMs and other areas are still to come. Some industry observers, Dataquest included, factored their forecasts to account for the cautious approach of "wait and see" taken by some of the major users and potential users, particularly in the digIC arena.

Papers to be presented at the International Solid States Circuits Conference (ISSCC) reflect a major emphasis on moving GaAs technology from the laboratory to the marketplace. For example, a paper by Mitsubishi describes a 16K SRAM with an access time of 15ns; this comes 2-1/2 years after an NTT paper that described a 4ns 16K GaAs SRAM.

START-UPS

Notable start-up activity occurred in 1986, including new companies in III-IV materials. In the United States, Kopin Corporation performed significant R&D in GaAs-on-Si technology. In France, a new firm called PicoGiga, founded by two individuals from Thomson-CSF, moved into the GaAs wafer arena.

Ford Microelectronics demonstrated several GaAs products at the GaAs IC Symposium in October and at GOMAC in November. These included amplifiers, coders, decoders, and a multiplier implemented on a gate array chip. Gain Electronics, TriQuint, and other GaAs start-ups also had hospitality suites and booths at one or both conferences.

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In addition to the companies previously reported by Dataquest, there are at least five start-up groups in GaAs technology, involved in initial planning that had not formally announced their intentions as of January 8, 1987.

CONTRACTS

A major contract, in excess of $3 million, was placed with GigaBit Logic (Newbury Park, California) by Cray Research, Inc., for logic and memory devices procured over a one-year period. This contract positions GigaBit to continue as Cray's principal outside GaAs IC supplier for the Cray-III Project. GigaBit claims to have achieved yields approaching 40 percent on GaAs VLSI ICs with 30,000 components per device in support of this project.

The U.S. Department of Defense reportedly has awarded at least 12 design contracts of up to $1 million each to prime contractors for the study phase of the MIMIC initiative. The teams include:

- Under Navy direction (prime contractor underlined):
  - Bendix, Pacific Monolithics, TriQuint
  - Ford, Singer, Pacific Monolithics, M/A-COM, TriQuint
  - Raytheon/TI (joint venture), General Dynamics, Magnavox, Norden, Teledyne, others
  - Sanders, others
- Under Air Force direction:
  - Harris, General Electric, TriQuint, others
  - Hughes, AT&T, M/A-COM
  - Unisys, Alpha Industries, M/A-COM, TriQuint, Varian
  - Westinghouse, Avantek, Cominco, Essof, Rockwell, TriQuint
- Under Army direction:
  - Eaton, M/A-COM
  - ITT, Pacific Monolithics, Watkins-Johnson
  - Martin-Marietta, Alpha Industries, Harris, TI, others
  - TRW, General Dynamics, Honeywell

Also, Hittite, Ball Aerospace, E-Systems, and Loral may receive contracts ranging to $500,000. A smaller number of contractors will be chosen for awards expected in fiscal year 1988, following the study phase. Dataquest believes that the MIMIC initiative may exceed $500 million over the next five years.

PRODUCT ANNOUNCEMENTS

Tables 1 and 2 summarize some of the significant products recently introduced in GaAs digital (digIC) and analog, including microwave ICs. The digital circuits of Table 1, together with gate arrays offered by several GaAs houses and SRAMs now in development, comprise a viable product set for use in the general-purpose logic design of very high-speed digital hardware. These circuits will lead to significant performance improvements in end equipment, such as minisupercomputers, high-speed VLSI testers, radar data processors and communications buffers.

Table 2 reflects impressive gains in cost reduction of amplifiers and associated analog circuitry. For example, Anadigics is now offering an operational amplifier with 350 MHz gain bandwidth at a 1,000-piece price of less than $85. TriQuint, Pacific Monolithics, and others also have made significant contributions to this technology, as shown in Table 2.

HONEYWELL DE-EMPHASIZES GaAs

Honeywell is dropping commercial GaAs ICs and consolidating its GaAs research and government work at the Physical Sciences Center (Bloomington, Minnesota). The Richardson, Texas, production facility will be converted to support silicon solid state centers after existing GaAs gate array and custom IC contracts are completed. Dataquest believes that these actions are a direct result of Honeywell's sale of 57.5 percent of its computer business and the associated de-emphasis of data processing, and expects additional cost-cutting measures in Honeywell's merchant silicon IC activities.

APPLICATIONS

The acceptance of GaAs by designers is rapidly increasing. Applications such as optical disk drives produced by Laser Magnetic Storage International (joint effort by CDC and Philips) and ITT's terabit optoelectronic program are creating new demands for GaAs ICs and discretes, including integrated optoelectronic devices. The popular "laser gun" toys introduced for the 1986 gift-giving season each contain an IR LED in the transmitter (gun) and a photodetector in the target. Sales of this type of toy may exceed 2 percent of the $12 billion toy market by late 1987.

FORECAST

Table 3 gives Dataquest's current forecast of the GaAs semiconductor worldwide consumption. The 1986 results were slightly lower than previously forecast, primarily due to difficulties experienced by several digital IC suppliers. Dataquest believes that the materials breakthroughs realized over the last several months will offset the softness of 1986, and that the long term outlook of the previous forecast is still valid. The MIMIC initiative will have a positive impact on analog/microwave consumption starting in 1988 or 1989 and may significantly impact the 1990 and 1991 forecast shown here.

NEW TECHNOLOGY

Table 4 summarizes the presently planned presentations at the ISSCC, to be held in New York City in February 1987. Four of the papers will cover digital device developments by Hitachi, Toshiba and Mitsubishi of Japan, and LEP of France. The highest density device is the 16K SRAM by Mitsubishi; however, the 4K SRAM presented by Hitachi has significantly higher performance with t_{aa} of 1ns, ECL interface and 1.6W power dissipation. LEP has demonstrated reduction of variations in SRAM access time through the use of word line clamping and other circuit techniques. Toshiba's 6K gate array uses SCFL to achieve 284ps tpd per gate at pd of 1mW per gate and attains noise margins of 400mV.

Four papers describe advances in analog and microwave ICs. Both Anadigics and Hewlett-Packard present results of breakthroughs in sample and hold design. Hughes and LEP (France) report advances in video signal processing at frequencies to 300 and 800 MHz respectively.

CONCLUSIONS

GaAs technology remains one of the bright spots in the semiconductor industry, with anticipated growth rates for digital and analog ICs far above the growth rates of most silicon IC product lines. This is characteristic of the relative youth of this emerging industry. The GaAs and other III-V compound IC business areas will offer substantial opportunities to astute participants for at least the decade to come.

Gene Miles

Table 1

GaAs DigIC PRODUCTS

Company	Part. No.	Description	100-Piece Price ($)	Comments
Anadigics	ADV3040	Divide-by-4 prescaler	435.00	3 GHz max data rate
GigaBit	10G022	Octal register	79.50	1.5 GHz max clock rate
	10G061	4-bit synchronous binary counter	99.50	1.5 GHz max clock rate
	10G045	9-bit parity generator	46.00	800ps t_{pd}
Harris Microwave	HMD11188-2	Clock fanout buffer	TBA	
	TDMX1500	8:1 multiplexer; 1.5 Gbit/s max data rate	400.00	
	TDDX1500	1:8 demultiplexer; 1.5 Gbit/s max data rate	400.00	
Vitesse	VE29G01	4-bit microprocessor slice; 72 MHz max clock frequency	435.00	29xx family architecture
	VE29G02	Lookahead carry generator; 200 MHz max clock frequency	225.00	29xx family architecture
	VE29G10A	Microcontroller; 100 MHz max clock frequency	475.00	29xx family architecture

Source: Dataquest January 1987

Table 2

GaAs ANALOG PRODUCTS*

Company	Part. No.	Description	100-Piece Price ($)	Comments
Anadigics	AOP3510	Op amp; 350 MHz gain	32.75**	
Harris Microwave	HMR10502	Monolithic rf amp; 10dB gain from 500 MHz to 5 GHz	29.00**	Needs external bypass capacitors
	MHR 10503	Same as 10502 but has on-chip source-bypass capacitors	39.00**	
	HMM-11810-0	Amplifier; 5dB gain from 6 to 18 GHz	175.00	
Microwave Semiconductor	LDCM1500	Diode-current modulator	100.00**	3 GHz max data rate
	TIA1500	Transimpedance amp	150.00	2 GHz max input rate
	TIRC1500	Transimpedance receiver	250.00	2 GHz max input rate
Pacific Monolithics	PM-AMO607	Amplifier; 10dB gain from 2 to 6 GHz	205.00	
TriQuint	TQ9111	Amplifier; 7dB gain from 1 to 18 GHz	144.00	
	TQ9141	Two-way power splitter 1 to 10 GHz frequency	155.00	
	TQ9151	SPDT switch; 1 to 10 GHz	143.00	
	TQ9161	Variable attenuator; 1 to 10 GHz	155.00	

*Analog includes a subset of high-frequency ICs called "MIMICs."
**1,000-piece pricing

Source: Dataquest
January 1987

Table 3

WORLDWIDE GaAs MERCHANT CONSUMPTION FORECAST BY TECHNOLOGY
(Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR 1984-1991
Analog ICs	46	80	117	173	237	331	448	551	42.6%
Digital ICs	11	26	51	99	187	337	506	657	79.4%
Discrete Opto	1,152	1,089	1,361	1,602	1,811	1,866	2,136	2,367	10.8%
Integrated Opto	8	20	28	43	67	104	162	267	65.1%
Microwave Discrete	122	156	210	273	341	410	450	529	23.3%
Total	1,339	1,371	1,767	2,190	2,643	3,048	3,702	4,371	18.4%

Columns may not add to totals shown because of rounding.

Assumptions:

Sustained materials, quality improvements and open-market availability of DF wafers.

No predatory pricing by major suppliers.

Successful MIMIC program funded in excess of $300 million over five years.

Source: Dataquest
January 1987

Table 4

1987 GaAs PRODUCT DEVELOPMENTS--ISSCC

Company	Description	Comments
Digital		
Hitachi	4K SRAM	0.7u gates, 1ns access, 1.6W, ECL interface, 3.7 x 4.7mm die
LEP	1K SRAM	2ns cycle, 210mW p_d, ECL compatible
Mitsubishi	16K SRAM	1.5ns t_{aa}, 1V supply, 1W, 5.8 x 4.7mm die
Toshiba	6K gate array	284ps t_{pd} 1mW gates
Analog		
Anadigics	GaAs sample and hold amp	170 MHz bandwidth; die size $1mm^2$
Hewlett-Packard	1 GHz 6-bit A/D converter	1 sample and hold chip, 4 A/D chips
Hughes	GaAs VSP circuit	Video signal processor with filters
LEP	Video front end	II-chip set; AGC, mixers, VCO, divider, amps, total chip area $2.15mm^2$

Source: AZTEK Associates

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RESEARCH NEWSLETTER

GATA Code: Newsletters
1987-2

JAPAN'S EXPANDING SPACE PROGRAMS DEMAND HI-REL ICs

SUMMARY

Dataquest expects Japan to increase emphasis on high-reliability (hi-rel) GaAs and Si ICs in support of its expanding space programs. While Japan claims to have a zero military budget, it has massed tremendous capabilities in aerospace hardware in recent years, and has aggressive plans for the next decade. This bulletin details some of Japan's capabilities and plans in this area.

Japan's space activities include the following programs, which require mil range and, in many cases, radiation-hardened (rad-hard) ICs and discrete semiconductors:

- Three new expandable boosters: H-I, M-38-2, and H-II
- More than ten advanced satellites
- Space platforms
- A space shuttle
- Participation in a U.S. shuttle mission
- Participation in the U.S./international space station
- Moon and Venus probes

Japan's space activities represent an increasing threat to Western leadership in satellites, platforms, and shuttles. Dataquest believes that there will be increased international interest in Japan's satellite launch capability as a result of 1986's shuttle, Ariane, and other launch failures.

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DISCUSSION AND ANALYSIS

Japan has two space agencies: NASDA (National Space Development Agency) and ISAS (Institute of Space and Astronautical Science). These agencies have been responsible for launching about one satellite per year since 1970. MITI (Ministry of International Trade and Industry) serves to create competitive pressures by funding specific payloads.

Japan's space agencies are developing more than 10 satellites and space probes, many designed for geosynchronous orbit (approximately 22,000 miles altitude). These satellites require state-of-the-art GaAs and Si ICs to accomplish the intended functions within launch payload constraints. In addition, rad-hard requirements are expected to impact the IC designs.

Thirteen Japanese companies are studying the MITI/ISAS platform concept for launch by the U.S. shuttle and Japan's H-II booster (developed by Mitsubishi). The H-II booster will support manned launches by 1995. A summary of Japan's spacecraft including launch dates, type of payload and other pertinent data is given in Table 1. These include four communications satellites and two meteorological satellites designed for geosynchronous orbit.

DATAQUEST CONCLUSIONS

Japan is developing a demand for low volumes of domestically produced hi-rel, rad-hard ICs. To achieve better economies of scale, the next logical step is to take these ICs to the international marketplace. Western suppliers of mil-range ICs may experience increased market pressure as a result of Japan's space efforts.

Japan's investment in its space efforts is resulting in far greater capacities in hi-rel semiconductors, satellite systems, and launch hardware than required to support the programs listed in Table 1. In view of recent Western launch failures, we believe that Japan will likely experience increasing difficulty in attempting to keep a low profile regarding its space programs.

Gene Miles

Table 1

JAPANESE SPACECRAFT

Launch Date	Type	Name	Company	Payload (Lbs.)	Orbit Height	Comments
8/1/86	EGP	Experimental Geodetic Payload	Kawasaki	1,500	900 miles	Laser target, first H-I payload
Mid-1987	ETS-5	Engineering Test Satellite #5	Mitsubishi	N/A	Geosync.	Mobile Satcom with ships, planes
1/87	MOS-1	Marine Observation Satellite	NEC	1,650	545 miles	Carrying CCDs and other multispectral detectors
Early 1988	CS-3A	Communications Satellite #3A	Mitsubishi	N/A	Geosync.	Third-generation, 6,000 voice channels plus K- and C-band transponders
Mid-1988	CS-3B	Communications Satellite #3B	Mitsubishi	N/A	Geosync.	Sister to CS-3A
Mid-1989	GMS-4	Geosync. Meteorological Sat.	NEC	N/A	Geosync.	Weather spacecraft; H-I launch vehicle
Mid-1989	GMS-5	Geosync. Meteorological Sat.	NEC	N/A	Geosync.	$185 million development cost; 3-axis stabilized; H-I launch vehicle
Mid-1990	BS-3A	Broadcast Satellite	NEC	N/A	Geosync.	Color TV--3 channels
Mid-1991	BS-3B	Broadcast Satellite	NEC	N/A	Geosync.	Sister to BS-3A
N/A	ERS-1	Earth Resources Satellite #1	NEC/Mitsubishi	3,000	N/A	Will carry synthetic aperture radar, visible and IR sensors
1/92	ETS-6	Engineering Test Satellite #6	Mitsubishi	N/A	N/A	First H-II payload
1994	N/A	Moon Probe	N/A	N/A	Inapplic.	H-II payload; seismic detection
Mid-1990s		Venus Probe	N/A	N/A	Inapplic.	H-II payload; magnetosphere probe

Geosync. = Geosynchronous orbit (approximately 22,700 miles above Earth's surface)
N/A = Not available at press time
Inapplic. = Inapplicable

Source: AZTEK Associates

Dataquest

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Computer Storage—Tape Drives

Copying and Duplicating

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Electronic Printer

Electronic Publishing

Electronic Typewriter

Electronic Whiteboard

European Semiconductor*

European Telecommunications

Gallium Arsenide

Graphics

Imaging Supplies

Japanese Semiconductor*

Office Systems

Personal Computer

Personal Computer—Worldwide Shipments and Forecasts

Robotics

Semiconductor*

Semiconductor Application Markets*

Semiconductor Equipment and Materials*

Semiconductor User Information*

Software—Artificial Intelligence

Software—Personal Computer

Software—UNIX

Technical Computer Systems

Technical Computer Systems—Minisupercomputers

Telecommunications

Western European Printer

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Corporate Alliance Program

Coporate Technology Program

Financial Services Program

Strategic Executive Service

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First Copy

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I.C. ASIA

I.C. USA

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European PC Retail Pricing

PC Distribution in Europe

PC Software Markets in Europe

PC Local Area Networking Markets in Europe

The Education Market for PCs in Europe

Japanese Corporations in the European PC Markets

Home Markets for PCs in Europe

Integrated Office Systems—The Market and Its Requirements

European Market for Text Processing

Image Processing in the Office

Work Group Computing

Translation Systems

Vendor Support

The IBM 3270 Market: 1986 and Beyond

Korean Semiconductor Industry Analysis

Diskettes—The Market and Its Requirements

Directory Products

I.C. Start-Ups—1987

SpecCheck—Competitive Copier Guide

SpecCheck—Competitive Electronic Typewriter Guide

SpecCheck—Competitive Whiteboard Guide

Who's Who in CAD/CAM 1986

Future Products

- Industry Services
  - Manufacturing Automation
  - Computer Storage—Optical
  - Computer Storage—Subsystems
- Focus Reports
  - Japanese Printer Strategy
  - Japanese Telecommunications Strategy
  - Canon CX Laser—User Survey
  - Digital Signal Processing
  - PC-based Publishing
  - Taiwan Semiconductor Industry Analysis
  - China Semiconductor Industry Analysis
  - PC Distribution Channels
- Directory Products
  - SpecCheck—Competitive Facsimile Guide
  - SpecCheck—Competitive Electronic Printer Guide

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Dataquest

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RESEARCH NEWSLETTER

GATA Code: Newsletters
1987-1

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The VE29GXX family is expected to permit customers to achieve a factor of 3x speed improvement over a CPU implementation using the AMD2901C, a bipolar device. Interestingly, Vitesse has employed LCC packaging to preserve the device speed advantage at the system level as much as practical. Very aggressive forward pricing is available from Vitesse, allowing the user to project systems costs through 1990. So far, more than 1,000 customers have expressed interest in this product set. Dataquest expects a wide range of applications to make use of this technology, including minisupercomputers, "smart" high-speed instrumentation, DSPs and other military functions, arithmetic/logic accelerators, and high-speed graphics equipment.

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STATIC RAMs

For several months, 1K SRAMs have been offered for beta site evaluation by GigaBit, Ford Microelectronics, and others. GigaBit just received a $500 thousand, two-year U.S.A.F. contract to perform Class 8 screening, reliability evaluation, and radiation hardness evaluation on its 1K SRAM.

Vitesse's VE12G474 is the first commercially available 4K GaAs SRAM. Other announcements are expected this month, including devices from Honeywell, Rockwell, and GAIN. Several Japanese companies have been working on SRAMs for at least three years; these products appear targeted first for internal needs before being taken to merchant market. GaAs SRAMs feature cycle times in the 0.6 to 3.5ns range at 1K and 4K densities, compared to the 5 to 7ns range for the fastest commercially available silicon ECL RAMs (see Table 1).

CUSTOM DESIGN

GAIN Electronics Corporation has announced a custom design service based initially on E/D MESFET technology and followed by SDHT (selectively doped heterostructure transistor), otherwise known as HEMT (high electron mobility transistor), technology. SDHT, invented by Dr. Raymond Dingle (GAIN's president), offers the highest-performance commercially available GaAs circuitry. Typical transistor cutoff frequency is 80 GHz, versus 50 and 15 GHz, respectively, for GaAs FETs and Si bipolar transistors. GAIN will also offer a full line of device and design capabilities, and an epitaxial GaAs/ALGaAs wafer.

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MMICs

Dataquest believes that the most significant announcement in GaAs MMIC (microwave monolithic IC) technology in recent months is the introduction of a GaAs linear/analog macrocell library by Pacific Monolithics. The library consists of more than 25 macrocells fabricated and tested prior to July 1986, with another 20 macros in development. The cells cover the 0.5 to 18 GHz frequency range and include amplifiers, switches, combiners, splitters, attenuators, and VCOs (see Table 2).

Pacific Monolithics' macrocell library offers its users two major advantages. First, the design lead time, which ranges from 1 to 2-1/2 years for a custom MMIC, can be reduced by a factor of 2 to 5 using standard cells. Second, development cost is dramatically reduced, by a

factor of 3 to 8 for a typical MMIC design. Dataquest believes that Pacific Monolithic's library availability at this device performance level may radically alter the approach to electronic warfare systems design. Furthermore, the approach may have a major impact on the entire present microwave industry structure, which includes hybrid houses, silicon device suppliers, third-party designers and other relatively expensive, time-consuming factors.

GATE ARRAYS

Honeywell, TriQuint, Texas Instruments, and others are developing gate arrays using GaAs technology. Honeywell recently withdrew its 2K gate array and is reportedly developing a standard cell alternative. Suppliers are polarizing into two camps regarding GaAs ASICs. One group is pursuing gate arrays of 400 to more than 5,000 gate density. The second group is proceeding on the basis that a standard cell solution will offer the best performance/cost trade-off to the user. Dataquest believes that sufficient applications exist to support both approaches, and expects additional announcements in this area in the coming months.

DATAQUEST CONCLUSIONS

The pace of GaAs product activity is quickening, spurred by major capital investments in 1984 and 1985 and by a soft electronics market in 1985 and 1986. Users have a growing variety of GaAs design options available, supported by an expanding infrastructure of suppliers. Dataquest believes that performance-oriented applications will gravitate at an accelerating rate toward the use of GaAs in critical hardware paths. Significant commercial systems house announcements based on the use of GaAs components are expected, starting in 1987.

Gene Miles

Table 1

GaAs RAM PRODUCTS

Part Number (Company)	Organization	Taa Maximum (ns)	Pd Maximum (mW)	100-Piece Price	Intro. Date	Package	Comments
40G01 (Ford)	256 x 4	3.0	1,400*	TBA	TBA	28-pin LCC	E/D MESFET, I/O latches
12G014 (GBL)	256 x 4	3.0	2,000	N/A	1Q87	40-pin LCC	D MESFET, I/O latches
12G474 (Vitesse)	1K x 4	3.5	N/A	$595	9/86	LCC, FP	E/D MESFET, I/O latches
Rockwell	1K	0.6	N/A	N/A	TBA	N/A	E/D HEMT
Honeywell	256 x 4	3.0	150	N/A	TBA	N/A	E/D MESFET, 110 x 110 sq. mil die
Texas Instruments	1K	6.0	500	N/A	N/A	N/A	GaAs on silicon substrate

*Typical Value
TBA = To Be Announced
N/A = Not Available

Source: AZTEK Associates

Table 2

PACIFIC MONOLITHICS CELL LIBRARY

Existing		In Development	
Function	Frequency (GHz)	Function	Frequency (GHz)
Amplifier Gain Blocks:		**Amplifiers:**	
10dB	2 to 6	SS amp, 10dB	6 to 18
15dB	0.1 to 2	SS amp, 10dB	6 to 12
15dB	1 to 3	LNA, 12dB	11 to 14
AGC amp, 10dB	2 to 6	Power amp, 10dB	6 to 18
		Power amp, 10dB	6 to 12
Oscillators (VCOs, DROs):		AGC amp, 10dB	6 to 18
Neg. resistance	1 to 3		
Neg. resistance	3 to 6	**Mixers:**	
		Balanced-Diode	6 to 10
Double-Balanced Mixers:		Balanced-Diode	10 to 18
Diode Mixer	1 to 3	Dual-Gate	2 to 6
Diode Mixer	3 to 6	High-Dynamic Range	6 to 10
Diode Mixer	6 to 8		
		Oscillators:	
Attenuator	DC-12	Neg. resistance	6 to 12
		Neg. resistance	12-18
FET SPDT switch	DC-12		
		Subsystems:	
Low-Noise Amplifiers		Freq. Downconv.	10 to 14
FET LNA, 16dB	3.7 to 4.2	Freq. Downconv.	6 to 17
FET LNA, 13bB	4.4 to 5.0	Freq. Synthesizers	DC-5
FET LNA, 16dB	1.2 to 1.6		
		Digital ICs:	
Power Amplifier, 12dB	3 to 7	Dividers	6
		Flip-Flops/Latches	1.5
Biphase Modulator	5 to 10		
		Other Building Blocks:	
QPSK Modulator	5 to 10	Balun	6 to 12
		Balun	6 to 18
Power Splitter/Combiner	5 to 10	Attenuator	6 to 18
90° Hybrid	3.5 to 4.5	Limiting Amplifiers	2 to 6
Active Isolator	0.1 to 10	Vector modulator	5 to 10
Balun	1 to 3	**Subsystems:**	
		Freq. Downconv.	1 to 3
Balun	2 to 6	Freq. Downconv.	3 to 6
		Freq. Downconv.	5 to 8
Balun	5 to 8	Image-Rej. Dnconv.	3.7 to 4.2

Source: Pacific Monolithics

Product Offerings

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Product Offerings

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  - Computer Storage—Optical
  - Computer Storage—Subsystems
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  - Japanese Printer Strategy
  - Japanese Telecommunications Strategy
  - Canon CX Laser—User Survey
  - Digital Signal Processing
  - PC-based Publishing
  - Taiwan Semiconductor Industry Analysis
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Attenuator	DC-12	Neg. resistance	6 to 12
		Neg. resistance	12-18
FET SPDT switch	DC-12		
		Subsystems:	
Low-Noise Amplifiers		Freq. Downconv.	10 to 14
FET LNA, 16dB	3.7 to 4.2	Freq. Downconv.	6 to 17
FET LNA, 13bB	4.4 to 5.0	Freq. Synthesizers	DC-5
FET LNA, 16dB	1.2 to 1.6		
		Digital ICs:	
Power Amplifier, 12dB	3 to 7	Dividers	6
		Flip-Flops/Latches	1.5
Biphase Modulator	5 to 10		
		Other Building Blocks:	
QPSK Modulator	5 to 10	Balun	6 to 12
		Balun	6 to 18
Power Splitter/Combiner	5 to 10	Attenuator	6 to 18
90° Hybrid	3.5 to 4.5	Limiting Amplifiers	2 to 6
Active Isolator	0.1 to 10	Vector modulator	5 to 10
Balun	1 to 3	Subsystems:	
		Freq. Downconv.	1 to 3
Balun	2 to 6	Freq. Downconv.	3 to 6
		Freq. Downconv.	5 to 8
Balun	5 to 8	Image-Rej. Dnconv.	3.7 to 4.2

Source: Pacific Monolithics

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PC Distribution in Europe
PC Software Markets in Europe
PC Local Area Networking Markets in Europe
The Education Market for PCs in Europe
Japanese Corporations in the European PC Markets
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Integrated Office Systems—The Market and Its Requirements
European Market for Text Processing
Image Processing in the Office
Work Group Computing
Translation Systems
Vendor Support
The IBM 3270 Market: 1986 and Beyond
Korean Semiconductor Industry Analysis
Diskettes—The Market and Its Requirements

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SpecCheck—Competitive Copier Guide
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  - Computer Storage—Subsystems
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  - Japanese Printer Strategy
  - Japanese Telecommunications Strategy
  - Canon CX Laser—User Survey
  - Digital Signal Processing
  - PC-based Publishing
  - Taiwan Semiconductor Industry Analysis
  - China Semiconductor Industry Analysis
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  - SpecCheck—Competitive Electronic Printer Guide

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1986

Semiconductor	October 20–22	Hotel Inter-Continental San Diego, California
Technical Computer	November 3–5	Silverado Country Club Napa, California
Asian Peripherals	November 5–7	Hotel Okura Tokyo, Japan
Semiconductor Users/ Semiconductor Application Markets	November 10	Sheraton Harbor Island San Diego, California
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CAD/CAM EDA	December 4–5	Santa Clara Marriott Santa Clara, California

1987

Semiconductor Users/ Semiconductor Application Markets	February 4–6	Saddlebrook Resort Tampa, Florida
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Electronic Printer	March 23–25	Silverado Country Club Napa, California
Japanese Semiconductor	April 13–14	The Miyako Kyoto, Japan
Telecommunications	April 13–15	Silverado Country Club Napa, California
CAD/CAM	May 14–15	Hyatt Regency Monterey Monterey, California
Display Terminals	May 20–22	San Diego Hilton Resort San Diego, California
European Semiconductor	June 4–5	Palace Hotel Madrid, Spain
European Copying and Duplicating	June 25–26	The Ritz Hotel Lisbon, Portugal
Financial Services	August 17–18	Silverado Country Club Napa, California
Western European Printer	September 9–11	Palace Hotel Madrid, Spain
European Telecommunications	October 1–2	Monte Carlo, Monaco
Semiconductor	October 19–21	The Pointe Resort Phoenix, Arizona
Office Equipment Dealers	November 5–6	Hyatt Regency Monterey, California
Electronic Publishing	November 16–17	Stouffer Hotel Bedford, Massachusetts
CAD/CAM EDA	December 10–11	Santa Clara Marriott Santa Clara, California

Conference Calendar

1984

[illegible]	[illegible]	[illegible]
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Annual [illegible]	[illegible]	[illegible]
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1983

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RESEARCH NEWSLETTER

GATA Code: Newsletters
1987-2

JAPAN'S EXPANDING SPACE PROGRAMS DEMAND HI-REL ICs

SUMMARY

Dataquest expects Japan to increase emphasis on high-reliability (hi-rel) GaAs and Si ICs in support of its expanding space programs. While Japan claims to have a zero military budget, it has massed tremendous capabilities in aerospace hardware in recent years, and has aggressive plans for the next decade. This bulletin details some of Japan's capabilities and plans in this area.

Japan's space activities include the following programs, which require mil range and, in many cases, radiation-hardened (rad-hard) ICs and discrete semiconductors:

- Three new expandable boosters: H-I, M-38-2, and H-II
- More than ten advanced satellites
- Space platforms
- A space shuttle
- Participation in a U.S. shuttle mission
- Participation in the U.S./international space station
- Moon and Venus probes

Japan's space activities represent an increasing threat to Western leadership in satellites, platforms, and shuttles. Dataquest believes that there will be increased international interest in Japan's satellite launch capability as a result of 1986's shuttle, Ariane, and other launch failures.

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DISCUSSION AND ANALYSIS

Japan has two space agencies: NASDA (National Space Development Agency) and ISAS (Institute of Space and Astronautical Science). These agencies have been responsible for launching about one satellite per year since 1970. MITI (Ministry of International Trade and Industry) serves to create competitive pressures by funding specific payloads.

Japan's space agencies are developing more than 10 satellites and space probes, many designed for geosynchronous orbit (approximately 22,000 miles altitude). These satellites require state-of-the-art GaAs and Si ICs to accomplish the intended functions within launch payload constraints. In addition, rad-hard requirements are expected to impact the IC designs.

Thirteen Japanese companies are studying the MITI/ISAS platform concept for launch by the U.S. shuttle and Japan's H-II booster (developed by Mitsubishi). The H-II booster will support manned launches by 1995. A summary of Japan's spacecraft including launch dates, type of payload and other pertinent data is given in Table 1. These include four communications satellites and two meteorological satellites designed for geosynchronous orbit.

DATAQUEST CONCLUSIONS

Japan is developing a demand for low volumes of domestically produced hi-rel, rad-hard ICs. To achieve better economies of scale, the next logical step is to take these ICs to the international marketplace. Western suppliers of mil-range ICs may experience increased market pressure as a result of Japan's space efforts.

Japan's investment in its space efforts is resulting in far greater capacities in hi-rel semiconductors, satellite systems, and launch hardware than required to support the programs listed in Table 1. In view of recent Western launch failures, we believe that Japan will likely experience increasing difficulty in attempting to keep a low profile regarding its space programs.

Gene Miles

Table 1

JAPANESE SPACECRAFT

Launch Date	Type	Name	Company	Payload (lbs.)	Orbit Height	Comments
8/1/86	EGP	Experimental Geodetic Payload	Kawasaki	1,500	900 miles	Laser target, first H-I payload
Mid-1987	ETS-5	Engineering Test Satellite #5	Mitsubishi	N/A	Geosync.	Mobile Satcom with ships, planes
1/87	MOS-1	Marine Observation Satellite	NEC	1,650	545 miles	Carrying CCDs and other multispectral detectors
Early 1988	CS-3A	Communications Satellite #3A	Mitsubishi	N/A	Geosync.	Third-generation, 6,000 voice channels plus K- and C-band transponders
Mid-1988	CS-3B	Communications Satellite #3B	Mitsubishi	N/A	Geosync.	Sister to CS-3A
Mid-1989	GMS-4	Geosync. Meteorological Sat.	NEC	N/A	Geosync.	Weather spacecraft; H-I launch vehicle
Mid-1989	GMS-5	Geosync. Meteorological Sat.	NEC	N/A	Geosync.	$185 million development cost; 3-axis stabilized; H-I launch vehicle
Mid-1990	BS-3A	Broadcast Satellite	NEC	N/A	Geosync.	Color TV--3 channels
Mid-1991	BS-3B	Broadcast Satellite	NEC	N/A	Geosync.	Sister to BS-3A
N/A	ERS-1	Earth Resources Satellite #1	NEC/Mitsubishi	3,000	N/A	Will carry synthetic aperture radar, visible and IR sensors
1/92	ETS-6	Engineering Test Satellite #6	Mitsubishi	N/A	N/A	First H-II payload
1994	N/A	Moon Probe	N/A	N/A	Inapplic.	H-II payload; seismic detection
Mid-1990s		Venus Probe	N/A	N/A	Inapplic.	H-II payload; magnetosphere probe

Geosync. = Geosynchronous orbit (approximately 22,700 miles above Earth's surface)
N/A = Not available at press time
Inapplic. = Inapplicable

Source: AZTEK Associates

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Research Newsletter

GATA Code: Newsletters
1987-03

GaAs TECHNOLOGY UPDATE

SUMMARY

The development activity in GaAs ICs in 1986 resulted in significant breakthroughs in materials, design techniques, and new products. There were more start-ups to aid the overall market growth, which exceeded 50 percent. The largest commercial contract for digital ICs (digICs) announced to date was awarded to GigaBit Logic by Cray Research, Inc. The year was not all rosy, however, as two participants were involved in staff reductions and a third withdrew from commercial activity.

Major product announcements expected in SRAMs and other areas are still to come. Some industry observers, Dataquest included, factored their forecasts to account for the cautious approach of "wait and see" taken by some of the major users and potential users, particularly in the digIC arena.

Papers to be presented at the International Solid States Circuits Conference (ISSCC) reflect a major emphasis on moving GaAs technology from the laboratory to the marketplace. For example, a paper by Mitsubishi describes a 16K SRAM with an access time of 15ns; this comes 2-1/2 years after an NTT paper that described a 4ns 16K GaAs SRAM.

START-UPS

Notable start-up activity occurred in 1986, including new companies in III-IV materials. In the United States, Kopin Corporation performed significant R&D in GaAs-on-Si technology. In France, a new firm called PicoGiga, founded by two individuals from Thomson-CSF, moved into the GaAs wafer arena.

Ford Microelectronics demonstrated several GaAs products at the GaAs IC Symposium in October and at GOMAC in November. These included amplifiers, coders, decoders, and a multiplier implemented on a gate array chip. Gain Electronics, TriQuint, and other GaAs start-ups also had hospitality suites and booths at one or both conferences.

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In addition to the companies previously reported by Dataquest, there are at least five start-up groups in GaAs technology, involved in initial planning that had not formally announced their intentions as of January 8, 1987.

CONTRACTS

A major contract, in excess of $3 million, was placed with GigaBit Logic (Newbury Park, California) by Cray Research, Inc., for logic and memory devices procured over a one-year period. This contract positions GigaBit to continue as Cray's principal outside GaAs IC supplier for the Cray-III Project. GigaBit claims to have achieved yields approaching 40 percent on GaAs VLSI ICs with 30,000 components per device in support of this project.

The U.S. Department of Defense reportedly has awarded at least 12 design contracts of up to $1 million each to prime contractors for the study phase of the MIMIC initiative. The teams include:

- Under Navy direction (prime contractor underlined):
  - Bendix, Pacific Monolithics, TriQuint
  - Ford, Singer, Pacific Monolithics, M/A-COM, TriQuint
  - Raytheon/TI (joint venture), General Dynamics, Magnavox, Norden, Teledyne, others
  - Sanders, others
- Under Air Force direction:
  - Harris, General Electric, TriQuint, others
  - Hughes, AT&T, M/A-COM
  - Unisys, Alpha Industries, M/A-COM, TriQuint, Varian
  - Westinghouse, Avantek, Cominco, Essof, Rockwell, TriQuint
- Under Army direction:
  - Eaton, M/A-COM
  - ITT, Pacific Monolithics, Watkins-Johnson
  - Martin-Marietta, Alpha Industries, Harris, TI, others
  - TRW, General Dynamics, Honeywell

Also, Hittite, Ball Aerospace, E-Systems, and Loral may receive contracts ranging to $500,000. A smaller number of contractors will be chosen for awards expected in fiscal year 1988, following the study phase. Dataquest believes that the MIMIC initiative may exceed $500 million over the next five years.

PRODUCT ANNOUNCEMENTS

Tables 1 and 2 summarize some of the significant products recently introduced in GaAs digital (digIC) and analog, including microwave ICs. The digital circuits of Table 1, together with gate arrays offered by several GaAs houses and SRAMs now in development, comprise a viable product set for use in the general-purpose logic design of very high-speed digital hardware. These circuits will lead to significant performance improvements in end equipment, such as minisupercomputers, high-speed VLSI testers, radar data processors and communications buffers.

Table 2 reflects impressive gains in cost reduction of amplifiers and associated analog circuitry. For example, Anadigics is now offering an operational amplifier with 350 MHz gain bandwidth at a 1,000-piece price of less than $85. TriQuint, Pacific Monolithics, and others also have made significant contributions to this technology, as shown in Table 2.

HONEYWELL DE-EMPHASIZES GaAs

Honeywell is dropping commercial GaAs ICs and consolidating its GaAs research and government work at the Physical Sciences Center (Bloomington, Minnesota). The Richardson, Texas, production facility will be converted to support silicon solid state centers after existing GaAs gate array and custom IC contracts are completed. Dataquest believes that these actions are a direct result of Honeywell's sale of 57.5 percent of its computer business and the associated de-emphasis of data processing, and expects additional cost-cutting measures in Honeywell's merchant silicon IC activities.

APPLICATIONS

The acceptance of GaAs by designers is rapidly increasing. Applications such as optical disk drives produced by Laser Magnetic Storage International (joint effort by CDC and Philips) and ITT's terabit optoelectronic program are creating new demands for GaAs ICs and discretes, including integrated optoelectronic devices. The popular "laser gun" toys introduced for the 1986 gift-giving season each contain an IR LED in the transmitter (gun) and a photodetector in the target. Sales of this type of toy may exceed 2 percent of the $12 billion toy market by late 1987.

FORECAST

Table 3 gives Dataquest's current forecast of the GaAs semiconductor worldwide consumption. The 1986 results were slightly lower than previously forecast, primarily due to difficulties experienced by several digital IC suppliers. Dataquest believes that the materials breakthroughs realized over the last several months will offset the softness of 1986, and that the long term outlook of the previous forecast is still valid. The MIMIC initiative will have a positive impact on analog/microwave consumption starting in 1988 or 1989 and may significantly impact the 1990 and 1991 forecast shown here.

NEW TECHNOLOGY

Table 4 summarizes the presently planned presentations at the ISSCC, to be held in New York City in February 1987. Four of the papers will cover digital device developments by Hitachi, Toshiba and Mitsubishi of Japan, and LEP of France. The highest density device is the 16K SRAM by Mitsubishi; however, the 4K SRAM presented by Hitachi has significantly higher performance with t_{aa} of 1ns, ECL interface and 1.6W power dissipation. LEP has demonstrated reduction of variations in SRAM access time through the use of word line clamping and other circuit techniques. Toshiba's 6K gate array uses SCFL to achieve 284ps tpd per gate at pd of 1mW per gate and attains noise margins of 400mV.

Four papers describe advances in analog and microwave ICs. Both Anadigics and Hewlett-Packard present results of breakthroughs in sample and hold design. Hughes and LEP (France) report advances in video signal processing at frequencies to 300 and 800 MHz respectively.

CONCLUSIONS

GaAs technology remains one of the bright spots in the semiconductor industry, with anticipated growth rates for digital and analog ICs far above the growth rates of most silicon IC product lines. This is characteristic of the relative youth of this emerging industry. The GaAs and other III-V compound IC business areas will offer substantial opportunities to astute participants for at least the decade to come.

Gene Miles

Table 1

GaAs DigIC PRODUCTS

Company	Part. No.	Description	100-Piece Price ($)	Comments
Anadigics	ADV3040	Divide-by-4 prescaler	435.00	3 GHz max data rate
GigaBit	10G022	Octal register	79.50	1.5 GHz max clock rate
	10G061	4-bit synchronous binary counter	99.50	1.5 GHz max clock rate
	10G045	9-bit parity generator	46.00	800ps t_{pd}
Harris Microwave	HMD11188-2	Clock fanout buffer	TBA	
	TDMX1500	8:1 multiplexer; 1.5 Gbit/s max data rate	400.00	
	TDDX1500	1:8 demultiplexer; 1.5 Gbit/s max data rate	400.00	
Vitesse	VE29G01	4-bit microprocessor slice; 72 MHz max clock frequency	435.00	29xx family architecture
	VE29G02	Lookahead carry generator; 200 MHz max clock frequency	225.00	29xx family architecture
	VE29G10A	Microcontroller; 100 MHz max clock frequency	475.00	29xx family architecture

Source: Dataquest
January 1987

Table 2

GaAs ANALOG PRODUCTS*

Company	Part. No.	Description	100-Piece Price ($)	Comments
Anadigics	AOP3510	Op amp; 350 MHz gain	32.75**	
Harris Microwave	HMR10502	Monolithic rf amp; 10dB gain from 500 MHz to 5 GHz	29.00**	Needs external bypass capacitors
	MHR 10503	Same as 10502 but has on-chip source-bypass capacitors	39.00**	
	HMM-11810-0	Amplifier; 5dB gain from 6 to 18 GHz	175.00	
Microwave Semiconductor	LDCM1500	Diode-current modulator	100.00**	3 GHz max data rate
	TIA1500	Transimpedance amp	150.00	2 GHz max input rate
	TIRC1500	Transimpedance receiver	250.00	2 GHz max input rate
Pacific Monolithics	PM-AM0607	Amplifier; 10dB gain from 2 to 6 GHz	205.00	
TriQuint	TQ9111	Amplifier; 7dB gain from 1 to 18 GHz	144.00	
	TQ9141	Two-way power splitter 1 to 10 GHz frequency	155.00	
	TQ9151	SPDT switch; 1 to 10 GHz	143.00	
	TQ9161	Variable attenuator; 1 to 10 GHz	155.00	

*Analog includes a subset of high-frequency ICs called "MIMICs."
**1,000-piece pricing

Source: Dataquest
January 1987

Table 3

WORLDWIDE GaAs MERCHANT CONSUMPTION FORECAST BY TECHNOLOGY
(Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR 1984-1991
Analog ICs	46	80	117	173	237	331	448	551	42.6%
Digital ICs	11	26	51	99	187	337	506	657	79.4%
Discrete Opto	1,152	1,089	1,361	1,602	1,811	1,866	2,136	2,367	10.8%
Integrated Opto	8	20	28	43	67	104	162	267	65.1%
Microwave Discrete	122	156	210	273	341	410	450	529	23.3%
Total	1,339	1,371	1,767	2,190	2,643	3,048	3,702	4,371	18.4%

Columns may not add to totals shown because of rounding.

Assumptions:

Sustained materials, quality improvements and open-market availability of DF wafers.

No predatory pricing by major suppliers.

Successful MIMIC program funded in excess of $300 million over five years.

Source: Dataquest
January 1987

Table 4

1987 GaAs PRODUCT DEVELOPMENTS--ISSCC

Company	Description	Comments
Digital		
Hitachi	4K SRAM	0.7u gates, 1ns access, 1.6W, ECL interface, 3.7 x 4.7mm die
LEP	1K SRAM	2ns cycle, 210mW p_d, ECL compatible
Mitsubishi	16K SRAM	1.5ns t_{aa}, 1V supply, 1W, 5.8 x 4.7mm die
Toshiba	6K gate array	284ps t_{pd} 1mW gates
Analog		
Anadigics	GaAs sample and hold amp	170 MHz bandwidth; die size $1mm^2$
Hewlett-Packard	1 GHz 6-bit A/D converter	1 sample and hold chip, 4 A/D chips
Hughes	GaAs VSP circuit	Video signal processor with filters
LEP	Video front end	II-chip set; AGC, mixers, VCO, divider, amps, total chip area $2.15mm^2$

Source: AZTEK Associates

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Research Newsletter

GATA Code: Newsletters
1987-04

ASIAN GaAs ACTIVITIES IN 1986

SUMMARY

This research report examines many of the major Asian company activities in GaAs and other III-V compound semiconductors in 1986. The report focuses on R&D, product announcements, specifications, pricing, production volumes, shipment data, and related business actions.

Thirty-seven Asian companies are referenced in this newsletter. Their activities in III-V compound semiconductors range from research through product sales of materials, devices, subsystems, and end equipment. Applications of III-V devices discussed herein are diverse, from chips costing 69 cents for use in consumer products to laser chips selling for more than $3,000 each for use in telecommunications and satellite applications. Brief summaries of Japan's activities in space and China's major thrusts in optoelectronic telecommunications are included. The 37 Asian companies in this report are listed below. Those companies making product announcements are indicated by an asterisk (*).

Anam Industrial Co. Ltd.
Fujitsu Ltd.*
Gakei Electric Works Co. Ltd.
Hamamatsu Photonics K.K.
Hitachi Cable Ltd.*
Hitachi Ltd.*
Kawasaki
Kadenshi Corp.*
Kwang Han Electronic Co. Ltd.
Kyokuto Bomki Kaisha, Ltd.
Matsushita Electric Ind. Co. Ltd.*
Matsushita Electronics Corp.*
Mitsubishi Corp.
Mitsubishi Electric Corp.*
Mitsubishi Monsanto Chemical Ind. Ltd.*
NEC Corp.*
Nippon Gakki Co. Ltd.*
Nippon Kogaku K.K.
Nippon Telegraph & Telephone (NTT)
Nisshin Steel Co. Ltd.
Oki Electric Industry Co. Ltd.
RHD Inc.
Roha
Samsung Electronic Parts Co. Ltd.
Sanken Electric Co. Ltd.*
Sanyo Electric Co. Ltd.
Sharp Corp.*
Showa Arco Solar Inc.
Showa Arco Solar Far East
Showa Shell Sekiyu K.K.
Sony Corp.*
Stanley Electric Co. Ltd.*
Sumitomo Electric Industries Ltd.
Teksel Co. Ltd.
Tokyo Electron Ltd.
Toshiba Corp.*
Toyo Ink Manufacturing Co. Ltd.

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1986 CHRONOLOGY AND DISCUSSION

The major activities in GaAs and other III-V semiconductors by Asian companies in 1986, listed by month, are as follows:

January

- Fujitsu has developed an InGaAsP APD for 1.55μ optical communications applications, to be commercialized later this year. The device has a current multiply ratio 15 to 20 times greater than other APDs.

- Mitsubishi Electric Corporation's LSI Research Laboratory announced a 1-GHz GaAs prescaler IC comprised of 440 transistors on a 1.0 x 1.1mm^2 die. Production of the IC started later in 1986.

- The Chemical Compound Semiconductor Division of Hitachi Cable, Ltd., announced 1989 target sales of $59 million, catching up with Sumitoac Electric Industries. Hitachi began quantity production of MOCVD GaAs wafers in the spring of 1986. The company expects to increase its epi wafer sales from one-third to one-half of total sales by late 1987.

- Mitsubishi Monsanto Chemical Industries, Ltd., developed the first 100mm DF GaAs wafers using full-encapsulated Czochralski vertical magnetic-field methodology developed by NTT. The company was in production of 75mm DF GaAs wafers in 1986 and planned quantity production of 100mm wafers starting in 1987.

- Sharp Corporation exceeded a production volume of 800,000 semiconductor lasers/month; Mitsubishi planned to increase its laser production by 50 percent to 600,000 per month by mid-1986. Sony and Matsushita also planned large increases. These four companies supply lasers to the CD player market. NEC and Hitachi planned increased production to support the telecom equipment market.

February

- Matsushita Electric Industrial Co. Ltd.'s Semiconductor Research Center has developed a set of three GaAs optoelectronic ICs. The E-FET structure provides IC operation of 1.6 Gbps at p_d less than 500mW. Shipments started in mid-1986. The ICs are:

Function	FETs	Die Size	Sample Lot Prices
Multiplexer	378	1.3 x 1.9mm	$1,478.00 (¥300,000) each
Demultiplexer	495	1.5 x 1.9mm	$2,463.00 (¥500,000) each
Recognition Logic	96	0.9 x 1.15mm	$ 493.00 (¥100,000) each

- Mitsubishi Electric Corporation began marketing three GaAs MMIC products in January 1986, with the production target set at 20,000 per month. The products are:

Product	Frequency Range	Noise Index	Gain	Sample Price
MBF7002	0.90 to 1.6 GHz	2.5dB	17dB	$4.09 (¥830)
MBF7003	0.21 to 1.8 GHz	2.5dB	9dB	$3.45 (¥700)
MBF7004	0.20 to 1.8 GHz	3.0dB	9dB	$2.46 (¥500)

- Dataquest forecasted the following GaAs SRAM research papers by NTT: 64K density by early 1987 and 256K density by mid-1988. The mid-1984 paper on 16K GaAs SRAMs was six months ahead of Dataquest's forecast.

- Matsushita Electronics Corporation announced a GaAs wideband, low-loss, double-balanced mixer IC for operation from 50 MHz to 2 GHz. The product is priced at $1.58 (¥300) each; planned run rate (by April 1986) was 50,000 per month.

- NEC entered the GaAs digIC (digital IC) market and began shipments of three ECL-compatible SSI chips. The μPG700 master-slave D-type flip-flop, the μPG701 T-type FF, and the μPG702 3-input OR/NOR gate are priced at $252.63 (¥48,000) each. Planned run rate (by late 1986) was 5,000 per month.

- Hitachi has developed an InP optoelectronic amplifier IC containing an optical switch, four DFB Lasers, and a waveguide on a 1.6 x 1.0mm die. Hitachi expects this to lead to the development of optical exchange equipment and optical computers.

- Under MITI sponsorship, Mitsubishi's LSI Development Laboratory has attained 9.6 percent conversion efficiency on a 100-cm^2 amorphous solar cell.

March

- Sharp began marketing the LT300 small-signal FED for 69 cents (¥125) per unit in miniature molded package, with production slated initially for 110,000 per month. The dual-gate MESFET has a typical gain of 20dB and a noise figure of 1.4dB at 1GHz. Die size is 0.52 x 0.54mm; package size is 2.9 x 1.5 x 1.1mm.

- NEC has developed a 3,000-gate GaAs gate array using 1.4μ structures. The 7.5 x 7.4mm die contains about 36K transistors and diodes and dissipates 4.6mW per gate. Unloaded gate t_{td} is 56ps; loaded with 2mm interconnect, the delay increases to 186ps.

- Mitsubishi started a fab line for telecommunications lasers at its Kitaitami Works, doubling the plant capacity for laser production. Plant production rate for lasers for CDs is 600,000 per month. Telecommunications lasers account for one-third of the company's semiconductor sales.

- Showa Shell Sekiyu K.K. planned to establish two joint ventures with Arco Solar Inc. to develop and sell amorphous solar cells. Capitalization is 75 percent by Showa Shell and 25 percent by Arco Solar. The companies are as follows:

  - Showa Arco Solar Inc., capitalized at $856,000 (¥154,000,000) and headquartered in Tokyo, will build a pilot plant for amorphous solar cells in Atsugi, Kanagawa Prefecture, in 1987.

  - Showa Arco Far East, to be established in Singapore, will take charge of all Far East sales except in Japan; the first year sales target is $5.6 million to $8.3 million (¥1 billion to ¥1.5 billion).

- Fujitsu has prototyped a 1,520-gate HEMT array and used it to test an 8-bit multiplier at 3.1ns t_{pd} when operated below 77 degrees Kelvin. The chip has an array of 76 x 20 cells and 72 I/Os.

April

- The Optoelectronic Industry and Technology Development Association of Japan has released production figures indicating huge growth in optoelectronics since 1980, as shown in Table 1.

- Matsushita introduced a GaAs laser nose canceller IC, the MEL5005, priced at $2.81 (¥500) each. Volume production was scheduled to start in June 1986 at 10,000 per month.

- Mitsubishi announced that it will begin marketing a 1.55μ-wavelength semiconductor laser in June 1986, priced at several hundred thousand yen per unit. The device functions to 115 degrees C and has a threshold current of approximately 10mA.

- Hitachi Cable Ltd. began sampling a high-powered linear LED array (LLA). The device was developed for optical printer applications and allows higher-speed operation than that of conventional serial scan beam printers.

- NEC announced an InP optoelectronic IC transceiver capable of 1.2 Gbps transfer speed with 1.2μ bandwidth. NEC plans to develop a production process and begin manufacturing the device within three years.

- Optoelectronics Joint Research Laboratory of Japan has developed a technology for InP single-crystal wafer production that reduces impurities by a factor of 10 and cuts production costs to less than one-tenth that of conventional methods.

Table 1

JAPANESE OPTOELECTRONIC PRODUCTION
(Millions of Dollars)

Products	1980	1983	1984	1985	CAGR 1980-1985
Optical Components	$345	$1,341	$1,549	$1,714	38%
Machines and Equipment	100	871	1,574	2,516	91%
Optical Fiber Systems	62	380	445	572	56%
Total	$507	$2,592	$3,568	$4,802	57%

Source: Optoelectronic Industry and Technology Development Association of Japan

May

- At the Applied Physics Society meeting, the Electrotechnical Laboratory of Japan's Agency of Industrial Science and Technology presented a paper on its GaAs IBT (inverted base bipolar transistor). The IBT is claimed to be faster than HEMT structures.

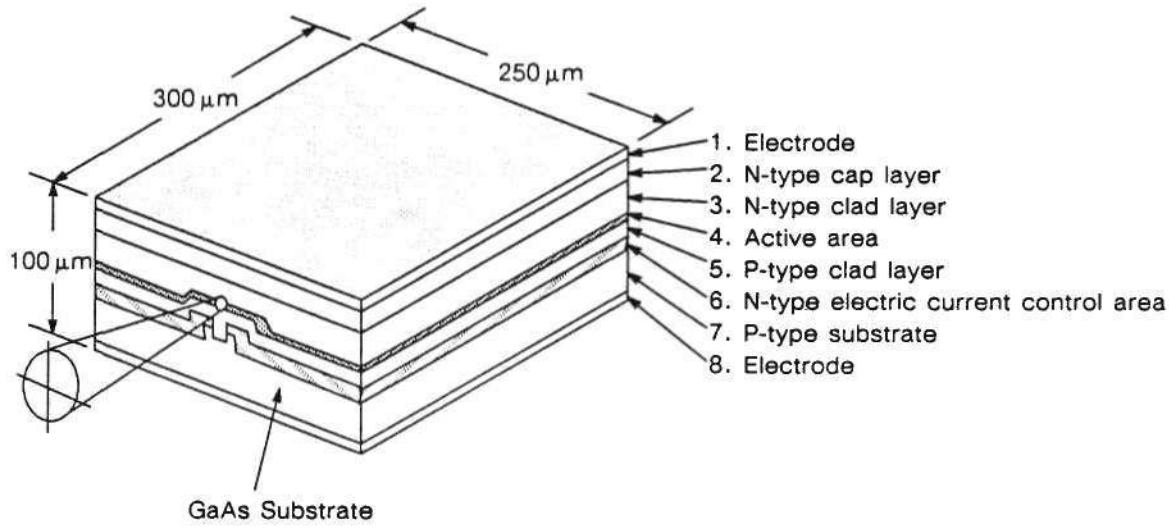
- Sony and Sharp announced an agreement on standardization of specifications for consumer equipment lasers. Under the agreement, both fires have developed miniaturized semiconductor lasers, one-fifth the volume and less than one-third the weight of existing lasers. Sharp is shipping its LTO22MS at $13.89 (¥2,500) each, and Sony began sampling its SLD101U at the same price. Both companies planned volume production by October 1986 at rates of 200,000 per month.

- Matsushita achieved 280mW output in a GaAlAs laser by improving its BTRS (buried twin ridge substrate) structure. The company will produce the chip in volume as a 50mW device. A BTRS structure is shown in Figure 1.

- Tokyo Electron Ltd. and Mitsubishi's Development Laboratory have jointly developed an opto/plasma assist laser CVD machine using a high-output excimer laser together with an ultraviolet lamp and plasma. The machine can handle wafers up to 6 inches in diameter.

Figure 1

BTRS SEMICONDUCTOR LASER STRUCTURE



Source: Dataquest
February 1987

- RHD Inc. and Gakei Electric Works Co. have jointly developed an InP/GaAs crystal-pulling machine and will soon begin producing test wafers. The equipment will be marketed within two years. RHD is an R&D concern owned jointly by Nisshin Steel Co. Ltd., Toyo Ink Manufacturing Co. Ltd., and Mitsubishi Corporation. The three parent companies and RHD may establish a new company for the pulling equipment and wafers in the future.

- Japanese production of CD and VD players and video cameras grew substantially from 1984 through 1986. These items represent 11.3 percent of Japan's total consumer electronics production. Details are given in Table 2.

- Japanese production of visible-range (0.78μ wavelength) semiconductor lasers has grown rapidly to support the CD and VD player markets. Company plans to increase production still further are as follows:

  - Sharp--800,000 per month; increase to 1,200,000 per month
  - Mitsubishi--500,000 per month; increase to 600,000 per month
  - Matsushita--160,000 per month; increase to 500,000 per month
  - Sony--200,000 per month; increase to 400,000 per month

- Toshiba--100,000 per month; increase to 400,000 per month

- Rohm--Will begin volume production at 100,000 per month

• Oki Electric Industry Co. Ltd. completed installation of a production line in its Hachioji Factory for GaAs device production to support the car telephone market. Oki plans sample shipments of GaAs digICs (digital ICs) for telecommunications and instrumentation equipment markets by late 1986.

Table 2

JAPANESE CD PLAYER, VD PLAYER, VIDEO CAMERA PRODUCTION
(Millions of Yen, Thousands of Units)

	CD Player	VD Player	Video Camera	Total
1984				
Units	769	403	1,571	2,743
Value	¥ 45,586	¥47,697	¥154,891	¥248,174
Ratio to Total CE Equipment (%)	1.0%	1.0%	3.3%	5.3%
1985				
Units	4,133	503	2,574	7,210
Percent Change 1984 to 1985	437.8%	24.9%	63.9%	162.9%
Amount	¥150,872	¥54,166	¥352,430	¥557,468
Percent Change 1984 to 1985	231.0%	13.6%	127.5%	124.6%
Ratio to Total CE Equipment (%)	3.1%	1.1%	7.1%	11.3%
1986				
Units	18,000	900	3,300	22,200
Percent Change 1985 to 1986	93.6%	78.9%	28.2%	207.9%
Amount	¥220,000	¥85,500	¥430,000	¥735,500
Percent Change 1985 to 1986	45.8%	57.8%	22.0%	31.9%
Ratio to Total CE Equipment (%)	4.5%	1.7%	8.8%	15.0%

Source: Dempa Shimbun
Dataquest
May 1986

June

- Fujitsu, Sony, and Toshiba are marketing HEMTs for the satellite communications market. Other major suppliers are expected to create heavy sales competition. Sample pricing ranges from $294 to $882 (¥50,000 to ¥150,000) each.

- Stanley Electric Co. Ltd. has started shipment of an outdoor electric lamp incorporating LEDs. Power consumption is 0.3W to 0.6W, about one-thirtieth that of conventional lamps. Pricing is $2.88 (¥1,000) to $5.76 (¥2,000) each; production volume is targeted at 15,000 to 20,000 per month.

- Toshiba's new Super MLEC method of pulling GaAs crystals is claimed to increase productivity by 5 to 6 times that of existing processes.

- NEC's Otsuki Factory in Yamanashi Prefecture began producing optical communications devices such as optical data links, LEDs, receiver modules, and optoconnectors. First-year production by the five-story, 16,000-square-meter factory is targeted at $174 million (¥30 billion).

July

- Hitachi announced production of its HL1341A (1.3μ wavelength) and HL1541A (1.55μ wavelength) DFB laser diodes. Device pricing is $2,410 (¥400,000) and $3,012 (¥500,000), with production to start at 500 units per month in July and September, respectively. Volumes are slated to increase to 3,000 per month for the HL1341A and 1,000 per month for the HL1541A by March 1987.

- Matsushita Electronics Corporation introduced a GaAs op amp IC, claimed to be 100 times faster than Si op amps, for high-frequency applications including video amplifiers. Die size is 0,93 x 1.18mm; operating frequency ranges to 200 MHz. Sampling is scheduled for late 1986.

- Matsushita Electric Company's Semiconductor Research Center announced development of an SHG (second harmonic generation) device for 0.4μ wavelength operation. The niobic acid lithium crystal device will be combined with YA6 lasers and semiconductor lasers to implement practical hardware. Matsushita expects to start sampling within six months.

- Anam Industrial Co. Ltd. of the Republic of Korea exported $249.7 million between January and May 1986, up 46 percent from the same period in 1985, according to Korea's Electronic Times. Exports included $1.87 million in LEDs.

- Hamamatsu Photonics K.K. planned volume production of optical semiconductors for January 1987. Its new $12 million (¥2 billion), 7,900-square-meter plant was built exclusively for optosemiconductor production. Planned start day for operation was October 1986.

- Sharp shipped its 10,000,000th semiconductor laser in July 1986. The company has produced these devices since 1981 for CD and VD players, laser beam printers, and other applications.

- Hitachi announced two low-noise GaAs FETs, the 2SK779 and the 2SK780. Sampling started in August 1986.

Product	Noise Specification	Sample Price	10,000 PC. Price
2SK779	1.3dB	$124.24 (¥20,000)	$62.11 (¥10,000)
2SK780	1.6dB	$ 31.11 (¥ 5,000)	$15.53 (¥ 2,500)

- Matsushita Electronics Corporation and Matsushita Electric Industrial Co. Ltd.'s Wireless Research Laboratory jointly developed a GaAs RF amplifier for UHF frequency operation, the GN1030/1031. Volume pricing is $1.00 (¥150); production was planned to start later in 1986 at 50,000 per month.

- Sharp Corporation announced the development of a low-noise semiconductor laser and a laser driver IC, both of which operate from a single +5V power supply.

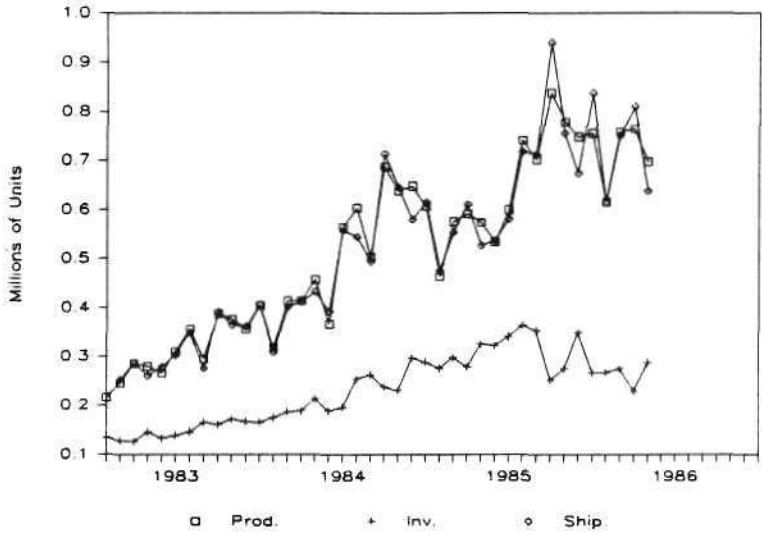
- Sanken Electric Co., Ltd., is now marketing a new series of contact-mounting LEDs. The devices are identified as the SEL3000 series. The company has also introduced an ultrahigh-brightness LED, the SEL1615. This LED product reportedly has achieved 1,000 millicandelas by employing GaAlAs.

- Japanese makers became increasingly concerned about excessive exports of compact disk players to the United States. Although the U.S. CD player market has been increasing, exports from Japan have exceeded the increase in demand. As a result, underselling the competition due to oversupply has started. Under the circumstances, Japanese makers might start controlling shipments to the United States. Because 40 percent of the CD players made in Japan are exported to the United States, oversupply in the U.S. market can greatly influence CD player production in Japan.

- The graph in Figure 2 shows Japanese production, inventory, and shipments of microwave ovens from January 1983 through April 1986.

Figure 2

JAPANESE PRODUCTION, INVENTORY, AND SHIPMENTS
OF MICROWAVE OVENS
(January 1983 through April 1986)



Source: Dataquest
February 1987

August

- Toshiba Corporation has developed an ultrasmall semiconductor laser that is compatible with standardized models built by Sharp Corporation and Sony Corporation. The laser features low noise through use of Toshiba's structure called the New ISSS (inner stripe square-channel substrate). Sample shipments will begin in September 1986 at a price of $15.82 (¥2,500) per unit. Other makers such as Hitachi Ltd., Matsushita Electronics Corporation, Mitsubishi Electric Corporation, and NEC Corporation also plan to manufacture standardized ultrasmall semiconductor lasers.

September

- Demand for compact disk player ICs continued to slow down. Among major makers, there is currently a move toward production control. Distributors expected orders received for September 1986 shipment to be 10 to 15 percent less than the record numbers reached in June and July 1986. CD player production had rapidly increased since the last half of 1985. Total production between January and May 1986 reached nearly 3.3 million units, about 80 percent of total production for the year 1985. The decline in demand for CD player ICs may indicate that CD player production has peaked.

- The Republic of Korea's Ministry of Trade and Industry has reported a national production plan for 116 items of electronic components. Eighty-four companies are participating in the project. Upon completion of the plan, we expect that national products will replace $472 million worth of imports and that the increase in exports will reach $309 million. Research and development costs for the project total W 137, which will be invested jointly by the government and the private companies. Major products included in the project are shown in Table 3.

- NEC Corporation announced that it started volume production of single-axis-mode, DFB (distributed feedback) lasers in September 1986. NEC is the second Japanese maker to start volume production of DFB lasers, following Hitachi Ltd. The lasers are the NDL5600 for the 1.3μ range, priced at $2,922 (¥450,000), and the NDL5650 for the 1.55μ range, priced at $3,571 (¥550,000). Initial run rate is 500 to 1,000 units per month, which are to be increased to 2,000 units in the first half of 1987.

- Teksel Co., Ltd., signed a sales agency contract with Anadigics Inc. of the United States and started selling GaAs ICs. Under the contract, Teksel markets the ADA25001, a superwideband amplifier, and the AOP1510, a superwideband operational amplifier. Prices are $246.10 (¥37,900) per unit (in 100-unit lots) for the ADA25001 and $80.52 (¥12,400) per unit for the AOP1510.

- Matsushita Electronics Corporation developed a new semiconductor laser called a monolithic 2-beam GaAlAs laser array, for read-write optical disk applications. The laser is capable of generating two kinds of laser optical output--one for writing and the other for reading--on a single chip. The new product makes it possible to produce compact optical pickups for disk systems.

- Matsushita Electronics Corporation prototyped an OEIC (optoelectronic integrated circuit). The device is a combination of an AlGaAs semiconductor laser with 30mW output and a high-frequency oscillator for laser noise reduction. Forty-four elements that include one semiconductor laser, 25 MESFETs, and 18 diodes are integrated onto a chip measuring 0.35 x 1.2mm. Laser noise has been reduced to negative 135dB. The new device will pave the way toward making small, high-performance optical disks. Matsushita expects to put the device to practical use within two years.

- Toshiba Corporation recently succeeded in exposing electronic circuits of 0.35μ line width on a silicon wafer by use of an excimer laser. The technology, which will enable the development of 64MB-class memories, will be put to practical use during 1987.

- NEC Corporation had developed a prototype InP FET for microwave/millimeter waveband width, succeeding in making a layer on InP substrate with ion implantation and, on that layer surface, forming a GaAlAs insulating gate using MBE. The new device, with 1μ gate features, has high-power gain of more than 83dB at 12 GHz. The company plans to commercialize a high-power, 30 GHz to 40 GHz device for satellites in 1987.

- Fujitsu Ltd. accomplished 20km nonrelay transmission at 600Mb per second, using an edge-emitting LED developed by the company. Fujitsu claims that this is a world's record in transmitting capacity in terms of distance and data volume. Using edge-emitting LEDs as light sources for optical communications can cut costs to one-tenth that of the existing method. The technical breakthrough is expected to accelerate the spread of optical communication to households.

Table 3

MAJOR DEVELOPMENTS OF CONSUMER PRODUCTS
BY KOREAN COMPANIES

Product	Company	Application	R&D Period	R&D Expense	Capital Expense
IR LEDs	Kwang Han	Televisions	6/86 to 12/86	$250,000	$375,000
Display LEDs	Kwang Han	Copiers, calculators	6/86 to 12/86	N/A	N/A
Solar Cells	Samsung	Computers, watches	7/85 to 10/87	$140,000	$2 million

Source: Electronic Times (Korea)

October

- Hitachi Ltd. recently disclosed that it shipped a large quantity of semiconductor lasers, which will be used for transpacific and transatlantic optical submarine cables, to AT&T Corp. of the United States. Shipment volume is estimated to total 4,000 to 5,000 units at a value of several billion yen. AT&T will equip submerged repeaters with the lasers.

- Hitachi Ltd. has entered the photodiode merchant market by introducing 15 models of InGaAs PIN diodes. The new series, which is adaptable to long-distance optical communication systems, has detector sensitivity for 1.3μ and 1.55μ wavelengths. The 50-, 80-, 100-, and 300- models were placed on the market in September 1986. The price for 10-unit lots is $180.65 (¥28,000) per unit. The 3mm versions were shipped as samples beginning in September. Sample price is $1,290.32 (¥200,000) per unit.

- Kodenshi Corp. has developed a series of photo interrupters and has started sample shipment. The devices, dubbed the Photo Interrupter LC Series, have been developed by using a GaAs LED and adding a photo IC for the light-emitting diode. Model numbers are LG-0101, 0201, 0401, and 0501.

- NEC Corporation has developed a 1.55μ bandwidth, single-mode semiconductor laser. By using a new laser, transmission distance by quartz fiber without relay can be extended from the current 30 kilometers to 50 kilometers or longer. The company is continuing research on the laser so that it can be used commercially as soon as possible.

- Nippon Gakki Co., Ltd., has developed an 18-bit signal processing LSI for compact disk players. The new LSI DSP chip is capable of processing CD signals at 16 times higher resolution than the attainable with the conventional digital processing method. By using the LSI in a CD player, noise can be substantially reduced. The device will be adapted to high-grade CD players to be marketed in October 1986.

- China is expected to experience major transitions in its communications technology and facilities over the next two to three decades. These include:

  - Conversion of electromechanical exchanges to solid state

  - Conversion of analog audio and video links to digital, incorporating ISDM

  - Replacement of copper networks with fiber optics

  Each of these changes will generate tremendous demand for silicon and III-V semiconductor technologies. China expects to organize these conversions into separate programs governed by sequential five-year plans.

  The fiber-optic intercity links will use InGaAsP laser sources and InGaAs PIN diode/GaAs FED preamp detectors. Conversion of intracity (local office) nets will occur later. In China, fiber-optic LANs are now used for highway traffic surveys, factory monitors, and OA. Shallow-sea fiber-optic cable links are planned along China's coasts, across bays, and among islands. Deep-sea cable will not convert to fiber optics before the late 1990s.

  China's first use of fiber optics for interoffice trunks was in Shanghai in 1979. All equipment and cables were made in Shanghai for a 1.8km link operated at 8Mb using GaAs LED sources and PIN detectors. A field trial of a 50km, 140Mb digital link is now planned in Shanghai. The Railway Ministry and the Electric Power Ministry of China have already installed fiber-optic systems.

November

- Fujitsu Ltd. is marketing four models of GaAs prescaler ICs. Two of the new devices, dubbed the MB50104/50106, are fixed-ratio prescaler ICs for microwave telecommunications; the other two, the MB50201/50202, are variable types for portable mobile radio communications systems. Sample prices are:

  - MB50104--$96.77 (¥15,000) per unit
  - MB50106--$193.55 (¥30,000) per unit
  - MB50201--$32.26 (¥5,000) per unit
  - MB50202--$58.06 (¥9,000) per unit

  Volume production will begin in spring of 1987 at a rate of 50,000 to 60,000 units per month.

- Sanyo Electric Co., Ltd., had developed a high-efficiency GaAlAs semiconductor laser, using the MBE method. In the new laser, external differential quantum efficiency has been increased to 80 percent. Internal quantum efficiency is 95 percent. The company plans to commercialize the semiconductor laser by March 1987 for use in short-distance optical communications applications.

- Sharp Corporation developed a new VSIS-structure (V-channeled substrate inner strip) semiconductor laser. Threshold current of the new laser has been reduced to 25mA at the 780nm visible range, half that of the conventional model. Volume production is planned for 1987. The VSIS-structure semiconductor laser is Sharp's original product. Since its development in October 1981, the company has sold more than 10 million units.

- Matsushita Electric Corporation developed a new semiconductor laser process by using MOCVD. With the new process, which applies the self-alignment method to crystal growth, submicron light-emitting stripes can be formed easily. The company has already manufactured on an experimental basis a 1μ stripe GaAlAs laser, which has 15mA threshold current and 1.05 ellipticity. It plans to commercialize the 1μ laser for short-distance optical communication within two years.

December

- According to a report from the Korean Ministry of Science and Technology (MOST), Korea will develop new semiconductor materials such as polycrystalline materials, ceramics, fiber optics, and high-quality single-crystal silicon. The specific areas of focus are:

  - Silicon semiconductors

    . Large integration and high purification of single crystals

    . Improvement of silicon wafer process

  - Polycrystalline materials

    . Mass production technology for solar cells (i.e., amorphous silicon)

    . New material development

  - Semiconductors

    . GaAs single-crystal technology

    . Now semiconductor components

  - Fiber optics

    . Laser diodes

    . Fiber-optic components

  - Semiconductor sensors

- While Japan claims to have a zero military budget, it has amassed tremendous capabilities in aerospace hardware in recent years and has aggressive plans for the next decade. The aerospace program is expected to cause Japanese companies to focus on rad-hardened circuits because many of the spacecraft must pass through the Van Allen Belt. Table 4 details some of Japan's capabilities and plans in this area.

- The Ministry of International Trade and Industry (MITI) in cooperation with the Optoelectronics Industry and Technology Development Association framed a rough plan to standardize 33 items of opto telecommunication products. It will gradually designate the products as JIS (Japanese Industrial Standard) items from March so that compatibility of optical fibers, which connect components and perform other functions, will be increased.

Table 4

PLANNED JAPANESE SPACECRAFT
AND SATELLITE LAUNCHINGS

Launch Date	Type	Company	Payload (Pounds)	Orbit (Height)	Comments
8/1/86	EGP	Kawasaki	1,500	900 miles	Laser target; first H-I payload
Mid-1987	ETS-5	Mitsubishi	N/A	Geosync.	Mobile satcom with ships and planes
1/87	MOS-1	NEC	1,650	545 miles	Carrying CCDs and other multispectral detectors
Early 1988	CS-30	Mitsubishi	N/A	Geosync.	Third-generation; 6,000 voice channels plus K- and C-band transponders
Mid-1988	CS-3B	Mitsubishi	N/A	Geosync.	Sister to CS-3A
Mid-1989	GMS-4	NEC	N/A	Geosync.	Weather spacecraft; H-I launch vehicle
Mid-1989	GMS-5	NEC	N/A	Geosync.	$185 million development cost; 3-axis stabilized; H-I launch vehicle
Mid-1990	BS-3A	NEC	N/A	Geosync.	Color television--three channels
Mid-1991	BS-3B	NEC	N/A	Geosync.	Sister to BS-3A
N/A	ERS-1	NEC/Mitsubishi	3,000	N/A	To carry synthetic aperture radar, IR and visible sensors; electrically sequenced transmitters used for careful study of ground

(Continued)

Table 4 (Continued)

PLANNED JAPANESE SPACECRAFT AND SATELLITE LAUNCHINGS

Launch Date	Type	Company	Payload (Pounds)	Orbit (Height)	Comments
81/92	ETS-6	Mitsubishi	N/A	N/A	First H-II payload
1994*	N/A	N/A	N/A	N/M	H-II payload; seismic detection
Mid-1990s	Venus Probe	N/A	N/A	N/M	H-II payload; magnetosphere probe

Geosync. = Geosynchronous orbit (approximately 22,000 miles above Earth's surface
N/M = Not Meaningful
N/A = Not Available

*Moon Probe

Source: AZTEK Associates

- Prices of semiconductor lasers to be used for CD players and video disks have declined sharply. In the case of 0.78μ lasers, the wholesale prices for large users in Tokyo are $5.25 to $5.86 (¥850 to ¥950) per unit, a 5.3 percent decline in two months. Some new makers' models are sold at $4.94 (¥800) per unit, with underselling competition expected to continue toward the end of the year as makers plan for production increases. Sharp Corporation's production capacity has increased six times since the beginning of this year.

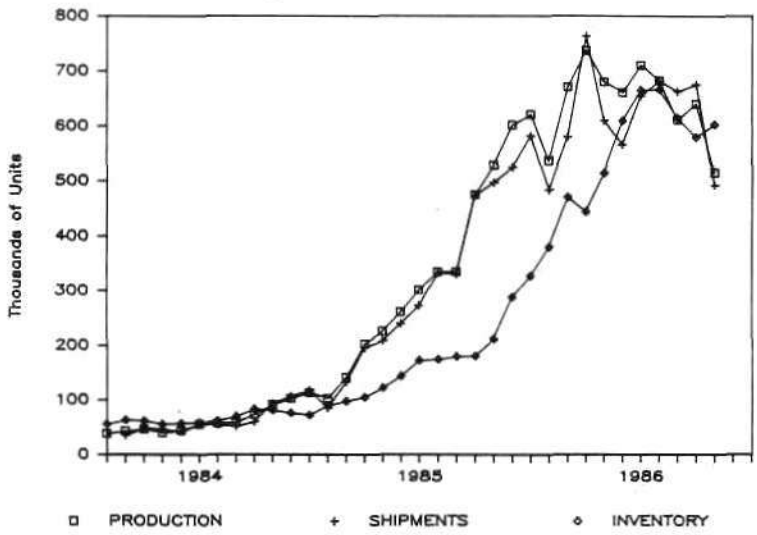
- Stanley Electric Co., Ltd., will supply Nissan Motor Co., Ltd., with LED high-mounted brake lights for the 1987 Fairlady 2, Nissan's sports car, marking the first time that LEDs will be used as automobile illuminators. Monthly shipments to Nissan are expected to be 6,000 units. Because of interest by automobile makers at home and abroad, including the big three U.S. companies, Stanley plans to expand its LED lamp market throughout the world.

- Stanley Electric Co., Ltd., and Kyokuto Bomki Kaisha, Ltd., have jointly established I.I. Stanley Inc. in Battle Creek, Michigan. The new company, capitalized at $1 million (60 percent by Stanley, 30 percent by Kyokuto, and 10 percent by Stanley Electric U.S.) will start production of LEDs and lighting apparatus in May 1987. Capital investment in the company is expected to total $10 million.

Dataquest estimated that semicondutor consumption for digital audio disk (DAD) players was around ¥3 billion ($18.52 million) per month in 1986. Since the production cost per unit was going down, semiconductor consumption tended to decrease also (see Figure 3).

Figure 3

JAPANESE DIGITAL AUDIO DISK PLAYERS PRODUCTION, SHIPMENTS, AND INVENTORY (January 1984 to October 1986)



Source: Dataquest
February 1987

DATAQUEST CONCLUSIONS

The field of GaAs and other III-V compound semiconductors is advancing rapidly every year, and 1986 was no exception. Asian companies are very active in the application of GaAs technology to consumer products, fiber-optic communications, and satellite hardware, and they continue to refine the traditional LED display devices. There is increasing competition in the IC field, particularly in MMICs and digICs, with new players entering the marketplace. Dataquest expects this pace of activity to continue into the 1990s as IC suppliers, pressured by declining profits in Si, seek out niches in III-V markets.

Gene Miles

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Research Newsletter

GATA Code: Newsletters
1987-5

III-V MATERIALS--WHO'S ON FIRST?

Since our August 1986 newsletter on GaAs materials, the compound semiconductor materials situation has evolved into a new game. In most high-technology business areas, innovation never ceases, leading to gyrations in the competitive lineup. The III-V materials industry is no exception.

Recent developments that we consider worth watching include:

- GaAs on Si substrates
- Progress in NDF wafer manufacture
- New entrants and start-ups
- Increases in the price of gallium in Japan
- Innovations in InP manufacture

DATAQUEST ANALYSIS

Although Sumitomo Electric in Japan is the acknowledged leader in GaAs wafers with an estimated world market share of 50 percent, the competition is heating up with major expansions under way. For this newsletter, Dataquest identified 39 companies in the Free World marketplace that are involved in compound semiconductor materials manufacturing operations. These include 18 in the United States, 2 in Canada, 11 in Japan, 3 in West Germany, 2 in the United Kingdom, 2 in France, and 1 in Sweden. As we predicted earlier, materials companies are becoming increasingly aggressive in their attempts to establish a significant presence in this market.

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A key factor in the growth of the compound semiconductor industry is the ability to move into LSI and VLSI levels of integration. This movement is presently limited by the quality of substrate material. Although NTT announced development of a 16K SRAM in 1984, none of the device suppliers has been able to mass-produce the chip for the commercial market, at any price. Dataquest believes that recent laboratory work by Westinghouse and others on GaAs crystal growth has resolved the technical problems associated with VLSI from the standpoint of materials. Which company or companies will be first to benefit from this in the merchant market is not yet clear.

A promising alternative to GaAs substrates is the possible move to GaAs on silicon substrates, with pioneering work under way at start-up Kopin Corporation and other companies. Vertically integrated companies believed to be working in the field of GaAs on Si include AT&T Bell Laboratories, Ford, Fujitsu, GTE, HP, NEC, NTT, Oki, Texas Instruments, and Xerox. TI demonstrated a 1K SRAM implemented on a GaAs on Si substrate, in 1986. IBM's position in this area is not known, although it is believed to be heavily engaged in GaAs device and chip development, and has publicized its work on GaAs ballistic transistors. GaAs on Si, when perfected, will also significantly reduce wafer and, therefore, chip costs, bringing GaAs cost/performance at the system level much closer to that of Si ECL.

Table 1 summarizes the activities of merchant suppliers of GaAs and other compound semiconductor materials companies. It is arranged alphabetically and identifies the companies' corporate nationalities, major compound semiconductor products, methods of manufacture, wafer sizes, expansion plans, and other information that Dataquest believes is of value to its clients.

In addition to Kopin Corporation, the table shows other compound semiconductor materials start-up companies including Picogiga (France) and Preussag AG (West Germany). Dataquest expects 1987 to bring more new players to this field, as if it weren't crowded already.

Gene Miles
Peggy Wood

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Table 1

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Airtron	U.S.	GaAs undoped and Si-doped wafers	Growth method: LPLEC Firm is a division of Litton Industries 2", 2.5", and 3" wafers available
Bertram Labs	U.S.	GaAs wafers	Growth method: HB 2" GaAs wafers available
Boliden Finemet AB	Sweden	GaAs wafers	Growth method: HPLEC 2" and 3" GaAs wafers available
Cominco Electronic Materials	Canada	GaAs GaSb, InSb, InAs, CdTe, HgTe, and CdHgTe wafers	Growth methods: HPLEC, HB Completed expansion of LEC GaAs wafer plant in Trail, BC, Canada in 1985. Capacity 250K sq. in./year; 2", 3", and 4" wafers available
Commercial Crystal	U.S.	GaAs, GaP, InP wafers	Growth methods: LEC, HB 2" wafers available
Cryscon Technologies	U.S.	GaAs wafers	Growth method: LEC Subsidiary of Alcan Aluminum of Canada. Started shipping GaAs Q4/85. Cryscon supplies 2" and 3" GaAs wafers produced by LEC and electrodynamic gradient freeze (EFG) technique. Annual capacity approx. 2 million sq. in./year. Cryscon was for sale as of 10/22/86
Crystacomm Inc.	U.S.	InP crystals and wafers	Growth method: LEC 2.5" wafers available
Crystal Specialties	U.S.	GaAs wafers, MOULD epi reactors	CSI became subsidiary of Kollmorgen Co. in summer 1984. Wafer facility moved to Colorado Springs, CO, from Ephraim, UT, in Q3/86; reactor facility in Portland, OR
Dowa Mining	Japan	GaAs, InP wafers, poly InP, high purity In	Growth method: HB Research lab located in Akita
EMCORE	U.S.	GaAs epitaxial wafers (MOCVD epi reactors)	Start-up in New Jersey Founded in late 1984 2" and 3" wafers
Epitaxy	U.S.	Epi wafers, photodetectors	Start-up in Puncton, NJ, founded in 1984. Adding InGaAs layer onto InP wafers for photonics and other applications
Epitronics	U.S.	GaAs expitaxial wafers	MOCVD and LPE epi methods Subsidiary of Alcan Aluminum of Canada

(Continued)

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Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Furukawa Electric	Japan	GaAs, InP wafers, GaAs epi wafers	Growth method: LEC Wafers produced at Tokyo lab
GAIN Corporation	U.S.	GaAs epi wafers	Production expected in 1987
Galarix Corporation	U.S.	GaAs wafers, poly and single-crystal GaAs ingots	Growth method: HB Started in 1983 as research organization Marketing of GaAs materials primarily focused toward R&D facilities
Gallium Arsenide Substrates	U.S.	GaAs wafers, poly and single-crystal GaAs ingots	Using gradient freeze process with less than 1,000 dislocation defects/square cm Capitalized with $1 million in private funding
Hitachi Cable	Japan	GaAs, InP epi wafers, single-crystal GaAs ingots	Growth method: LEC Production of III-V materials at Takasago plant in Ibaraki. Investing ¥2 billion to expand two plants including epi plant at Kidaka
Hitachi Metals	Japan	Single-crystal GaAs ingots	Growth method: LEC Developing single-crystal undoped GaAs
ICI Wafer Technology	U.K.	GaAs, InP wafers, poly and single-crystal GaAs and InP ingots	Growth method: LEC ICI bought Cambridge Instruments' III-V operations in 1/85. 2" and 3" GaAs and 2" InP wafers available
Iwaki Handotai	Japan	GaAs wafers	Growth method: LEC 50-50 joint venture of Furukawa Mining/Shin-Etsu Handotai (SEH), founded 1982. Plant in Fukushima prefecture began 2" and 3" wafer production in June 1983. SEH began shipping 2" GaAs wafers to subsidiary, SEH America, from Iwaki Handotai June 1985. 3" wafers available in R&D quantities
Kopin Corporation	U.S.	GaAs-on-Si wafers	Start-up in Taunton, MA 3" and 4" wafers. Developing MOCVD epi process
M/A-COM Semiconductor Products	U.S.	GaAs and GaAs epi wafers	Growth method: LEC Merchant sales as well as captive consumption of GaAs wafers. Microwave Assoc. Ltd. is M/A-COM distributor in the United Kingdom
MCP Limited	U.K.	GaAs wafers	Located in Wembley, Middlesex, England

(Continued)

Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Metal-Specialties Inc.	U.S.	GaAs, GaP, GaSb InAs, InP, InSb wafers	Growth methods: LEC, HB
Meteaux Speciaux	France	InP ingots wafers	Growth method: LEC Plant located in Moutiers, France Production expected mid-1987
Mitsubishi Metal Corporation	Japan	GaAs wafers	Growth methods: LEC, HB Wafer plant located in Omiya, Saitama prefecture. Nissho Iwai Corp. is the U.K. distributor
Mitsubishi Monsanto Kasei (MMK)	Japan	GaAs, GaP wafers	Growth methods: LEC, HB Production system for 3" NDF GaAs wafers developed at Tsukuba plant. MMK spending ¥3 billion for expansion; plans to double sales by 1989. Planned capacity is 500 wafers/month. MMK using NTT's vertical magnetic CZ method to produce 3" wafers with 10 defects/ square cm. max. MEMC to sell MMK wafers in U.S. market
Morgan Semiconductor (division of Ethyl Corp.)	U.S.	GaAs wafers; GaAs epitaxial wafers	Growth methods: LEC, HB Started sampling LP LEC 3" GaAs wafers in 1984; med. pressure LEC 3" GaAs in September 1986. Shipment of 2" and 3" GaAs epi wafers began 4Q/1986
Nippon Mining	Japan	InP wafers, poly and single-crystal InP, single-crystal GaAs and CdTe ingots	Growth method: LEC First Japanese company to grow NDF 3" InP crystal material. Nimio (Cupertino, CA) is a Nippon Mining subsidiary; purpose is to promote sales of GaAs, InP, CdTe, other III-V and II-VI materials in the U.S. market
OMVPE Technologies	Canada	GaAs epitaxial wafers	Start-up located in St. Laurent, Quebec, Canada
Picogiga	France	GaAs epi wafers	Start-up with $4 million in private funding, located in Les Ulis (Orsay). Began operation in August 1986. 2" GaAs MBE wafers
Preussag AG	West Germany	GaAs wafers	New division of Preussag, located in Gossiar, West Germany. Spending $30 million+ to develop wafer capability. Preussag is a major mining interest and supplier of Ga material.

(Continued)

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Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Raytheon	U.S.	GaAs epitaxial wafers	Growth methods: LEC, HB
Showa Denko	Japan	GaAs, GaP, InP wafers	Growth method: LEC First company in Japan to produce InP wafers by MLEC. Sampled reduced-defect GaAs wafers in summer 1985
Siemens Company, Inc. Opto Div. (Litronix)	U.S.	GaAs wafers	Growth method: HB Facility located in Cupertino, CA 1.6" to 3" wafers available
Spectrum Technology	U.S.	GaAs wafers	Growth method: HP and LP LEC Spectrum founded in 1982, acquired in Q2/1985 by NERCO Advanced Materials, Inc. (Portland, OR), a large mining interest
Spire Corporation	U.S.	GaAs epitaxial wafers and equipment	Located in Bedford, MA. MOCVD growth of III-V and II-VI compounds, including GaAs, AlGaAs, GaAsP, InP, ZnS, ZnSe on 2" and 3" substrates
Sumitomo Electric	Japan	GaAs, GaP, InP, InSb, InAs, GaSb wafers	Growth method: LEC, HB Largest III-V substrate supplier in the world; 50 percent share of GaAs market. Has capacity for 3,000 3" GaAs wafers/month. GaAs material produced in Itami City (north of Osaka), Hyogo prefecture
Sumitomo Metal Mining	Japan	GaAs, GaP and CdTe wafers	Growth method: LEC
United Epitaxial Technologies	U.S.	GaAs and AlGaAs epitaxial wafers	Start-up in Oregon; received approx. $5 million in first-round venture funding. Founded mid-1984. Working with Crystal Specialties to develop MOCVD equipment. 2" and 3" epi wafers
Wacker	West Germany	GaAs, GaP InP wafers	Growth methods: LEC, HB Shipping 2" and 3" epi wafers

Note: LPLEC = Low Pressure Liquid-Encapsulated Czochralski, HB = Horizontal Bridgeman, HPLEC = High Pressure Liquid-Encapsulated Czochralski, LEC = Liquid Encapsulated Czochralski, MOCUD = Metal Organic Chemical Vapor Desposition, LPE = Liquid Phase Epitaxy, MBE = Molecular Beam Epitaxy, MLEC = Magnetic Liquid-Encapsulated Czochralski

Source: Dataquest
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Research Newsletter

GATA Code: Newsletters
1987-7

ADVANCED PRODUCTION-WORTHY GaAs ICs PRESENTED AT CICC

SUMMARY

The 1987 IEEE Custom Integrated Circuits Conference, held in Portland, Oregon, earlier this month, featured a special session on GaAs ICs. Late papers added emphasis to the rapid changes that are taking place in this technology. This newsletter highlights the significant products and related technology featured in several of the presentations.

The papers showed that the GaAs industry is experiencing difficulty as it moves to the VLSI level of integration, not unlike the Si industry of the mid-1970s. E/D MESFET technology is believed to be the vehicle for the next advancement in chip density. Several of the papers indicated that yields of up to 70 percent are now being realized in producing MSI level functions such as error detection chips and encoder/decoder-enhanced optical transceivers. Experience was reported showing yields to 35 percent for LSI circuits containing more than 40,000 transistors and other components.

PROGRESS IN GaAs FOR COMMUNICATIONS APPLICATIONS

Encoder/decoder functions for serial data streams readily lend themselves to GaAs implementation. For example, in fiber-optic transmission systems, a line code is often used to achieve an equal distribution of 1s and 0s to optimize performance over long distances. Because this line code adds redundancy to the signal, it can be used to monitor the link for bit errors. The low I/O count and high bit rates involved, coupled with the real-time nature of these functions, dictate the use of a highly exotic version of silicon technology or a straightforward, loose-tolerance approach with GaAs technology. Companies presenting results of efforts in this field included ITT and GE, in addition to work by the Center for Digital Systems Research (Research Triangle Park, North Carolina).

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The ITT device features a 144-gate error detection circuit that has been tested at 2.5 GHz and has experienced less than 12 percent speed degradation when operated at 125 degrees C. The chip was designed, fabricated, and tested by a team of engineers from ITT Standard Telefon O.G. Kabelfabrik A/S (Oslo, Norway) and ITT GaAs Technology Center (Roanoke, Virginia).

The GE chip incorporates an encoder, laser driver, optical detector, and decode logic; die size is 45 mils x 90 mils. TriQuint fabricated the GE circuit using a 1u E/D process, as part of a multichip project. A lot of four wafers was tested, with combined transceiver yields of 65, 70, and 82 percent for the three best wafers.

Triple modular redundancy (TMR) is a fault-tolerant technique used extensively in hardware for high reliability. Because TMR can lengthen system cycle time, GaAs is a more attractive medium than Si for implementation. A TMR chip developed by Research Triangle Institute has been built and demonstrated. The design was based on TriQuint's 1u D-MESFET process; TriQuint fabricated the prototypes. Initial tests indicate that the circuit adds less than 3ns overhead to a TMR processor configuration.

MSC DEVELOPS 1.5-GHz, DIVIDE-BY-N PRESCALER

Microwave Semiconductor Corporation discussed a 1.5-GHz, divide-by-N prescaler with the highest operating frequency reported to date. The circuit is capable of dividing an input frequency of DC to 1.5 GHz by any integer from 3 to 64. The MSC design is based on 3-diode BFL internal logic, and features ECL-compatible output buffers.

GBL AND SEATTLE SILICON PRODUCE AND APPLY GaAs COMPILER

GigaBit Logic, Inc., (GBL) presented a GaAs standard cell family developed for LSI applications. The family was created to support the wide variety of applications for ultrahigh-speed, low-power GaAs LSI. GBL stated that it chose D-MESFET technology for this family because it has obtained yields of more than 35 percent on 14,000-transistor, 28,000-component circuits at its Newbury Park facility. The microcell family offers gate delays of less than 100ps and flip-flop toggle rates above 2 GHz. The family is commercially available for design of chips of up to 4,000 gates.

A joint paper by Seattle Silicon Corporation and GigaBit Logic described a 4-bit ALU that was designed using a compiler. The ALU is functionally equivalent to the 100181, 100K ECL chip. The GaAs ALU chip contains 96 CDFL gates, features ECL compatible I/Os, and measures 64 x 96 mils. Initial tests demonstrated power dissipation of less than 4mW per gate and gate propagation delays of 155ps for a speed-power product of 565 femtojoules under system loading conditions. This performance contrasts very favorably with that of a commercially available silicon 100181; the GaAs 100181 offers one-half of the power consumption and 5.7 times faster throughput than its silicon counterpart.

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HEMT GATE ARRAY EXCEEDS 4,000 GATES

A late paper by Fujitsu described a 4.1K gate array using HEMT devices. The company has fabricated a 16 x 16 parallel multiplier that was operated at 4.9ns at 300°K and 3.1ns at 77°K. The chip was developed as a part of Japan's Research and Development Program on the Scientific Computing System, a MITI-sponsored project.

GaAs DSPs NOW INCLUDE FIR FILTERS

A GaAs MESFET implementation of a FIR (finite-duration impulse response) filter design was presented by a team from the Computer Systems Laboratory of Tampere University of Technology (Finland) and the Department of Electrical and Computer Engineering of the University of California at Santa Barbara. The circuit consists of approximately 260 BFL gates, dissipates 1.6W, and has ECL-compatible I/Os. Process is depletion mode, 1u, n-type MESFET.

NEW SPICE MODEL OF GaAs MESFET

GaAs MESFET modeling, featured in several of the papers, was the subject of a presentation by a team from the University of California at Berkeley. This group's model has been implemented in SPICE 2G.6. This work was supported by Digital Equipment Corporation, McDonnell Douglas Astronautics Company, and the California MICRO Program.

DATAQUEST CONCLUSIONS

Practical GaAs functions, usable in upgrades of existing electronic hardware and in next-generation designs, have become increasingly available. The major investments of the last few years are producing workable, Si-compatible GaAs at MSI/LSI density levels. Systems designers can no longer ignore GaAs technology in today's competitive environment, where a delta of 200ps per clock cycle can make or break a new design. Foundry services of companies like TriQuint stand ready to support new users of this exciting, rapidly growing, technology.

Gene Miles

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Research *Bulletin*

GATA Code: Newsletters
1987-6

FORD OFFERS E/D GaAs FOUNDRY SERVICES

Ford Microelectronics, Inc., has established a 12,000-square foot GaAs foundry at Colorado Springs, Colorado, the United States. This facility has a 3-inch capacity of 500 wafers per week. The clean room exceeds Class 10 criteria and reduces LSI/MSI density devices on a self-aligned E/D process. The circuits feature loaded gate delays of 150ps at 0.7mW per gate pd and a worst case noise margin of 300mV.

Ford offers proprietary SPICE-based circuit simulation software called GASSIM. Hermetic IC packaging capability includes a variety of standard packages. The fab site has both environmental screening and 100 percent burn-in capabilities. Electrical testing is performed on Sentry 21 and MegaTest's MegaOne VLSI testers. Table 1 delineates foundry charges at the new Ford Microelectronics facility.

Table 1

Ford Microelectronics, Inc.
FOUNDRY CHARGES

E/D Gate Array--1,000 Equivalent Gates	
NRE and 10 Prototypes	$75,000
Custom Foundry--E/D SAGFET	
Foundry Kit	$24,000
Engineering Consultation	$3,000
5-wafer minimum:	
First 25 wafers	$7,000 each
Next 25 wafers	$6,000 each
Next 50 wafers	$5,000 each
More than 100 wafers	Negotiable

Source: Dataquest
March 1987

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Ford Microelectronics is a full-service supplier of GaAs digital and analog standard, semicustom, and full-custom products. The company reportedly is establishing an E/D GaAs IC alternate source agreement and capability in conjunction with Vitesse Electronics Corporation of Camarillo, California.

Dataquest believes that adequate E/D foundry capacity is critical to the successful long-term application of GaAs technology to commercial digital hardware, and that Ford's capabilities will enhance the development and growth of this industry.

Gene Miles
Tom Wang

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Research Newsletter

GATA Code: Newsletters
1987-8

GaAs IC FOUNDRIES EXPAND THEIR SERVICES

SUMMARY

GaAs foundry activity is intensifying. The lineup of players is changing, and new services are being offered the market. Since our 1986 newsletter on this topic, Ford, GAIN, ANADIGICS, Tachonics, and Texas Instruments have joined the quest for market share; Honeywell has consolidated its effort, closing its Richardson, Texas, facility in favor of the Minneapolis operation. This newsletter is an update on available merchant market GaAs foundry services. A revised list of GaAs foundries, contact names, and telephone numbers is included for your convenience in Table 1.

THE COMPANIES

Adams-Russell

Adams-Russell offers custom-fabricated GaAs MMICs, 1u MESFET foundry service, and a design seminar for GaAs IC users. The company's 54,000-square-foot semiconductor center was established in Burlington, Massachusetts, in 1982. Foundry charges are approximately $40,000 per four-wafer prototype lot for customer-owned mask set and tooling. Multiproject design participation is priced at $10,000 per group (up to four persons per group). The available library of MMIC components includes transistors, diodes, capacitors, resistors, and spiral inductors for MMIC design. The company accepts Calma GDSII or CIF data base tapes and offers 10- to 12-week throughput for tested chips.

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Table 1

GaAs MERCHANT MARKET FOUNDRY CONTACTS

Company/Location	Phone	Foundry Contact
Adams-Russell Burlington, Massachusetts	(617) 273-5830	Bryan Reardon Marketing Director
ANADIGICS Warren, New Jersey	(201) 668-5000	Michael Gagnon Marketing Director
Avantek Santa Clara, California	(408) 970-3084	Peter Manno Marketing
Ford Microelectronics Colorado Springs, Colorado	(303) 528-7660	Charlotte Diener Marketing Manager
GAIN Somerville, New Jersey	(201) 526-7111	Michael D. Logan Marketing Director
GigaBit Logic Newbury Park, California	(805) 499-0610	Michael Pawlik Foundry Manager
Harris Microwave Milpitas, California	(408) 433-2222	Jim Klug Program Director
Honeywell Minneapolis, Minnesota	(612) 887-4047	Dr. Richard Cirillo Program Manager
ITT GTC Roanoke, Virginia	(703) 563-8600	Ed Donoho Senior Manager, Technical Services
M/A-COM Lowell, Massachusetts	(617) 937-2800	Larry Ward Marketing Director
Plessey Towcester, United Kingdom	(0327) 51871	Ray Evans Foundry Marketing
Rockwell Anaheim, California	(714) 762-4074	Phil Dee Marketing Manager
Tachonics Plainsboro, New Jersey	(609) 275-2525	Leonard Lea Marketing Director
Texas Instruments Dallas, Texas	(214) 995-0899	Ray Toole Operations Manager

(Continued)

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Table 1 (Continued)

GaAs MERCHANT MARKET FOUNDRY CONTACTS

Company/Location	Phone	Foundry Contact
TriQuint Beaverton, Oregon	(503) 629-3100	Dr. Ajit Rode Foundry Manager
Vitesse Semiconductor Camarillo, California	(805) 388-3700	Jim Brye Marketing Vice President

Source: AZTEK Associates

ANADIGICS

ANADIGICS offers GaAsIC (a trademark of ANADIGICS) foundry services. The process is 0.5u gate length D-MESFET with 24-GHz foot standard transistors. ANADIGICS' design tools include the following trademarked services and support: AISPICE design software, AIGRAPH layout, and AICHECK verification programs. Examples of microwave circuits that can be designed using the company's tools and processing are: wideband, power, and low-noise amplifiers; limiters, buffers, and mixers; and switches, VCOs, and phase shifters. Linear and digital circuit examples include: transimpedance amplifiers, mux/demux circuits, laser drivers, A/Ds and D/As, dividers, and ECL-compatible logic.

Capacity of ANADIGICS' 6,400-square-foot, Class 100 clean room is claimed to be 300 3-inch wafers per week. Wafer probe equipment is rated to 40 GHz; final testing is rated at DC to 26.5 GHz (rf) and 4 Gb/s (digital). High-speed linear testing includes automatic on-wafer laser trimming. In addition to wafer fab, dicing, packaging, and screening, ANADIGICS offers backside processing including thinning metallization and via holes. Packaging includes DIPs, LCCs, flatpacks, and proprietary metal-ceramic packages to 20 GHz.

Avantek

Avantek has recently expanded its facilities to include a 3-inch wafer fab. Process is state-of-the-art 0.5u GaAs MESFET. Foundry charges are $40,000 for the first wafer, which includes design rule package and engineering services, $10,000 each for additional wafers (minimum lot size is five wafers).

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Ford Microelectronics

Ford Microelectronics, Inc., has established a 12,000-square-foot GaAs foundry at Colorado Springs, Colorado, with a 3-inch capacity of 500 wafers per week. The clean room exceeds Class 10 criteria and is producing LSI/MSI density devices on a self-aligned E/D process. The circuits feature loaded gate delays of 150ps at 0.7mW per gate pd and a worst-case noise margin of 300mV.

Ford offers proprietary SPICE-based circuit simulation software called GASSIM (a trademark of Ford Microelectronics). Hermetic IC packaging capability includes a variety of standard packages. The fab site has both environmental screening and 100 percent burn-in capabilities. Electrical testing is performed on Sentry 21 and MegaTest MegaOne VLSI testers. Table 2 delineates Ford's foundry charges.

Ford Microelectronics is a full-service supplier of GaAs digital and analog standard, semicustom, and full-custom products. The company reportedly is establishing an E/D GaAs IC alternate source agreement and capability in conjunction with Vitesse Semiconductor of Camarillo, California.

Table 2

Ford Microelectronics, Inc.
FOUNDRY CHARGES

E/D Gate Array, 1,000 equivalent gates	
NRE and 10 prototypes	$75,000
Custom Foundry, E/D SAGFET	
Foundry Kit	$24,000
Engineering Consultation	$ 3,000
5 Wafer Minimum	
First 25 wafers	$ 7,000 each
Next 25 wafers	$ 6,000 each
Next 50 wafers	$ 5,000 each
Over 100 wafers	Negotiable

Source: Ford Microelectronics

GAIN Electronics Corporation

GAIN has placed in operation a 55,000-square-foot facility including a foundry at Branchburg (near Somerville), New Jersey. Initially, the foundry services are based on GAIN's E/D process; migration to SDHT structures is planned. The company recently introduced a 3,456 E/D gate array based on its proprietary GFL device architecture. Design tools are Mentor/Apollo based.

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The GFL35000 features E/D processing, 100ps gate delays, 250uW/gate p_d and 140 I/Os that may be ECL or TTL/CMOS compatible. NRE costs are competitive. GAIN states that the production cost of its array is less than twice that of equivalent-density ECL arrays.

GigaBit Logic

GBL has developed a standard cell library for custom digital designs to support chips of up to 4,000-gate density. GBL states it chose D-MESFET technology for this family because it has obtained yields of over 35 percent on 14,000-transistor, 28,000-component circuits at its Newbury Park, California, facility. The macrocell family offers gate delays of less than 100ps and flip-flop toggle rates above 2 GHz. Foundry charges are $50,000 for two prototype runs and $35,000 per production run at eight wafers per run.

Harris Microwave Semiconductor, Inc.

In April 1987, Harris Microwave Semiconductor, Inc., announced the availability of a library of GaAs standard cells for semicustom digital designs. The process is Harris' proprietary DIGI-2, 1u MESFET using two-layer metal; t_{pd} is typically 280ps/cell at 10 to 40mW/cell ps. I/Os consume 11 to 88mW each and may be ECL, TTL, CMOS, and GaAs compatible. The cells range in complexity from two-input NAND gates to a two-bit full adder.

Harris' CAD/CAE tools are a modification of tools developed by Silicon Design Automation for the ASIC business. Other tools include a logic simulator, developed by SIMUCAD, and place-and-route software. The system is UNIX-based and runs on the Harris MCX-3, Sun 3/160, Apollo, Masscomp, and other workstations.

Harris states that a typical prototype digital chip design effort costs approximately $60,000, which includes a CAE user's manual, cell library manual and 25 packaged, tested prototypes. The company plans to expand the existing library of 38 standard cells during 1987. Harris' Milpitas, California, facilities include a 0.5u foundry that also supports custom MMIC production. Cost for a prototype two-wafer run for MMICs is similar to that for a prototype digital run.

Honeywell

During a recent major reorganization of Honeywell operations, the company consolidated its GaAs activities into the corporate R&D center at Minneapolis, Minnesota, under the direction of Dr. Richard Cirillo, GaAs Department Program Manager. New opportunities are being addressed on a case-by-case basis. A spokesperson stated that the Richardson GaAs facility has been transferred to the control of the Opto Division of Honeywell.

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ITT

ITT's Roanoke, Virginia, GaAs Technology Center (GTC) offers MMIC and high-speed digIC foundry support on a limited basis for military and commercial applications. Foundry charges are negotiable.

M/A-COM

M/A-COM has one of the largest GaAs foundry production facilities available, exceeding 90,000 square feet. The company primarily supports MMIC designs, and offers processing to 0.8u, 0.5u, and 0.25u design rules. Wafer runs processed to 0.8u fab cost $25,000; processing to 0.5u rules costs $30,000 per run. Mask charges usually involve 9 to 14 levels at $1,200 per level. Special testing and other services are negotiable.

Plessey

Plessey's Three-Five Group offers its F1 foundry process based on D-MESFETs with 0.9u nominal gate length. Available circuit elements include FETs, diodes, resistors, capacitors, and inductors. Cost is approximately $40,000 for a design manual that includes a description of standard components and $14,000 per wafer run. Plessey prefers projects that require at least two to five runs per year.

Rockwell

Rockwell's Microelectronics Research and Development Center (MRDC) pioneered the development of GaAs materials and ICs. Its 41,000-square-foot Newbury Park facility near Thousand Oaks, California, is equipped to produce 250 3-inch wafers per week per shift. Foundry operations started in August 1985, initially supporting D-MESFET designs including LSI density chips. HEMT and HBT processes are in development. Calma and Daisy Chipmaster systems are in place; additional design tools are added as needed. Foundry charges are negotiable.

Tachonics

A subsidiary of Grumman, Tachonics has established a GaAs IC standard product and foundry facility in Plainsboro, New Jersey, with initial capacity of 300 3-inch wafer starts per week. The company is developing a fully self-aligned gate E/D digital process and a 0.5-micron microwave process. The digital capability includes a cell library based on typical gate speed-power characteristics of 100ps/500uW. Tachonics will provide workstation capability and support for Mentor workstations on the Apollo network.

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Texas Instruments

In April 1987, Texas Instruments announced availability of MMIC foundry services at its Microwave Military Components Division (MMCD). The division has an 8,000-square-foot fab that runs three process profiles on 3-inch wafers. The 0.5-micron processes are each optimized with special characteristics, such as low noise high gain or high power intermediate gain. Texas Instruments offers a training course to familiarize designers with design runs, process parameters, and circuit examples. Pricing of Texas Instruments' foundry services is available from the factory.

TriQuint

TriQuint offers its foundry customers Q-chip, multiproject chip, full custom, and ASIC services. Full-custom charges for customer-designed chips range from $42,000 for a 1-micron D-MESFET design to $60,000 for a 1-micron E/D design. These charges include design manual, mask making, and first prototype wafer run. ASIC charges for TriQuint designs to customer specifications are negotiable.

The company charges $55,000 for first 5 to 10 Q-chip samples, including design manual, standard cells on Daisy equipment, and evaluation board. Multiproject wafer cost is $9,900 for MSI-density design samples.

TriQuint periodically offers multiproject chip design courses, such as the two during March 16-20, 1987, in Portland, Oregon. The courses were led by 14 of their expert staff who had a combined engineering experience of more than 190 years. The microwave design course typically consists of lectures on design logistics, GaAs processing, circuit models and SPICE modeling, chip design, packaging, testing, and reliability. The digital design course is similar, focusing on E/D processing, digital IC design, and standard cells. Informal design consulting is included in each course. TriQuint offers each of the attendees the opportunity to successfully specify, design, and evaluate samples of a custom state-of-the-art GaAs IC.

Vitesse Semiconductor Corporation

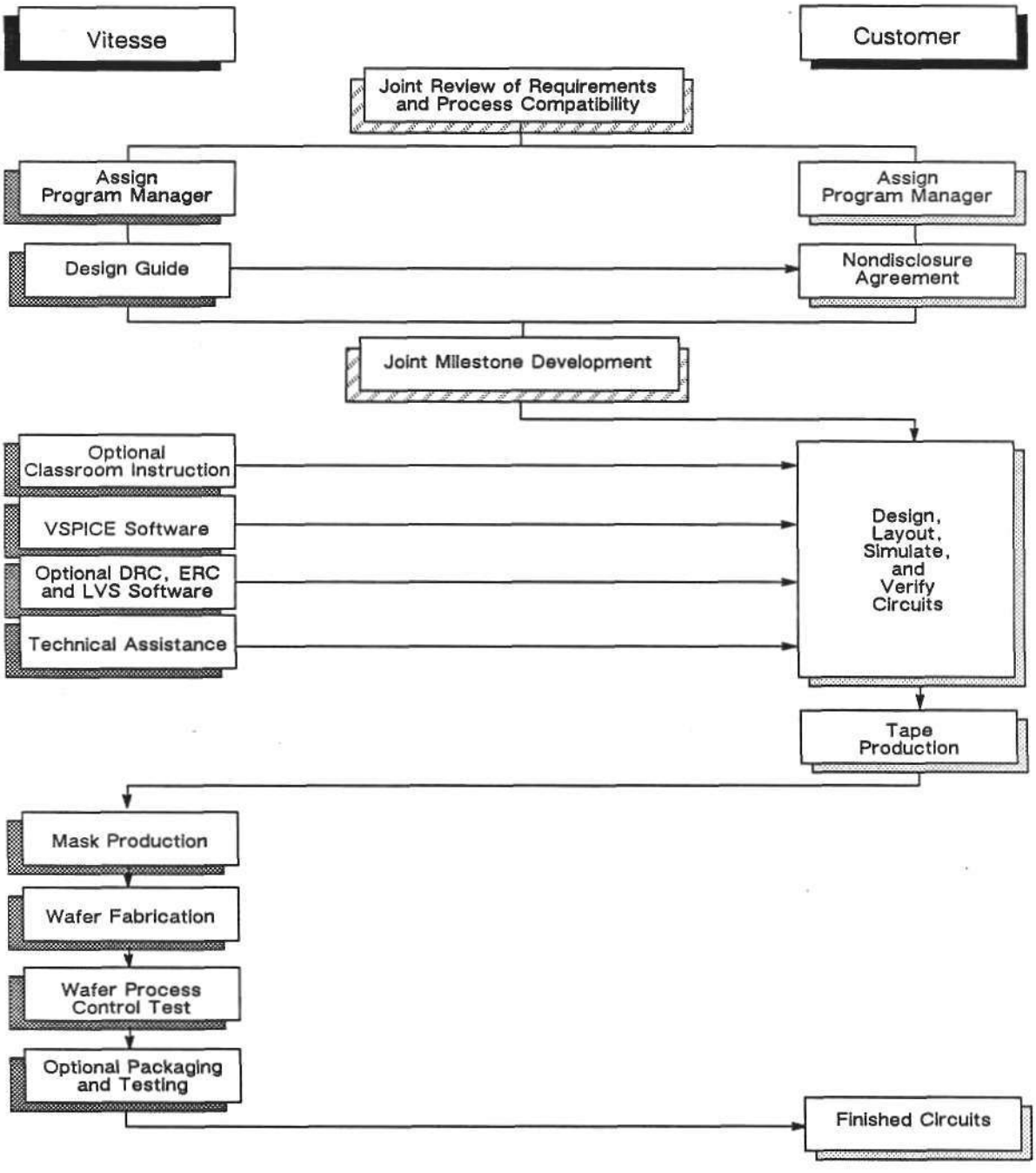
Vitesse's facilities in Camarillo, California, include an E/D foundry. The company has demonstrated production capability in such standard products as the VE29G01, a GaAs equivalent of the popular silicon 2901 4-bit microprocessor slice. Vitesse's foundry has implemented a proprietary process called VEGA (Vitesse E-D GaAs), a 1.25-micron, enhancement/depletion mode self-aligned, nine-mask process featuring three levels of interconnects and subloop gate delays. Figure 1 illustrates a typical Vitesse and customer relationship and flow chart for a typical foundry project.

Vitesse has a one-time setup charge of $33,000 per design for a typical nine-layer chip. V-SPICE software, rule-check software, and a design guide cost $5,000. Engineering consultation costs $100 per hour. Processing cost for the first five wafers is approximately $6,000 per wafer; charges for more than five wafers are negotiable.

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Figure 1

FOUNDRY-CUSTOMER INTERFACE AND PROJECT FLOW



Source: Vitesse Semiconductors

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DATAQUEST CONCLUSIONS

The GaAs industry clearly has an abundance of capacity to support MSI/LSI density digital and microwave analog custom and semicustom IC production. Substantial advancement in yields and level of service have been noted over the last year. Commercially viable products are increasingly evident in the many multiproject wafer and semicustom activities now under way throughout this industry. The infrastructure is rapidly evolving to provide CAD tools and other necessary support. GaAs foundries represent a valuable resource that can be used by electronic systems houses to maintain or regain leadership positions in their respective markets.

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Research Newsletter

GATA Code: Newsletters
1987-9

GaAs TEAMS, AGREEMENTS, PARTNERSHIPS, AND ACQUISITIONS

SUMMARY

A natural consequence of GaAs technology development in the United States is the increasing number of partnerships, agreements, mergers/acquisitions, joint ventures, and team efforts. This newsletter summarizes some of the major such actions in this industry.

MIMIC PROGRAM

The DOD MIMIC (millimeter-microwave IC) initiative represents a major effort to incorporate the advantages of compound semiconductors into a variety of military applications. These applications include:

- Ultrareliable radar for the U.S. Air Force ATF
- Shared-aperture radar for the U.S. Navy ATA
- MILSTAR network communications terminals
- Smart munitions
- Wideband jammers
- Antiradiation missiles
- Other "brilliant" weapons

The MIMIC program entered Phase 0 early in 1987 with the award of 12 major and 4 smaller contracts to prime contractors. Table 1 is a compilation of the responsible services, prime contractors,, approximate amounts of awards, and team members involved in the major Phase 0 contracts. Additional awards went to Hittite Microwave ($500,000), Ball Aerospace ($497,000), E-Systems ($100,000), and Loral ($100,000). Funding for the remainder of the seven-year program recently was estimated at more than $530 million. Dataquest believes that Phase I of MIMIC will see some realignment of the participants, as the program becomes more competitive and the number of teams decreases.

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Table 1

MIMIC PHASE 0

Service	Army			
Prime Contractor	Eaton	ITT	Martin Marietta	TRW
Award ($K)	886	995	986	1,000
Team Members:				
Adams Russell				
Aerojet				
Airtron (Litton)				
Alpha Industries			X	
AT&T				
Avantek				
Cascade			X	
Cominco				
Compact Software				
Consilium				
Cornell University				
EEsof			X	
General Dynamics				X
General Electric				
Harris			X	
Honeywell				X
Lockheed				
M/A-COM				
Magnavox				
Motorola				
Norden (United Technologies)				
Pacific Monolithics		X		
Rockwell				
Singer				
Spectrum			X	
Teledyne Ryan				
Texas Instruments			X	
TriQuint				
Varian				
Watkins-Johnson		X		

(Continued)

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Table 1 (Continued)

MIMIC PHASE 0

Service	Navy			
Prime Contractor	Bendix	Ford	Raytheon/TI	Sandecs
Award ($K)	751	1,000	999	981
Team Members:				
Adams Russell				X
Aerojet			X	
Airtron (Litton)			X	
Alpha Industries				
AT&T				
Avantek				
Cascade				
Cominco				
Compact Software			X	
Consilium			X	
Cornell University				
EEsof				
General Dynamics			X	
General Electric				
Harris				
Honeywell				
Lockheed				X
M/A-COM		X		
Magnavox			X	
Motorola				X
Norden (United Technologies)			X	
Pacific Monolithics	X	X		
Rockwell				
Singer		X		
Spectrum				
Teledyne Ryan			X	
Texas Instruments				
TriQuint	X	X		
Varian				X
Watkins-Johnson				

(Continued)

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Table 1 (Continued)

MIMIC PHASE 0

Service	Air Force			
Prime Contractor	Harris	Hughes	UNISYS	Westinghouse
Award ($K)	748	998	953	989
Team Members:				
Adams Russell				
Aerojet				
Airtron (Litton)				
Alpha Industries			X	
AT&T		X		
Avantek				X
Cascade				
Cominco				X
Compact Software				
Consilium				
Cornell University	X			
EEsof	X			X
General Dynamics				
General Electric	X	X		
Harris		X		
Honeywell				
Lockheed				
M/A-COM				
Magnavox				
Motorola				
Norden (United Technologies)				
Pacific Monolithics				
Rockwell				X
Singer				
Spectrum				
Teledyne Ryan				
Texas Instruments				
TriQuint	X		X	X
Varian			X	
Watkins-Johnson				

Source: Dataquest
August 1987

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Pacific Monolithics/TriQuint

TriQuint has performed well as Pacific Monolithics' primary foundry, supplying processed wafers to mutually acceptable specifications. Dataquest believes that this relationship led to some of the specific teaming on the DOD MIMIC program (see Table 1).

Pacific Monolithics/COMSAT LABS

In July 1987, Pacific Monolithics announced it had signed an exclusive agreement with COMSAT Laboratories of Clarksburg, Maryland, to develop and pursue products and markets for power and millimeter-wave MMICs, and to seek Phase I through III contracts under the DOD MIMIC program. Pacific will provide design and marketing skills; COMSAT will contribute 30-GHz MESFET foundry capability. The agreement is also intended as a vehicle for exploring additional business opportunities in monolithic and millimeter-wave devices.

Rockwell/IBM

Early in 1987, Rockwell International and IBM entered into an agreement for the cooperative development of high-speed digital and optoelectronic GaAs devices for future computers and telecommunications equipment. The program involves Rockwell's GaAs pilot line at Newbury Park, California; Rockwell development teams at Newbury Park and Thousand Oaks, California; and IBM development teams at East Fishkill, New York; and Yorktown Heights, New York. Dataquest believes that this agreement positions IBM to take a leadership role in GaAs digIC (digital integrated circuit) applications.

Cray/GigaBit

For about three years, Cray Research, Inc., has been working with GigaBit Logic, Inc., to develop a reliable source of GaAs devices for use in a Cray-3 computer. Early in 1987, Cray increased the amount of its order for GigaBit GaAs IC chips to be delivered in 1987 to $5.2 million. Dataquest believes that this agreement allows Cray to redirect its internal GaAs capability toward development of HEMT, E/D MESFET, or other high-speed technology. Cray Research participated in GigaBit Logic's round 3 financing in May 1987, along with Analog Devices, Inc., Digital Equipment Corporation, and others.

AMD/Vitesse

In 1986, AMD and Vitesse agreed to a technology exchange involving AMD's 2900 bit-slice family and Vitesse's E/D MESFET GaAs technology. The effort resulted in Vitesse's announcement of its 29G01, 29G10 and other GaAs bit-slice products late in 1986.

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GigaBit/Seattle Silicon

GigaBit and Seattle Silicon Corporation have developed a 4-bit ALU that is functionally equivalent to the 100181, a 100K ECL chip. Design engineering support was provided by the Washington Technology Center (WTC). The chip is 5.7 times faster than its silicon counterpart and consumes half the power.

GigaBit/Prisma Corporation

In July 1987, GigaBit and Prisma Corporation announced an agreement to produce a complete family of custom GaAs logic and memory digICs for use in Prisma's new family of real-time supercomputers. The machine architecture is based on a 32-bit RISC structure. Under the agreement, Prisma will design the ICs to GigaBit's newly released HME/D (high-margin enhancement/depletion) process, which is characterized by sub-100ps gate delays at power levels significantly lower than those of silicon ECL gates.

Ford/Vitesse

Ford Microelectronics, Colorado Springs, Colorado, and Vitesse Semiconductor Corporation, Camarillo, California, are establishing an E/D self-aligned gate GaAs IC alternate-source agreement and capability. Initially, the agreement includes custom and semicustom circuits, but it may be extended to standard products. Dataquest believes that Ford has successfully processed wafers containing gate array chips to mutually agreed-upon design rules.

Microwave Technology, Inc./Monolithic Microsystems, Inc.

In June 1987, Microwave Technology, Inc., Fremont, California, completed its acquisition of Monolithic Microsystems, Inc., of Santa Cruz, California. Under the agreement, Monolithic Microsystems will become a wholly owned subsidiary of Microwave Technology and will continue manufacturing at its present 8,200-square-foot facilities.

TRW/TriQuint

TRW Components International (a subsidiary of TRW, Inc.) and TriQuint have agreed to jointly supply GaAs devices for space applications. The companies are working together on procedures for producing Class S-level GaAs components. TriQuint will provide foundry support.

Ciba-Geigy/Spectra-Physics

In June 1987, it was reported that Ciba-Geigy had signed a definitive agreement to acquire Spectra-Physics for $266 million. A prior lawsuit seeking to enjoin Ciba-Geigy's initial (reportedly hostile) takeover offer

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was reported as being dismissed without prejudice by the Delaware Federal Court. Dataquest believes that this acquisition will strengthen Ciba-Geigy's ability to participate in the GaAs industry infrastructure.

California Micro Devices/Tachonics

A June 1987 announcement stated that California Micro Devices, Milpitas, California, has formed an alliance with Tachonics, Plainsboro, New Jersey, to produce a family of GaAs ASICs for military applications. Tachonics is a subsidiary of Grumman Aerospace Corporation of Bethpage, New York.

Amoco/Spectra Diode/Kodak/Litton Airtron

Amoco Laser Company, a wholly owned subsidiary of Amoco Corporation, has formed a strategic alliance with Eastman Kodak, the Airtron Division of Litton Industries, and Spectra Diode Labs to support Amoco's laser systems product line. Kodak provides production support, Litton Airtron supplies wafers, and Spectra Diode makes the semiconductor lasers. Amoco intends to use this alliance to pursue communications, projection TV, reprography, and other commercial and military applications.

Thorne-EMI/Varian

TEV is a United Kingdom-based joint venture of Thorne-EMI Electronics (United Kingdom) and Varian Associates (United States). The company supplies tubes for broadband EW and expendables for military applications. TEV also is developing 70 to 80mW 90-GHz oscillators for missile-seeking mortars (smart munitions). The company is focusing on applications in earth resources satellites and SARs (synthetic aperture radars).

DATAQUEST CONCLUSIONS

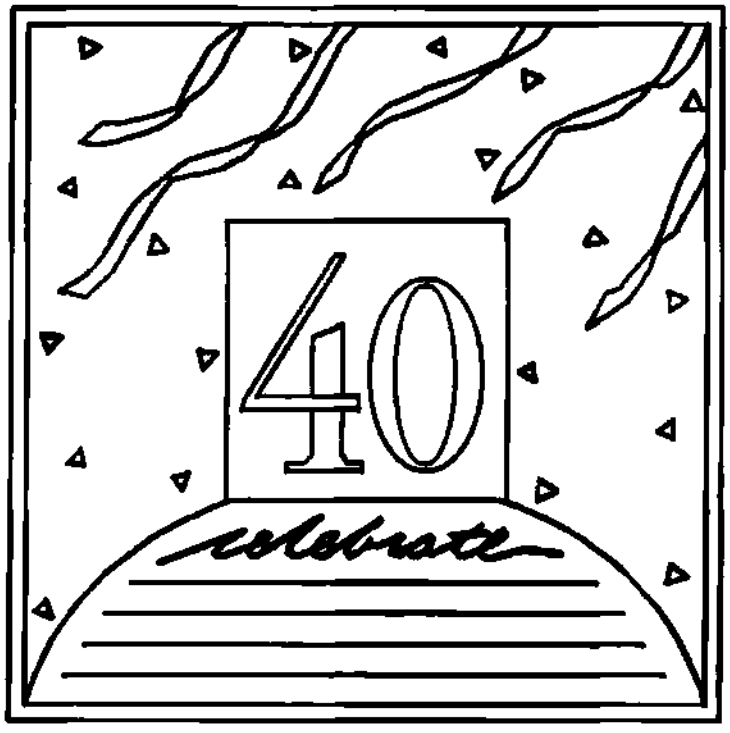
The interaction of GaAs industry participants is intensifying as this industry moves ahead, with national objectives as much a part of the scenario as they were in the silicon world 15 years ago. Interestingly, the majority of large computer houses have remained silent about their GaAs technology plans. The commercial marketplace now has IBM to consider, and one has to wonder how long IBM's competitors have left to refine their strategies and to take viable positions, either with GaAs merchant suppliers or by acquisition, or both.

Gene Miles

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Mark your calendars now!

Semiconductors' Midlife Crisis



1987 Semiconductor Industry Conference

October 18–21
The Pointe at Squaw Peak
Phoenix, Arizona

To register, please call Dataquest's Conference Department at (408) 971-9000, extension 245.

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Research *Newsletter*

GATA Code: Newsletters
1987–10

ANOTHER APPLICATION FOR GALLIUM ARSENIDE: LOW–COST COLLISION–AVOIDANCE RADAR

SUMMARY

Low–cost collision–avoidance radar, a new application for gallium arsenide semiconductors, can significantly improve motor vehicle safety. One company, Vehicle Radar Safety Systems, Inc., is already producing a $900 unit, and development activity among other companies and major auto makers is intense.

We expect widespread use of this equipment on passenger automobiles by the mid– to late 1990s. We believe that this will create a high–frequency GaAs circuits market that will exceed today's military market.

This is another example of a new application for gallium arsenide that is emerging as designers become familiar with the unique properties of the material. Gallium arsenide devices originally were developed for high–speed supercomputing applications, but now designers are realizing that these devices can also be used for high–temperature, radiation hard, and ultrahigh frequency applications.

BACKGROUND

More than two years ago, companies such as Pacific Monolithics developed low–cost (less than $10) GaAs ICs for satellite downconverters in TVRO applications. This and similar efforts in discrete GaAs have resulted in production–worthy GaAs chips, which in turn have made possible low–cost Doppler radar units. By adding a nominal amount of DSP hardware, such units can provide collision–danger warning signals to the driver of an automobile or other vehicle. Functions such as a Gunn diode oscillator, power amplifier, mixer, receiver low–noise amplifier (LNA), filters and, if required, an A/D converter, are easily implemented with GaAs. Other functions in the unit, including DSP, can be built with silicon devices as can the filters and A/D converter (depending on operating frequency).

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DEVELOPMENT PROJECTS

The following paragraphs discuss the current collision–avoidance projects.

Battelle

Battelle has recently developed a millimeter–wave radar concept for vehicle collision–avoidance systems. The proposed system operates at a frequency between 35 and 95 GHz, has a beam–steerable antenna, uses FM/CW (frequency modulated, continuous wave) Doppler radar circuitry, and requires a 10Mb/second computer for DSP. Battelle estimates the prototype funding requirement at approximately $750,000.

Daimler–Benz

The European Prometheus project, launched in 1986 by Daimler–Benz, includes development of a collision–avoidance system. A spokesman for Daimler–Benz estimates that the Prometheus system could reduce European traffic casualties by a factor of two within 15 years. The project involves more than 15 European auto producers and at least 50 research organizations throughout Europe.

Nissan

Nissan Motor Corp. is developing a system using two pulse–Doppler transceivers and an on–board computer to detect danger conditions ahead. Progressive audible alarms will alert the driver as conditions change.

Ford

In the United States, the Ford Motor Company and GM/Hughes are working on collision–avoidance systems for vehicles. These companies had not announced availability dates for any such products as of press time.

DATAQUEST CONCLUSIONS

GaAs semiconductors have unique properties that lend themselves to heretofore unrealized applications. Automotive collision–avoidance radar is a prime illustration of innovation made possible by GaAs technology. Other examples are:

- Fiber–optic transceivers
- High–speed, high–resolution color–graphics mux/demux functions
- The Cray–3 supercomputer

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- Multi-GHz satellite communications links
- Hall-effect sensors for automotive brakes and other high-temperature environments
- Low-cost TVRO chips

Dataquest believes that the semiconductor industry has an exciting opportunity for growth in the emerging market for vehicular collision-avoidance radar. A major contribution to highway and street safety can be made by those manufacturers that excel in this marketplace.

Gene Miles

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Research Newsletter

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GOMAC-87: "CHALLENGES FACING GOVERNMENT ELECTRONICS IN THE 1990s"

The 1987 Government Microcircuits Applications (GOMAC) conference was held in Orlando, Florida, on October 27 through 29, 1987. Approximately 1,000 attendees participated in 21 sessions on subjects ranging from IC design concepts to discontinued parts. Due to time constraints, parallel sessions were held, up to four at a time, making it necessary for those involved in defense programs to split up their delegations in order to attend as many sessions as possible. Exhibits of products, services, and capabilities of more than 30 companies were on display in an area adjoining the lecture halls. This newsletter discusses some highlights of this important conference.

VHSIC INSERTION

Progress in VHSIC insertion was reported by most of the participating companies. Many of the exhibits featured examples of VHSIC chips and their application to defense electronics systems. The presentations indicate that VHSIC technology has been applied to a wide range of hardware including ruggedized computers, imaging systems, digital signal processing (DSP) functions, and radar electronics.

SIGNAL PROCESSING

Applications of silicon or Si/GaAs IC technology to signal processing problems have been accomplished by numerous defense electronics suppliers. For example, TRW described its superchip family and presented data on its high-performance 6-bit analog-to-digital converter (ADC). The TRW ADC uses a GaAs front end to drive a silicon bipolar flash quantizer.

Bipolar Integrated Technology, Inc. (Beaverton, Oregon), presented a family of integer and floating-point DSP circuits based on its 2.0 silicon bipolar process. The company claims that the process offers the higher speeds of ECL at the VLSI functional density of CMOS.

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VTC (Bloomington, Minnesota) has developed a bipolar cell library of analog/digital cells for signal processing applications. The bipolar structures use complementary transistors with f_T of 6 GHz (NPNs) and 1 GHz (PNPs). The cell library is augmented with components for use in customization.

MIL-STD-1750A

Performance Semiconductor presented and displayed information on its 40-MHz VHSIC-class PACE 1750A system. The system is a CMOS three-chip set consisting of a central processor unit, a processor interface chip, and a memory management unit/combination support chip. The set provides system performance greater than 2 mips. Performance Semiconductor supports its PACE 1750A with a product line consisting of the world's fastest CMOS SRAMs, with chip densities ranging through 256Kx1.

Other companies presenting information on 1750A architectures and products included Allied Signal, General Electric, IBM, Loral, Texas Instruments, TRW, and UTMC.

GaAs SEMICONDUCTORS

GaAs has been applied to high-performance military electronics for several reasons, among which are frequency response and speed superior to silicon, and inherent radiation hardness. General Electric described innovations in using GaAs to implement radar transmit/receive modules.

Several companies, including AT&T, GAIN Electronics, Raytheon, TriQuint, and TRW, made presentations or displayed information about their progress in developing and producing GaAs ICs. AT&T is offering a 1-GHz divide-by-128/129 prescaler, the DG1096AX. The circuit is fabricated using GaAs E/D MESFET process and comes in 8-lead flatpack or DIP. The chip consumes less than 40mW and has TTL/MOS-compatible I/Os.

GAIN Electronics Corporation is marketing a family of gate arrays including its GFL6000. This product is a 5,776-gate array with 204 I/O buffers, 3W maximum power dissipation, and unloaded gate delays of 100ps. I/Os may be CMOS-, TTL-, or ECL-compatible. Package options include chip carriers and pin-grid arrays. The company is processing production orders for its gate arrays.

Raytheon offers GaAs IMPATT diodes for selected applications. The devices are specified to 60-GHz frequency and 10W output power, and to 44-GHz and 25W output. The devices are produced at the research division in Lexington, Massachusetts.

TriQuint is producing a 3,000-gate ASIC array called the TQ3000, which has 1,020 core cells and 64 I/Os. NRE charges are $80,000 including design manual and workstation software. The ASIC is supported by Daisy, Mentor, and Tek/CAE workstations.

TRW is developing microwave and millimeter wave ICs for communications and other defense applications. TRW, Honeywell, and General Dynamics compose one of the DOD teams developing this technology; TRW is the prime contractor for this team.

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RELIABILITY AND FAULT TOLERANCE

The United States Air Force has launched a program called R&M 2000. In implementing this program, the Air Force Systems Command is challenging the electronics industry with specific goals, such as "double-R, half-M" (double the reliability and half the maintenance) and 2,000-hour MTBF for line-replaceable units (LRUs), to be met by defense contractors.

TRW summarized the historical development of fault diagnosis and presented fault-tolerant methodologies that lend themselves to present-day design activities. The discussion emphasized the need for increased focus on fault-tolerance in future designs.

Fault-tolerant software was the subject of a joint paper by Westinghouse, SRI International, and NASA. The authors described a distributed general-purpose, fault-tolerant operating system for use on VHSIC 1750A processors.

Intel reported close work between its Military Operation (Chandler, Arizona) and one of its major accounts to significantly reduce incoming VLSI reject rates. The company said it plans to extend the approach to other customers.

Lockheed described a design methodology for extending traditional fault-tolerant design techniques to analog functions. Included are techniques for self-test, self-diagnosis, and self-correction, previously used only in digital circuit design.

TESTABILITY

Honeywell made two presentations on VHSIC testability and maintainability. The first described a control function block to be included on-chip. The second described a standard design methodology for producing inherently testable systems on a consistent basis.

Teradyne has developed a tester calibration architecture for VHSIC modules. The company says the system calibration allows maintaining a maximum of ±1.5ns skew at 40-MHz frequency across more than 400 pins.

Silicon Compiler Systems described the growing importance of integrating test development into the design process. The company's exhibit included a demonstration of its automatic test generation (ATG) system.

A joint presentation was made by VTC, Inc., and Control Data Corporation describing a rad-hard standard cell testability structure. Other companies presenting information on testability included Mitre, Unisys, and UTMC.

RADIATION HARDNESS

Two of the GOMAC sessions and more than a dozen papers were devoted to radiation hardness. LockHeed, M/A-COM, Motorola, VTC, and others made presentations on this subject.

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The UTMC exhibit included information on its UTB–R and UTD–R rad–hard gate array families and other rad–hard products. The UTMC products are designed to withstand these levels of radiation:

- Data sheet specification operation to $2x10^5$ rads (Si) total dose
- Functional to 10^6 rads (Si) total dose
- No upset of less than 10^9 rads (Si)/s dose rate
- Dose rate latch–up $>10^{10}$ rads (Si)/s
- Neutron fluency 10^{14} N/cm

DISCONTINUED PARTS

The life cycles of many commercial IC devices and families are shorter than those of most military electronics equipment. As the rate of technological change increases, discontinued parts generate a growing set of problems to defense contractors. Four organizations made presentations of methods useful in resolving some of these problems.

Honeywell, for example, has developed a replacement for many of the (DTL) functions that are no longer procurable. The replacement device is a 16–pin bipolar generic array. Another company, SAIC, has worked with DESC on an R&D program to develop TTL, LSTTL, ECL, linear, and other emulation devices for fabrication on a bipolar baseline process at a silicon foundry.

PACKAGING AND INTERCONNECTION

Kyocera Corporation, Kyoto, Japan, displayed state–of–the–art packages at its exhibit. The company claims world leadership in technical ceramics. One of the more exotic of Kyocera's products was a 1,700–pin grid array (PGA) of approximately 15–square inches.

Kyocera has steadily increased its account penetration in the United States and is a leading supplier to VHSIC chip houses. This raises an interesting issue regarding DOD's dependence on foreign suppliers.

Dow Corning Corporation has developed materials for implementing a novel hermetic package concept for improved chip reliability. The approach is called surface protected electronic circuits (SPEC) and involves applying multiple layers of polymeric materials directly to the circuits.

Honeywell discussed a package design that may in many instances solve the problem of having to tool separate packages to accommodate various chip designs and multiple chip suppliers. A joint paper by Interamics and Texas Instruments described a package development to support multiple VHSIC chips in a single ceramic module.

DATAQUEST CONCLUSIONS

Although much progress has been made in semiconductors for military applications, major challenges remain. The R&M 2000 initiative, requiring doubling of MTBFs and halving maintenance, is but one example.

Although great strides are being taken in domestic chip technology, it appears that the U.S. defense industry still relies heavily on a sole foreign source for large-volume production of IC packages. This is not new; the situation has existed for several years. Two questions remain:

- Is reliance on non-United States-based sources of electronic parts really a high-priority matter?
- If so, who in the industry or in Washington is responsible for working on the packaging issue, and what is the timetable for resolution?

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Research Newsletter

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ASIAN GaAs ACTIVITIES IN 1988

SUMMARY

A recent Dataquest research study examined Asian activities in GaAs and related compound semiconductors in 1988. This newsletter summarizes the results of that study, and examines materials developments, product R&D, applications, and related business activities. Where relevant, space and defense electronics developments are included to add perspective. The study confirmed the increasing pervasiveness of Asian III–V semiconductors into electronics systems. Examples of this pervasiveness include the development by Japanese companies of GaAs ICs and other compound semiconductors for use in VCR/VTR equipment and for fiber–to–home applications.

1988 CHRONOLOGY AND DISCUSSION

The major GaAs and related activities by Asian companies, universities, and other organizations are described by month in the following paragraphs.

January

China's Ministry of Posts and Telecommunications and other agencies are giving strong government support to III–V semiconductor and fiber–optic developments. China's goals are to produce 1,300nm and 1,550nm OEICs using InP and GaAs, with lifetimes of 100,000 hours or more.

Japan's Defense Institute is studying eutectic alloys of GaSb and CrSb grown by the Tammann–Bridgman process; the application was not disclosed. Japan's fiscal 1988 military budget is the first since 1945 to exceed 1 percent of the country's gross national product. The $28.5 billion budget is expected to benefit Mitsubishi, NEC, Toshiba, and others with increased orders for military–range ICs and systems.

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February

Japan's new cruise missiles are using IR image homing and related electronics systems. The Japan Defense Agency plans call for the purchase of 54 launchers and an undisclosed number of missile systems by 1990. Fujitsu is increasing its share of this electronic warfare (EW) business by supplying infrared (IR) seeker electronics jointly with NEC for Kawasaki antitank missile systems.

The Japan Manufacturers' Society of Compound Materials reported Japanese production of III–V wafers in 1987 at ¥20 billion ($157 million). The society predicted 20 percent growth in 1988.

March

Sanyo Electric Company Ltd. announced development of a 0.5–micron gate–length, 12–GHz HEMT by using a g–line stepper, MBE, and ECR plasma CVD. The chip was marketed in Japan starting in April 1988.

DSP chips were among those described by Japanese companies at the recent ISSCC. Although the chips are based on silicon CMOS processes, they are indicators of the desired complexities sought by the manufacturers, all of whom have GaAs process capability.

The Optoelectronic Industry & Technology Development Association of Japan reported that production of the domestic opto industry in 1987 reached ¥1,233 billion ($9.6 billion), up 18 percent over fiscal year 1986 and consisting of the following:

- Optoelectronic components, including lasers and optical fibers—¥371 billion ($2.9 billion) (component ratio 30 percent)
- Optoelectronic equipment, including optical disks—¥707 billion ($5.5 billion) (component ratio 57 percent)
- Optoapplication systems, including optocommunications systems—¥154 billion ($1.2 billion) (component ratio 13 percent)

April

China's drive to become a superpower in the early 21st century involves a mix of geopolitical and commercial goals, including weapons exports. Collaborations with Israel on tank and jet fighter radars, and with Brazil on rocket and satellite technology, are expected to result in a growing demand by China for military ICs. China placed a communication satellite in a geosynchronous orbit earlier this year.

May

Sony reported a GaInAs–based HET (hot electron transistor) design, planned for use in ultrahigh–frequency applications. The chip structure consists of GaInAs and GaAs layers on a GaAs substrate.

Toyota Central R&D Labs has made studies of GaAs/AlGaAs double quantum well heterostructures, which were built using MBE. The hot-electron properties of test devices were evaluated and reported.

June

Hitachi Central Research Labs and Device Development Center developed a buried p-layer structure to enhance immunity of its 1K GaAs SRAM design to soft errors induced by alpha particles. The approach may also lead to much higher levels of integration of GaAs IC designs.

NTT recently reported analysis of the electron velocity overshoot in HBTs. The company expects to use HBTs to achieve operation up to 100 GHz.

Mitsubishi's LSI R&D Laboratory built and tested GaAs HEMTs using 0.25u geometries with beryllium and silicon ion implantation to achieve a 0.68dB noise figure at 12 GHz. The noise figure is below 0.85dB at 18 GHz.

Sharp Corporation increased production of 5.6mm lasers to 1.2 million units per month in June and 1.5 million units per month by year-end to meet the demand for smaller, thinner chips for CD and video disk players.

July

Between 1966 and 1976, the cultural revolution in China halted progress in science and technology; the average age of China's technologists is now 50. China's Research Center for Strategies in Development of Space Technology (under the Commissar of Science, Technology, and Industry for Defense) will lower the age to 40 by the year 2000.

Kokusai Denshin Denwa Co. Ltd.(KDD) ran reliability studies of the Ge APD detectors, InGaAsP/InP lasers, and Si ICs used in repeaters for the KDD OS-280M cable system. The OS-280M will be used in TPC-3, a 9,000km optical submarine cable connecting Japan, Guam, and Hawaii. The ICs met the required failure rate of more than $0.2/10^9$ hours at 45°C T_j at 60 percent confidence. NTT and Fujitsu helped in the tests.

At least four Japanese manufacturers now supply diode lasers for LANs and other fiber-optic communications applications, as shown in Table 1.

Korea's ERTI (Electronics and Telecommunications Research Institute) has purchased a model 450 MOCVD system manufactured by Spire Corporation of Bedford, Massachusetts, for use in developing InGaAs and InGaAs OEICs.

Fujitsu increased its prime military contracts to $187 million in 1987 and booked $32 million more in military subcontracts, moving from thirteenth to eighth place among Japanese defense houses. This includes $100 million for an EW evaluation system. Electronics comprises at least 30 percent of the other contracts, according to Tadaski Takeshima, Fujitsu's deputy GM of defense systems.

Mitsubishi won more than $1 billion in defense procurements in 1987. The company has at least a 70 percent share of the electronic warfare market in Japan, according to Takeshi Abe, deputy GM of Mitsubishi's EP&SG.

Table 1

Japanese Laser Diode Products

Company	Laser Wavelength (nm)	Mode	Package	Comments
Fujitsu	1,300, 1,550	SM	DIP	Developing modules
Hitachi	1,200, 1,300, 1,550	SM, MM	DIP	DFB laser in development
Mitsubishi	1,300	SM, MM	DIP,TO	DFB available
NEC	1,200, 1,300, 1,550	SM, MM	DIP	DFB in development

Note: DIP = dual in-line package, TO = transistor header, SM = single mode, MM = multimode.

Source: Dataquest
December 1988

August

Sumitomo is mass-producing higher-quality, lower-cost 3-inch GaAs wafers, which should result in price decreases. The reductions result from longer boules (yielding 150 wafers each), improved growth-chamber thermal environment, computerized automatic boule diameter control, optimized annealing conditions, and reduced qualification test costs. Sumitomo has improved its vapor-phase epitaxy (VPE) process using new reactor tubes. Reactor gas flow and thermal properties were refined according to computer simulation of the VPE process. These changes should result in major price reductions of Sumitomo epi wafers.

Matsushita has developed InGaAsP/InP multiple quantum well (MQW) planar buried heterostructure (PBH) lasers, using MOCVD process. These lasers have threshold current of 35mA and quantum efficiency of 45 percent.

Japan will spend $7.5 billion on its FSX, a U.S. Air Force F-16 derivative. Deployment is expected by 1997. As many as 170 FSXs are on order. Japan intends to use stealth technology on the FSX. Mitsubishi is the prime contractor and other domestic partners have developed advanced radar, head-up displays, and other avionics for the Japanese Defense Agency's Technical R&D Institute. They do not want U.S. companies to obtain this technology. Traditionally, Japan awards such contracts, including funds for military range ICs, to domestic suppliers.

Researchers at NTT's Applied Electronics Laboratory determined that etch-pit density (EPD) of GaAs-on-Si can be significantly reduced by combining growth interrupt and thermal cycling (in situ TC) with the growth of InGaAs/GaAs superlattices. NTT achieved EPD of $1.4 \times 10^6/cm^2$ in 3.5u GaAs epilayers with this approach. It represented a major gain over the company's prior results.

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Japanese companies now marketing GaAs digital ICs (digICs) into the United States include Fujitsu, NEC, and Oki. Fujitsu offers a family of ECL-compatible chips that operate to 6.5 GHz. Oki's products include multiplexers and demultiplexers. NEC, which markets its GaAs products in the United States through California Eastern Labs, has an extensive set of SSI and MSI chips that includes gates, flip-flops, counters, mux/demuxes, and laser drivers.

The major electronics companies and universities in Japan reported results of their R&D activities in GaAs and related materials at the GaAs Materials Conference in Atlanta, Georgia. This information is summarized in Table 2.

Table 2

Recent GaAs Materials Research in Japan

Company	Location	Area(s) of Research
ATR Res Labs	Osaka	Si-doped GaAs
Fujitsu Labs	Atsugi	MOVPE heterostructures, MBE HEMTs, InGaAsP/InP quantum wells
Furukawa Elec. Co. Ltd.	Yokohama	4-in. MLEC GaAs crystal growth
Hitachi Ltd.	Tokyo	Monolayer heterointerfaces
Matsushita Ltd.	Osaka	WSi-gate MESFETs, LDD SiF_3-implanted FETs, MQW integrated laser arrays
Mitsubishi Elec. Corp.	Hyogo	Transverse-junction-stripe (TJS) lasers for OEICs, AlGaAs-on-Si LEDs
NEC	Kanagawa	High-vacuum MBE, AlN-encapsulated GaAs for ion implantation, monolayer epi
NHK	Tokyo	Si-doped GaAs
NTT	Tokyo	FME-grown AlGaAs/GaAs (modified MOCVD)
NTT	Kanagawa	Co-implanted P and Si for improved GaAs LSI yields
Oki Elec. Ind. Co. Ltd.	Tokyo	GaAs-on-Si growth by MOCVD
Sony Corp. Res. Ctr.	Yokohama	AlGaAsP lasers, Si-implanted GaAs
Sumitomo	Yokohama	OMVPE growth of GaInAs on InP
Toshiba Corp.	Kawasaki	30GHz InP power D-MISFETs

University	Location	Area(s) of Research
Hokkaido Univ.	Sapporo	Si-implanted GaAs
Kyoto Univ.	Kyoto	AlGaSb structures
Nippon Inst. of Tech.	Saitama	MBE growth of AlGaAs-on-GaAs, GaAs-on-Si
Tohoku Univ.	Sendai	InSb epi on GaAs
Tokyo Inst. of Tech.	Tokyo	MOMBE growth of C-doped p-GaAs
Tokyo Inst. of Tech.	Yokohama	AlGaSb structures
Univ. of Tokyo	Tokyo	Novel quantum well devices, GaAs-on-Si growth by MOCVD, Er-doped GaAs and InP

Source: Aztek Associates

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Hitachi demonstrated a 3-band (VHF/CATV/UHF) GaAs IC tuner for TV/VCR receivers. This project integrates a mixer, oscillators, and IF amplifier, decreasing the size and improving noise properties of the tuner circuit while reducing parts count by 30 percent.

October

Matsushita's Discrete Device Division in Kyoto and R&D Laboratory in Osaka reported developing a GaAs RF amplifier IC for UHF TV/VTR tuner applications in a 6-pin plastic package. The chip reduces the size of the amplifier in the RF tuner by a factor of two and reduces the cost.

NTT achieved 12dB gain with 8.5-GHz bandwidth in an amplifier design using AlGaAs/GaAs ballistic collection transistors (BCTs). NTT has built a CaF_2-gate GaAs MISFET also. CaF_2 deposited by MBE has thickness accuracy of a few monolayers and virtually no contamination.

November

Mitsubishi built a 1Kx4, 7ns GaAs SRAM, which dissipates 850mW using a 1.6V supply. The process was 1.0-micron gate-length E/D DCFL; reported wafer sort yield was 22 percent. Oki described its 1.2-GHz 256-bit GaAs shift register for signal storage applications, and Toshiba reported a 2-GHz 128-bit shift register using 0.5u tungsten-nitride-gate MESFETs.

December

In 1987, six Japanese companies were among the world's top 100 defense electronics suppliers, with two or more of these outranking Motorola, Hewlett-Packard, AT&T, M/A-COM, Zenith, Control Data Corporation, Digital Equipment Corporation, and other major U.S. companies. All six of the Japanese companies have significant GaAs IC and silicon IC capabilities in-house, while many top U.S. suppliers do not. Table 3 presents 1987 performance information on these six companies.

Table 3

Japanese Defense Electronics Company Performance in 1987

Top 100 Rank	Company Name	1987 Def. Elec. Sales ($M)	1987 Total Sales ($M)	Share of Total 1987 Company Sales
34th	Mitsubishi	715	19,321	3.7%
36th	Toshiba	602	30,083	2.0%
42nd	NEC	504	22,915	2.2%
72nd	Fujitsu	183	16,617	1.1%
84th	Oki	136	3,686	3.7%
95th	Hitachi	93	46,281	0.2%

Source: Defense Electronics

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Hiroshima University and Matsushita physicists used hydrogen plasma to lower the temperature of cleaning GaAs wafers to 200 to 300°C, as compared with 700 to 1,000°C for previous processes. This allows the MOMBE growth of GaAs–on–Si at 400°C using triethyl gallium (TEGa) and triethyl arsenic (TEAs) without inducing thermal cracking. This development is expected to lead to the 3–D integration of III–V opto devices with silicon VLSI.

DATAQUEST CONCLUSIONS

Asian activities in III–V compound semiconductors are predominantly driven by Japanese efforts to penetrate new markets. The results to date reflect the level and degree of national attention provided by MITI's Optoelectronic Initiative and other initiatives introduced several years ago. Dataquest believes that these programs are starting to pay off, as evidenced by product introductions by almost all of the Japanese companies involved during 1988. We expect more of the same in 1989, as well as more InP–based chips.

We believe that Korea and China will assume increasingly more important roles in compound semiconductor technology in the 1990s. Korea will focus initially on such applications as consumer and automotive electronics, whereas China will continue its push in telecommunications–related device development.

Gene Miles

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Research Newsletter

1989 ASIAN ACTIVITIES IN GaAs TECHNOLOGY

INTRODUCTION

This newsletter summarizes many of the Asian government, company, and university activities in GaAs and related compound semiconductor technologies reported during 1989. The items are described chronologically as received by Dataquest.

THE YEAR IN REVIEW

January

A study supported by the National Science Council of the Republic of China (ROC) resulted in successful growth of GaInP/GaAs on silicon substrates. The buffer layer of GaAs was grown by low-pressure MOCVD. The work is under way at National Sun Yat-Sen University, Kaohsiung, Taiwan, ROC. Another National Science Council study is directed toward modeling and demonstrating hot-electron effects in heterostructure bipolar transistors (DHBTs). This work was performed at National Taiwan University, Taipei, Taiwan, ROC.

Fujitsu has fabricated lateral-current-injection multiple-quantum-well (MQW) lasers using zinc- and silicon-induced disordering of AlGaAs/GaAs QWs. The company achieved differential quantum efficiency of 18 percent per facet (pulsed) at room temperature. Fujitsu expects to develop OEICs incorporating the new structure.

February

NTT researchers have developed GaAs-on-silicon (GaAs-on-Si) solar cells for use in satellite power generators on Japanese satellites to be launched in the 1990s. The approach uses a sandwich of alternating InGaAs and AlGaAs layers to provide relief of the stress caused by the 4 percent lattice mismatch of GaAs atoms and silicon atoms. GaAs-on-Si offers a 50 percent weight reduction compared with the use of GaAs-only wafers.

Varian's new equipment facility in Ansan City, South Korea, will assemble and test ion implanters and other plant equipment for semiconductor makers such as Daewoo, Goldstar, Hyundai, and Samsung—all multibillion-dollar companies producing compound semiconductors. The new plant strengthens Korea's infrastructure for making state-of-the-art GaAs ICs, which use all-implant processing (eliminating the diffusion steps).

Oki Electric started sampling the KGL-4101, a GaAs 256-bit shift register. Initial pricing is ¥40,000 ($320) for the 1.2-GHz version. The company initially is pursuing the instrumentation market with this device.

Japan's fiscal 1989 defense budget will grow 5.9 percent to $30.9 billion, marking the third annual increase of nearly 6.0 percent and the second year it has exceeded 1.0 percent of the country's GNP. Included are $3.2 billion for the purchase of 109 aircraft and unspecified amounts for military ICs and other electronics. Beneficiaries include Fuji, Kawasaki, Mitsubishi, and other major Japanese companies.

Oki Electric's Compound Semiconductor Devices Center reported test results for a new version of its superluminescent diode (SLD) laser, made of alternating GaInAsP and InP layers on an InP substrate. The laser generated 1mW coupled power at 150mA and 1.3-micron continuous-wave (CW) operation. Oki began developing such devices before 1985.

Mitsubishi is also developing 1.3-micron GaInAsP/InP lasers. The company has operated a low-threshold CW device at current levels of 3.1mA at 1mW output. The fabrication process is a hybrid MOCVD/LPE approach. Mitsubishi found that negative differential resistance (tunneling) was

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induced by the diffusion of the impurities Zn and Te into the GaInAsP layer.

Fujitsu reported that it is the first to integrate AlInAs/GaInAs high-electron mobility transistor (HEMT) and InP/GaInAs PIN photodiodes on a monolithic die. The company is developing this technology for use in optical networks for video database, CATV, and related applications.

Engineers at Fujitsu Laboratories have fabricated OR/NOR gates, D-type flip-flops (FFs), and toggle FFs using a 0.6-micron gate-length GaAs MESFET process. The OR/NOR gates exhibited 45/35ps rise/fall times, and the FFs operated at 8-GHz divide rate. Cutoff frequency for the MESFETs is 47 GHz. Fujitsu is developing the chips for digital optical transmission systems.

Fujitsu Laboratories Ltd., Atsugi, Japan, has built and successfully characterized GaAs HEMTs using a quarter-micron gate-length MBE process. Drain current/voltage measurements at 77°K indicate the formation of transverse domains due to intervalley electron transfer. A WSi/Ti/Pt/Au gate was used to minimize noise. Cutoff frequency of 61 GHz was achieved.

NEC's Optoelectronics Research Laboratories has fabricated a device that it believes will have much the same impact on optoelectronic ICs as the 1K NMOS DRAM had on electronic ICs. The 32x32 array is fabricated on a $1mm^2$ die using a superlattice of alternating layers of GaAs and AlGaAs on a GaAs substrate. The light power required for element switching is 2.6 microwatts. The pnpn structure allows data retention time of 10 microseconds without refresh. The OEIC meets NEC's minimum requirements for use in optical computer systems developments.

March

Asian university activities in compound semiconductor research have intensified. Table 1 shows examples of recent studies in this technology.

April

Engineers at Kyoto University, Kyoto, Japan, analyzed results of wafer-containing AlGaInP lasers in a dual-purpose effort to fabricate short-wavelength visible lasers and to evolve a process for higher-speed optical logic circuits. The group's MOMBE growth tests defined the conditions under which InP defects and phosphorus evaporation can be controlled.

The Tsukuba Research Laboratory of Nippon Sheet Glass Company Ltd. is studying methods for growing high-quality zinc selenide (ZnSe) homoepitaxial layers on ZnSe substrates using MOVPE processing. This approach eliminates the 7 percent mismatch-induced defects experienced when using GaAs as the substrate and can be used to produce blue LEDs.

Under a grant from Japan's Ministry of Education, Science, and Culture (MESC), scientists at Shizuoka University in Hamamatsu, Japan, are studying ZnTe-ZnSe superlattices as candidates for blue LEDs. The layers are grown by hot-wall epitaxy (HWE) on GaAs substrates. This work is classified as "Scientific Research in Priority Areas."

For several months, Oki Electric Industry Company has been increasing its level of investment in AlGaAs laser diodes for applications in erasable optical recording systems, laser printers, and telecommunications. The company is now moving from pilot production to volume production of 830nm wavelength (±10nm) AlGaAs lasers having 45mA threshold current, 190mW maximum power, 10 to 30 degrees beam divergence, and 67 percent external differential quantum efficiency.

AT&T and Japan's Kokusai Denshin Denwa (KDD) began operating the Pacific Link, the first submarine fiber-optic cable to span the Pacific Ocean, in April. The link, which has compound semiconductor repeaters buried in the cable, can handle 40,000 simultaneous telephone calls.

May

Sumitomo Heavy Industries is offering to purchase all of the outstanding shares of Lumonics Inc. of Kanata, Ontario, Canada, for $7.75 per share. This acquisition will provide Sumitomo with industrial laser capability for such operations as semiconductor-manufacturing robotics. The companies have been collaborating for more than a year in selling laser systems to the Japanese materials processing market.

NTT reported that it has successfully operated a 1.8-Gbps fiber link with repeater spacing of 127 miles. This development is expected to lead to major cost savings in long-haul transmission systems.

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TABLE 1
Recent Asian University Research in Compound Semiconductors

Institution	Location	Topic(s)
Academy Sinica	Beijing, China	LPE growth of GaAs; defect studies of bulk GaAs crystals
Birla Institute of Technology	Mesra, India	GaInAs/InP superlattice photodiodes
Burdwan University	West Bengal, India	Refractive index studies of III-V and II-VI semiconductor alloys
Calcutta University	Calcutta, India	Magnetic field effects on GaAs devices; GaAs and GaInAs QWs
Chung Shan Institute	Lung-Tan, Taiwan	Defect studies of MBE-grown GaAs epi layers
Institute for Physical and Chemical Research	Wako, Japan	Analysis of MOVPE-grown GaAs
Kurume University	Kurume, Japan	Studies of Cd-doped InSe crystals grown by Bridgman process
Meiji University	Kawasaki, Japan	AlGaAs/GaAs heterostructure MESFETs
Nagoya Institute of Technology	Nagoya, Japan	Thermal annealing of GaAs wafers
National Sun Yat-Sen University	Kaohsiung, Taiwan	LP MOCVD growth of InP-on-Si
Osaka University	Suita, Japan	Analysis of GaAs IMPATT diodes; recrystallization in MBE GaAs
Sardar Patel University	Gujarat, India	Growth of InSe thin films
Shizuoka University	Hamamatsu, Japan	Annealing and doping effects in MOVPE-grown GaAs epitaxial layers
Toyohashi University	Toyohashi, Japan	InN growth by microwave-excited MOVPE
Tsinghua University	Beijing, China	AlGaAs/GaAs heterojunction phototransistors (HPTs)
University of Tokyo	Tokyo, Japan	Studies of GaAs absorption of TMGa; rare-earth diffusion into InP and GaAs wafers

Source: Aztec Associates

NTT's Optoelectronics Laboratories of Kanagawa, Japan, have fabricated devices called MQW etalons, which have the property of optical bistability at room temperature. The devices consist of 99 alternating layers of InGaAs and InAlAs grown by MBE on InP substrates. NTT expects to use the devices in future optically controlled communications systems.

June

Scientists at Tohoku University in Sendai, Japan, have formed InAs layers by plasma-assisted epitaxy on GaAs, InP, and GaSb wafers to increase the integration level above discrete chips for optical applications. The work is sponsored and supported by Japan's MESC.

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Fujitsu Laboratories in Atsugi, Japan, is studying 10nm, 20-period InGaAsP/InP quantum wells formed by low-pressure MOVPE at 570°C. Observed absorption coefficient shift is 1,500 to 1,530nm at 300°K. Possible applications are high-speed optical logic devices such as switches, flip-flops, and modulators.

The Central R&D Laboratories of OMRON Tateisi Electronics Company, Kyoto, Japan, is developing double quantum-well lasers using AlGaAs/GaAs layers on GaAs wafers. Enhanced properties include lower driving current, higher cutoff frequency, better temperature stability, and higher output power than available using previous methods.

Hitachi's Central Research Laboratories, Tokyo, Japan, developed an improved manufacturing process for its transverse-mode-stabilized AlGaInP lasers. A GaAs etch-stop enhances reproducibility.

Mitsubishi's Central Research Labs, Hyogo, Japan, demonstrated an optical comparator using AlGaAs pnpn optical switches connected in parallel. When three or more of the switches are connected in parallel, only the one with highest input intensity will switch on. The minimum switching energy was 1.7 picojoules.

July

NTT Transmission Systems Laboratories, Kanagawa, Japan, has fabricated and tested a GaAs carrier-injection type optical switch operable over the wavelength range of 1,060 to 1,550nm. The chip incorporates a carrier-blocking diffusion layer to improve the effective refractive index, which increases the efficiency of coupling in single-mode fiber systems. The broad-wavelength device is intended for use in WDM transmission of optical signals.

Scientists at KDD's Meguro R&D Labs, Tokyo, Japan, have reported the frequency stabilization of a 1,550nm-range GaInAsP quarter-wavelength-shifted DFB laser to a variance of less than one part in 100 billion for averaging times of more than one second, without frequency modulation of the diode. Previous approaches were more costly and complex, requiring a frequency modulator for this level of stabilization.

Process development at NTT's Atsugi LSI Labs, Tokyo, Japan, resulted in the growth of 3-inch GaAs crystals by a vertical Bridgman process using boron dioxide as an encapsulant to reduce dislocation density. NTT claims a two- to fivefold improvement, reportedly resulting in wafers of IC quality.

Scientists at the Electro Technical Labs in Tsukuba, Japan, claim to have accomplished the first MBE growth of single-domain InP films on silicon. This achievement is a first step toward developing InP-on-Si wafers.

Engineers at Osaka University, Ibaraki, Japan, claim the first growth of GaSb, InSb, and InGaSb layers on GaSb wafers using trimethyl gallium, trimethyl indium, and solid antimony. This development is expected to lead to new types of compound semiconductors having unique properties.

August

Starting in 1984, Matsushita has operated a 100-kilowatt photovoltaic energy system in support of its car battery manufacturing plant at Lake Hamanako, Shizuoka, Japan. The system was developed by the New Energy Development Organization (NEDO) with Japanese government support. It is composed of 1,440 single-crystal silicon modules, 1,056 polysilicon modules, and 48 CdS/CdTe solar cell modules, arranged to generate 230 volts. Matsushita reported that the roof-mounted facility supplies 21 to 41 percent of the total energy required for plant operation, depending on cloud conditions.

NTT recently reported the following GaAs digIC and MMIC developments:

- 8-bit ALU with 57ps LSCFL gates
- 10.6-GHz BFL static frequency divider
- 20.2-GHz BFL dynamic frequency divider
- 740-MHz 16-channel GaAs E/D DCFL time switch
- 4096-bit ROM with 1.2ns address access time

The company also reported a set of MMIC cells for a 26-GHz receiver, consisting of a 26-GHz LNA (low-noise amplifier), 6.5-GHz VCO (voltage controlled oscillator), 6.5/13- and 13/26-GHz frequency doublers, 26-GHz/1-GHz FET mixer, and 1-GHz IF amplifier. All of the MMIC circuits were combined on a single IC that also contains coplanar waveguides, slot lines, air bridges, FETs, and other required active and passive components.

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September

A NASA contract with the University of Illinois resulted in an assessment of the state of the art of the design of multiprocessor systems for artificial intelligence (AI) applications, including the performance advantages to be gained through adaptation of advanced GaAs technology. A key scientist on the project has returned to Beijing, People's Republic of China (PRC), to pursue AI interests at the Institute of Computing Technology, Academia Sinica.

Scientists at Academia Sinica in Beijing have investigated the growth of Te-doped GaAs crystals grown in space, and they have determined that the space-grown crystals have a more homogeneous distribution of impurities than is the case for GaAs crystals grown on Earth. The source of the samples was not disclosed.

Several recent reports emphasize the PRC's research into advanced compound semiconductors. These include the investigations of MBE-grown GaAs on GaAs substrates, superlattices of alternating layers of AlGaAs on GaAs, and GaInAsP layers on InP wafers. Also, Xiamen University researchers have reported low-temperature photoluminescence spectra studies of LPE-grown GaP crystals, and Academia Sinica (Changchun, PRC) is exploring MOCVD growth of InP.

Engineers at Matsushita's development labs in Osaka, Japan, reported a very compact millimeter-wave transmitter/receiver set for satellite video-link

TABLE 2
Japanese GaAs Chips Reported at GaAs IC Conference

Device/Technology	Company
7ns GaAs 16K SRAM	Mitsubishi Electric Corp.
0.5-micron SRAM process	Hitachi Company
0.5u WSi-MESFET gate arrays	NEC Corporation
8-bit slice logic LSI chip	Toshiba
3-Gbps 16-channel MUX/DEMUX	Fujitsu
15-Gbps HBT MUX/DEMUX chips	Toshiba
12-Gbps SONET chip set	Toshiba
32-bit serial interface chips	Oki Electric Co.
12-GHz 256/258 JFET prescaler	Sony Corporation
15.6-GHz dynamic prescaler	NEC Corporation
0.25-micron HEMT DCFL divider	Oki Electric Co.
34.8-GHz HBT divider	NTT LSI Labs
L-band GaAs MMICs	NTT Comm. Systems Labs
TV tuner mixer/osc. IC	Matsushita
Broadband MMIC mixer	ATR Labs, Kyoto
10-GHz laser-driver IC	NEC Corporation
Power MESFETs	Mitsubishi Electric Corp.
MMIC packaging	NTT Labs

Source: Aztec Associates

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applications. It uses Fujitsu transistors in the DRO oscillator and frequency doublers to multiply 25-GHz operation and achieve 50-GHz operation.

October

The GaAs chip developments in Table 2 were presented by authors from the companies indicated, during the GaAs IC conference at San Diego, California.

November

Fujitsu announced that it will manufacture Vitesse's Fury Series of GaAs gate arrays and mixed logic/SRAM arrays. The Fury arrays will be manufactured in Japan using the Fujitsu self-aligned gate GaAs MESFET process. (Fujitsu claims that it invented self-aligned gate GaAs technology in 1980.) The agreement includes gate array densities from 3,000 to 30,000 gates and provides for joint development of additional products.

December

At the 1989 IEDM meeting in Washington, DC, NEC engineers reported the development of striped-channel MODFETs and ICs based on DCFL structures. NEC also described a two-dimensional transient simulator incorporating deep-trap modeling in another paper presented at the conference.

Mitsubshi has developed a GaAs BiFET structure for LSI applications. The approach achieves the speed of HBTs and the low power of MODFETs. A ring oscillator based on the BiFET structure has operated at 150ps gate delays with power dissipation of 3 microwatts per gate.

DATAQUEST CONCLUSIONS

The activities described herein encompass the full spectrum of GaAs and related compound semiconductor technologies. Vertically integrated Asian companies have accelerated their efforts to cash in on the emerging strategic markets in the 1990s. Asian university research also has intensified, assuring another decade of rapid progress.

The lead of such U.S.-based companies as AT&T is narrowing. Dataquest expects this trend to continue into the mid-1990s, as the U.S. government's budget pressures keep tight limits on the funds available for basic research.

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Research Newsletter

PROGRESS IN GaAs DIGITAL ICS

GaAs digital ICs (digICs) have undergone rapid improvements in recent months, as demonstrated by current product offerings. This research newsletter briefly describes the state of the art of GaAs digICs and examines near-future product expectations.

GaAs DigIC COMPLEXITY

GaAs gate arrays and cell-based designs advanced to VLSI density level in 1989, with products available from GigaBit Logic, TriQuint, and Vitesse at 8,000 to 15,000 gates per chip. Last month, Vitesse announced a 30,000-gate GaAs array, and related reports indicate that the company plans to offer 100,000-gate GaAs ASICs within this calendar year. Dataquest believes that Vitesse's alternate-source agreement with Fujitsu will include the 100,000-gate chips because these chips are part of Vitesse's Fury Series. We believe that customers designing state-of-the-art systems for introduction late in 1990 should be considering such devices for possible use.

The recent rapid increase in GaAs digIC density is evolutionary, not revolutionary, in nature. The E/D MESFET process required to support GaAs chips of 100,000-gate complexity has been proven on both 3-inch and 4-inch wafers. Such processing involves fewer mask levels and operations than does either BiCMOS or bipolar ECL technology.

GaAs ASIC PRICING

In 1989, Dataquest's cost model of a 15,000-gate GaAs ASIC chip showed a break-even cost for an efficient supplier at less than two cents per gate. More than a dozen GaAs digIC suppliers in the free world are capable of sustaining the volume required to support this cost level; thus, it should not come as a surprise that GaAs VLSI suppliers are able to meet or beat the three- to five-cents-per-gate figures of ECL gate arrays.

Silicon ECL is now in the position—with respect to GaAs VLSI—of being slower, consuming more power, and presenting a price penalty at the device level. Armed with this advantage, GaAs digIC suppliers are taking a more aggressive posture in the marketplace.

RECENT GaAs DigIC PRODUCT INTRODUCTIONS

Several suppliers of GaAs digICs have introduced new products to the commercial marketplace within recent months. These chipmakers include Fujitsu, GigaBit Logic, TriQuint, Vitesse, and others. All of these companies are now using submicron enhancement-depletion (E/D) processing to fabricate their chips. Table 1 summarizes several of the major new product offerings from the companies named, showing performance and complexity specifications.

GROWTH IN GaAs DigIC APPLICATIONS

With GaAs digIC functional density growing faster than that of ECL and BiCMOS, many systems houses are actively pursuing the insertion of this technology into new designs, as well as considering retrofits to upgrade existing hardware.

TriQuint has indicated that its customers are increasingly demanding more tools for designing GaAs DDS (direct digital synthesis) functions. TriQuint has responded by adding to its library hard macros such as 256x8 ROMs and two-bit pipelined accumulator elements. These functions will help users save as much as two months in time to market when developing hardware for GPS (global

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TABLE 1
Recent GaAs DigIC Product Introductions

Company	Gates Per Chip	Process	Gate Delay (ps)	Gate Power (mW)	I/Os	Comments
Fujitsu	3,000-30,000+	E/D	90	0.3	256	Alternate source to Vitesse
GigaBit Logic	15,000+	HMED	50	Varies	96	Standard cell-based designs
TriQuint	10,000+	Q/ED	78	N/A	84	Up to 4K ROM macro available
Vitesse	30,528	E/D	90	0.3	256	344-pin ceramic LCC package

N/A = Not Available

Source: Dataquest February 1990

positioning satellite) system applications, phase-tracking hardware, and test equipment.

The long-awaited SPARC-architecture GaAs RISC machine is being developed by Systems and Processes Engineering Corporation under a licensing arrangement with Sun Microsystems. The NASA contract is expected to result in a rad-hard multiprocessor based on Vitesse's standard-cell custom capability. The three-chip set includes an integer processor chip of approximately 25,000-gate density. Sun has retained the right to license back the designs for production by any of Sun's semiconductor licensees.

DATAQUEST CONCLUSIONS

Dataquest believes that GaAs VLSI products are here to stay. GaAs digital IC suppliers are strengthening their positions with aggressive product offerings, and GaAs VLSI products are realizing new applications. Despite the delay in shipment of the first CRAY-3 and the demise of Prisma, we expect 1990 to bring the introduction of major digital equipment designs based on cost-effective GaAs digIC technology.

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Research *Bulletin*

THE IMPACT OF PHOTONICS ON IC TECHNOLOGY

This is 1990, and already the technology of the next century is being sold at $2,000 a copy, presumably to anyone with the appropriate credentials. AT&T has done an about-face and is offering the most advanced semiconductor chip on the world market today to research labs. This bulletin briefly discusses this watershed event and its implications on the future of communications and information technology.

SILICON AND METAL REVERSE ROLES

In conventional electronic circuit technology, metal is used for interconnecting digital and analog functions, and silicon is used as the basic substrate material for accomplishing the amplification, switching, storage, and whatever other functions the designer chooses for components in a system. The advent of photonics technology, which takes advantage of the movements and other affects of photons instead of electrons, has reversed these roles. Compound semiconducting substrates such as GaAs and InP incorporate a metal such as gallium or indium in the wafer structure and take advantage of the photon-conducting properties of glass fiber (which is made of silicon) for the interchip connections. Because the sun and other light sources emit photons, the use of photonic technology to replace electronics elegantly solves many problems that demand many millions to billions of transistors to accomplish electronically. A simple example is image transfer in high-definition TV (HDTV); another is the switching of signals on 10-Gbps communications lines in a telephone switching center.

AT&T REMAINS THE LEADER

Since the inventions of Alexander Graham Bell, Claude Shannon (information theory), and others, the technology cloners of the world have beaten a path to Bell Labs' door. This year is no exception; however, the big surprise is that AT&T has offered a major R&D breakthrough at bargain-basement pricing. The invention of the self electro-optic effect device (SEED) allowed AT&T engineers to grow, atom by atom, structures containing 2,048 AlGaAs/GaAs photonic cells, each of which is a switch/gate/storage element that operates in the picoseconds range, the most complex structure ever produced using molecular beam epitaxy (MBE). These devices can interface directly with prisms, lenses, mirrors, and other optical devices.

Silicon chip electronic world, take note! The dilemma of what to do with billion-transistor chips may be resolved by very efficient competing technology. Some industry sources expect AT&T's breakthrough to cause hundreds of electronic companies to make major changes to their R&D plans.

WHAT IT MEANS

If simple glass lenses, mirrors, and prisms ultimately replace billions to trillions of transistors in many major systems, and sunlight replaces conventional energy sources to power the systems, whole corporate cultures may become obsolete. The internal combustion engine had a similar effect in terms of time compression and labor savings. The real issue facing electronics firms is, what happens when major applications of electronic devices, boxes, and systems become obsolete, and the end customers turn to companies that under-

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stand optics? Corporate managers may be well advised to rethink their position on the so-called electronic engineering shortage. The issue facing the university student is, should I plan on a career in saddles and buggywhips, or is it remotely possible that photonics technology will surprise all of us before graduation day (as Sputnik did in the late 1950s)?

DATAQUEST CONCLUSIONS

AT&T clearly remains the leader in information and communication technology and is willing to share much of what it learns. Dataquest believes that photonics technology may enter the mainstream of high-end equipment designs long before 1999.

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Research *Bulletin*

TRIQUINT-GIGABIT MERGER INCLUDES GAZELLE

On May 10, TriQuint Semiconductor Inc. announced a definitive agreement that adds Gazelle Microcircuits to the TriQuint-GigaBit Logic merger. Regulatory and shareholder approval are expected, and transactions are to be completed by May 31. The combined company will have 320 employees, 97,000 square feet of facilities, and annual sales in excess of $40 million per year. Operations are located in Beaverton, Oregon; Newbury Park, California; and Santa Clara, California. TriQuint is the world's largest commercial GaAs IC products company.

TriQuint is experiencing rapid growth in the consumption of GaAs custom and semicustom ICs by the computer, communications, military systems, and instrumentation markets. The company's customer base totals more than 1,200, including many Fortune 500 companies.

Gazelle, founded in 1986, utilized TriQuint as its primary foundry. Gazelle initially focused on TTL-compatible GaAs PLDs and other high-performance circuits based on GaAs technology. The merger provides a vehicle for continuation of the $4 million DARPA development contract booked by Gazelle, amid some controversy, in April 1990. Gazelle's performance in 1990 was lackluster, and 1990 saw the departure of cofounder David MacMillan and other key employees.

The new company will be jointly owned by existing investors in the three merging companies. Corporate investors include Tektronix, Digital Equipment Corporation, Analog Devices, NKT (Denmark), and several venture capital firms. Venture capital investors include Kleiner, Perkins, Caufield and Byers; Hambrecht & Quist; Dillon-Reed-Concord Partners; Merrill, Pickard, Anderson and Eyre; Venrock Associates; InterVen Partners; Canaan Venture; and DFC (New Zealand).

The new seven-person board of directors includes chairman Gary Arnold, vice president and CFO of Tektronix; John Vold, vice president of business development for Tektronix; Richard Hill, vice president of test and measurement operations for Tektronix; Spencer Brown, former president of GigaBit Logic; David B. Jones, general partner with InterVen Partners; Steve Sharp, with Mohr-Davidow; and Floyd Kvamme, partner in Kleiner, Perkins, Caufield and Byers. A three-person management operating committee has been formed, consisting of interim president and CEO A.J. "Bert" Moyers, formerly vice president and CFO of Western Digital and National Semiconductor; executive vice president Al Patz, former president of TriQuint; and executive vice president Spencer Brown.

DATAQUEST CONCLUSIONS

The combined companies bring many strengths to the marketplace, including state-of-the-art innovative designs, automated circuit analysis, fabrication, packaging and test facilities and capabilities, extensive market coverage, remote design centers, and a 10-year history of performance in making new GaAs products a reality. Dataquest expects TriQuint to capitalize on these strengths.

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Research *Bulletin*

HBTs INTENSIFY THE GaAs-VERSUS-SILICON ECL BATTLE

SUMMARY

The GaAs-versus-silicon emitter-coupled logic (ECL) competition has wavered back and forth as both technologies continue to evolve. In 1988, the silicon cost advantage was virtually eliminated with the advent of GaAs standard cell and gate array chips of 10,000-gate density, forward priced at parity with silicon ECL gate arrays of similar density. Now, less than two years later, a major process breakthrough in GaAs promises to tilt the price/performance curve permanently against silicon. This bulletin highlights recent developments in the two technologies.

WHY HBT TECHNOLOGY?

The GaAs ECL logic functions presently available are built with FETs, whereas true silicon ECL logic uses bipolar transistors. Compared with bipolar transistors, FETs are notoriously poor performers in terms of driving capacitive loads regardless of substrate type (silicon or GaAs). This lack of performance results in a speed disadvantage in currently produced GaAs circuitry, particularly in highly parallel logic designs. Thus the full speed potential of GaAs over silicon has not yet been realized.

A heterojunction bipolar transistor (HBT) structure constructed with AlGaAs and GaAs offers remarkable digital circuit performance. In 1988, NTT reported implementing GaAs ECL gates with delay times of 5.5 picoseconds per gate, using HBT technology. Last year, Rockwell presented results on several frequency-divider designs using HBTs that operated at 17 and 25 GHz, respectively, and Hughes developed 48-GHz HBTs using a process incorporating AlInAs and GaInAs on an InP (indium phosphide) substrate.

Also in 1989, NTT described a GaAs 35-GHz frequency divider that used relatively small HBT transistors (emitters of 2 x 3 microns and collectors of 4 x 5 microns), believed at the time to be the fastest frequency divider ever reported. IBM has been notably silent in discussing any work it may be doing in HBT technology.

The speed advantage gained in each of the instances described above is possible primarily because of the high current gain inherent in bipolar transistor structures. High current gain allows faster charging and discharging of base capacitance, interconnect capacitance, and other stray impedance involved in both the chip itself and in the supporting package and interconnection hardware.

WHY THE DELAY IN PRODUCING HBTS?

Until recently, there was a major problem in the known HBT device-processing methodology. The p-type dopant used in the base region (usually beryllium or zinc) rediffuses during subsequent heat treatment steps. Although carbon is known to have a lower diffusivity, no reliable procedure was known to exist for achieving carbon diffusion at very high concentrations. These limitations have heretofore prevented the economically feasible production of GaAs HBTs.

In March 1990, AT&T Bell Laboratories researchers described a method for growing carbon-doped base AlGaAs/GaAs HBTs using a process that incorporates both MOMBE (metal organic molecular beam epitaxy) and MOCVD (metal organic chemical vapor deposition) in the growth sequence. In the AT&T process, layers are grown in the following sequence, starting with a semi-insulating GaAs substrate:

- MOMBE-grown subcollector—6,000 angstroms of n^+ GaAs
- MOMBE-grown collector—4,000 angstroms of n^- GaAs

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- MOMBE-grown base—400 to 800 angstroms of GaAs, carbon-doped at 1 x 10^{19} to 1 x 10^{20} atoms per cubic centimeter
- MOMBE-grown GaAs spacer—50 to 100 angstroms thickness
- MOCVD-grown emitter—1,200 angstroms of n^+ AlGaAs in two layers with silane doping varied for each layer
- MOCVD-grown emitter contact layers—1,500 angstroms of n^+GaAs followed by 300 angstroms of graded n^+ AlGaAs

Metallization used for the emitter and collector layers was AuGeNi, and alloyed AuBe was used for base ohmic contacts. The DC current gain achieved was 20. AT&T expects this process to prove useful in the production of AlGaAs/GaAs HBTs.

WHAT'S HAPPENING IN THE SILICON ECL WORLD?

Silicon ECL technology has reached a practical limit at present production levels. Although gate delays have approached approximately 100 picoseconds, the associated power (exceeding 30 watts per chip) now prohibits the use of air cooling for arrays of useful density. To achieve higher densities, silicon suppliers recently have resorted to the same tactics previously used by GaAs chip suppliers; namely, to incorporate FET structures internal to the chips and to set ECL levels at the chip interface. However, from the standpoint of performance, this is a self-defeating approach in that the bipolar silicon speeds are already marginal for next-generation, high-performance computing, and FET structures are inherently slower. The silicon ECL suppliers are, in the vernacular, "caught between a rock and a hard place." This is abundantly clear in Cray's choice of GaAs for the CRAY 3 supercomputer CPU logic.

DATAQUEST CONCLUSIONS

The world of high-speed digital hardware is facing some hard decisions. Although silicon ECL has been the workhorse of high-performance logic designers, the technology is rapidly maturing. GaAs-based chips using some form of FET-device logic have allowed leading-edge equipment designers a generation or two of additional system-performance improvement. The next step in technology is to move on to GaAs bipolar designs, although no supplier base presently exists for such ICs. Just as the early 1970s required a round of custom silicon ECL- and CML-based IC designs by system houses to establish the silicon ECL 10K/100K standards, it appears that the early 1990s need a similar push in GaAs HBT-based chip designs. The remaining issues are who will be first to "bite the bullet" and invest in the technology, and who will remain in the high-performance chip business (and for how long) after this occurs?

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Research *Bulletin*

GaAs IC GROWTH OFFSETS DECLINE IN OPTO SEMICONDUCTORS

INTRODUCTION

The 1989 worldwide market for GaAs semiconductors was characterized by double-digit growth in ICs and microwave/millimeter-wave (uw/mmw) discretes, tempered by a 5 percent decrease in discrete optoelectronics. Discrete opto declined by more than $100 million to less than $2.1 billion in 1989 consumption. GaAs ICs now account for 14 percent of the total. Record GaAs device sales in all categories resulted from the continuing growth of IC market share in computers, telecommunications, instrumentation, and related electronic equipment applications.

1989 GaAs MARKET DEVELOPMENTS

GaAs IC devices, including optoelectronic integrated circuits (OEICs), led 1989 growth, followed closely by uw/mmw discrete devices. NRE (nonrecurring engineering) costs were lower in 1989 than in 1988, confirming the maturation of GaAs ASICs and certain developmental programs that have been under way for nearly 10 years. During 1989, GaAs IC growth was somewhat lower than expected, primarily due to tempering of the overall growth of the marketplace and the withdrawal of Tachonics, the merger of Adams-Russell's foundry with M/A-COM, and other factors. Although Vitesse and Fujitsu announced a partnership in GaAs ASICs, no significant effect on the size of the market is expected for another year or more. U.S. Department of Defense budget cuts have further tempered the near- and intermediate-term markets.

Major activities in 1989 included a decision by Cray Research to restart fabrication of GaAs ICs at its Colorado Springs facilities, which had the immediate effect of reducing the commercially available market by at least several million dollars per year. Countering this situation is the recent agreement between McDonnell Douglas and TriQuint involving coproduction of 64K GaAs SRAMs and other VLSI devices. Table 1 summarizes shipment estimates for GaAs and other compound semiconductor devices from 1985 through 1989.

DATAQUEST CONCLUSIONS

GaAs IC technology has reached a level at which it may be used by a broad-based electronics company to offset cyclical declines in its semiconductor business. Dataquest believes that astute semiconductor producers will consider this an important factor in rethinking their overall business strategies for the 1990s and beyond.

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TABLE 1
Worldwide GaAs Semiconductor Shipments (Millions of Dollars)

Category	1985	1986	1987	1988	1989	Percent Change 1988-1989
Total GaAs Semiconductors	1,517	1,902	2,183	2,723	2,743	0.7%
Analog/Linear ICs	80	107	138	157	187	19.1%
Devices	40	56	85	107	142	32.7%
NRE Costs	40	51	53	50	45	(10.0%)
DigICs	26	51	71	86	117	36.0%
Devices	6	21	35	51	88	72.5%
NRE Costs	20	30	36	35	29	(17.1%)
Optoelectronics	1,233	1,514	1,752	2,237	2,148	(4.0%)
Discrete Opto	1,213	1,486	1,709	2,179	2,071	(5.0%)
OEICs	20	28	43	58	77	32.8%
uw/mmw Discretes	178	228	222	243	291	19.8%

Notes: Columns may not add to subtotals and totals shown because of rounding.
Dataquest's merchant shipment figures include intracompany transfers for merchant suppliers at estimated market value. No full-captive supplier data are included.
Optoelectronics data for 1985-1989 include silicon emitters and detectors.

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Research Newsletter

GaAs MATERIALS REVISITED: THE SHAKEOUT TAKES ITS TOLL

SUMMARY

Two years ago, Dataquest reported that more than 40 companies were addressing the issues involved in the economic production of high-quality GaAs wafers and other compound semiconductor wafers. Since that time, the massive oversupply has resulted in significant structural adjustments. This newsletter updates our clients on these changes and reviews the current situation in this area of technology.

DISCUSSION AND ANALYSIS

Following our 1988 newsletter on this subject, GaAs-on-silicon production quickly surpassed market demand, and molecular beam epitaxy (MBE) technology grew in importance. Although MBE has gained acceptance in microwave, millimeter wave, and optical (OEIC and photonic) applications, neither approach has made major inroads into existing technology for GaAs digital IC (digIC) production.

Volume consumption of GaAs wafers has grown rapidly, driven by the emergence of large-volume GaAs digIC markets and other factors. However, GaAs wafer consumption has grown less rapidly than has the GaAs device market, as a result of declining prices and improvements in users' yields. InP and other III-V wafer volumes remain at very low R&D levels.

Dropouts

Several companies have ceased operations or have de-emphasized GaAs materials since our 1988 newsletter on this subject. These companies include Commercial Crystal Laboratories, GAIN Electronics Corporation, MSC (Siemens), Morgan Semiconductor (Ethyl Corporation), OMVPE Technologies, and Spectrum Technology Corporation.

Acquisitions and Mergers

Other compound semiconductor materials suppliers have been acquired by or have merged into larger organizations. Chemetall GmbH, a Frankfurt-based holding company, acquired Bertram; Bertram acquired Epitronics. Enimont, an Italian company, acquired Cryscon. MCP acquired ICI Wafer Technology Ltd.'s GaAs wafer facilities and moved MPC's existing GaAs wafer operation to the ICI plant. Semitronic acquired Boliden Finemet, based in Sweden.

Start-Up Activity

The number of recent start-up companies in GaAs materials decreased to one: Bandgap Technology Corporation, which introduced products in 1989. Another start-up venture, to be located in southern California, is rumored; Dataquest believes that Asian-sourced capital has been invested in the acquisition of some of Spectrum Technology's wafer production equipment.

GaAs Materials Market, Volume, and Pricing

The overall GaAs wafer market is still dominated by a relatively small number of major suppliers—namely, Hitachi Cable, MMK, Sumitomo, and Wacker. Sumitomo, which shipped more than 30 percent of the world consumption of GaAs wafers in 1988, is probably still number one, although its share of the US market has dropped into the range of 15 percent. Wacker is believed to be the major supplier to the US market now, at approximately 25 percent, having reversed roles with Sumitomo in the US market over the last two years.

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Sumitomo remains the number one supplier in Japan, followed by Hitachi Cable in second position and Dowa Mining, third. Wacker is the leading European supplier of GaAs wafers. MMK is believed to be number three in the worldwide market.

Reportedly, the first order over $1 million for unprocessed GaAs wafers was placed by Vitesse with Wacker earlier in 1990. The order value was estimated to be near $1.5 million for more than 5,000 100mm semi-insulating GaAs wafers to be used in producing GaAs digICs.

Presently, undoped LEC wafers cost users approximately $23 per square inch, or approximately $280 each for 4-inch wafers, in large volume. This cost represents approximately a 10 percent per year decline in raw wafer prices since mid-1988. Epitaxial wafers cost several times more, depending on quality; MBE wafer costs range to more than $1,500 for 3-inch material. Corresponding reductions in epi wafer pricing should follow as volumes increase. Epi wafer costs are expected to decline further as metalorganic chemical vapor deposition (MOCVD) and MBE equipment throughputs increase.

Present Supplier Base

Table 1 provides an update of the GaAs and other III-V compound materials suppliers' product offerings. Parent companies are shown in parentheses.

TABLE 1
III-V Wafer Suppliers and Products

Company	Location	Wafer Sizes (Inches)	III-V Products
Airtron (Litton)	Morris Plains, NJ	2, 2.5, 3, 4	GaAs wafers, other advanced materials
Atomergic Chemetals	Farmingdale, NY	2, 3	GaAs,GaP, InP ingots and wafers; GaAs epi
ATTC (Chemetall GmbH)	Hsin Chu, ROC	2, 3	GaAs, GaP, and InP ingots and wafers
Bandgap Technology	Broomfield, CO	2, 3, 4	III-V epi wafers
Bertram Labs (Chemetall)	North Branch, NJ	2, 3	GaAs, GaP, InP wafers
Chemetall GmbH	Frankfurt, W. Ger.		Holding company
Crystacomm	Mountain View, CA	2.5	LEC-grown InP wafers
Crystal Specialties (Akzo N.V.)	Colorado Springs, CO	2, 3	HB and VGF wafers
Dowa Mining	Japan	2, 3	GaAs, InP wafers
EMCORE Corp.	Somerset, NJ		GaAs, InP epi services; MBE and MOCVD systems
EML	Ely, UK	2, 3	GaAs epitaxial wafers
Enimont	Italy	2, 3	Epi wafers
Epitaxx	Princeton, NJ	2, 3	InGaAs epi on InP
Epitronics (Bertram)	Phoenix, AZ	2, 3	AlGaAs and other epi wafers and services
Furukawa Electric	Tokyo, Japan	2, 3	GaAs, InP wafers, and GaAs epi wafers

(Continued)

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TABLE 1 (Continued)
III-V Wafer Suppliers and Products

Company	Location	Wafer Sizes (Inches)	III-V Products
Hitachi Cable	Ibaraki, Japan	2, 3, 4	LEC GaAs and InP ingots, wafers, and epi wafers
Hitachi Metals	Hitachi City, Japan		GaAs ingots
Iwaki Handotai	Fukushima, Japan	2, 3	LEC GaAs (epi) wafers
Johnson Matthey	Spokane, WA	2, 3, 4	GaAs, GaSb, InAs, and InSb wafers
Kopin Corporation	Taunton, MA	2, 3, 4, 6	GaAs-on-Si, GaAs epi wafers, others
M/A-COM	Burlington, MA	2, 2.5, 3	GaAs ingots, wafers, epi
MCP Ltd.	Milton Keynes, UK	2, 3, 4	GaAs, InP, and II-VI wafers
Metal Specialties (MCP)	Fairfield, CT	2, 3	LEC- and HB-grown GaAs, GaP, GaSb, InAs, InP, and InSb wafers
Meteaux Speciaux	Moutiers, France	2	LEC InP ingots and wafers
Mitsubishi Metal	Omiya, Japan	2, 3	HB, LEC GaAs wafers
Mitsubishi-Monsanto Kokusai	Tokyo, Japan	2, 3, 4	GaAs and GaP wafers
Nippon Mining	Tokyo, Japan	3	InP ingots, wafers; GaAs and CdTe ingots
Picogiga	Les Ulis, France	2, 3	GaAs MBE epi wafers
Preussag	Gossiar, W. Ger.	2, 3, 4	GaAs wafers
Raytheon	Bedford, MA	2, 3	LEC, HB GaAs wafers
Semitronic	Sweden	2, 3	HPLEC wafers
Showa Denko	Tokyo, Japan	2, 3	MLEC InP wafers; GaAs and GaP NDF wafers
Siemens Opto Division	Cupertino, CA	1.6 to 3	HB-grown GaAs wafers
Spire Corporation	Bedford, MA	2, 3	GaAs and AlGaAs epi wafers and systems

(Continued)

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TABLE 1 (Continued)
III-V Wafer Suppliers and Products

Company	Location	Wafer Sizes (Inches)	III-V Products
Sumitomo Electric	Hyogo, Japan	2, 3, 4	GaAs, GaP, GaSb, InP, InSb, InAs ingots and wafers; epi wafers
United Epitaxial Tech.	Beaverton, OR	2, 3	Advanced materials including GaAs epi
Wacker	Burghausen, W. Ger.	2, 3, 4	Semi-insulating and doped GaAs wafers

Note: The parent company is indicated in parentheses.
Source: Aziak Associates

DATAQUEST OBSERVATIONS AND CONCLUSIONS

Consolidation has taken place among GaAs wafer producers in the last two years. Although some shakeout has occurred, the III-V compound semiconductor materials marketplace is still supported by a broad range of increasingly capable suppliers, each dedicated to continual improvement of its products and services. Pricing has declined under the intense competitive pressure, although not as fast as expected by some chip suppliers. Digital GaAs IC chip suppliers still prefer "raw" GaAs wafers for use in an implant process (proton and/or ion rather than GaAs-on-Si or epitaxial GaAs wafers). Dataquest believes that GaAs wafer overcapacity still exists and that further consolidation is likely.

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Research *Bulletin*

VARIAN OEICs ENABLE OPTICAL TRANSFER OF ELECTRICAL POWER

Varian Associates, Incorporated, has developed optoelectronic integrated circuits (OEICs), which enable the optical transfer of electrical power through a fiber cable. This breakthrough makes possible a host of applications that were heretofore not feasible and promises incremental growth in the GaAs OEIC market.

GaAs OPTICAL POWER CONVERSION

Because GaAs circuits respond to incident light and may be designed to operate at light-wave frequencies, it is possible to build ICs that convert light into electrical power. Varian's VRC PR-6C power receiver is one of an emerging family of GaAs OEICs that accomplish this task in a single chip. Electrical power operating a laser diode is converted to light at a frequency at or near the visible spectrum; the light then is transferred through a fiber-optic cable to a point near the VRC PR-6C, which converts the light back into electrical power at an efficiency that can approach 50 percent. Thus, the power receiver is operating in a fashion similar to that of a group of interconnected solar cells.

VARIAN'S APPROACH

The VRC PR-6C is believed to be the first OEIC capable of converting optical energy to a 6V electrical output of up to 1 watt. To produce the device, Varian uses proven GaAs IC production technology, including air bridges to interconnect the circuit sections. The active area of the chip is relatively small, with a diameter of 3 millimeters. Because the device responds efficiently to light of wavelengths in the range of 800 to 850 nanometers as well as to IR light of wavelengths longer than 900 nanometers, the chip can be used in systems where power and data are transferred over a single fiber cable.

POTENTIAL APPLICATIONS

A multitude of needs are uniquely met by the optical transfer of electrical energy. The elimination of electrical power transfer in situations involving life support or intrusion of the human body, for example, lowers the risk of shock. Spark hazards in volatile atmospheres can be similarly reduced. Electromagnetic interference (EMI) in such applications as aircraft control systems and other critical sensor systems can be virtually eliminated. By transferring power and data over single fibers at optical frequencies, interconnections within computers may be greatly simplified.

DATAQUEST OBSERVATIONS

Dataquest believes that Varian's accomplishment in developing the VRC family of power receiver chips is significant and merits recognition. Like the operational amplifier IC and the microprocessor, the existence of optical power converter ICs is expected to increase the pervasiveness of monolithic chip technology in everyday life. Dataquest believes that this breakthrough is just the first in a new stream of developments that will impact the direction of future design of systems employing IC technology.

Gene Miles

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Research Newsletter

UPDATE ON GaAs RAMs

The increasing demand for GaAs RAM* ICs has resulted from the growing use of digital GaAs in high-speed data processing systems. This demand is driving the evolution of more sophisticated GaAs memory chips, including both static and dynamic RAM (SRAM and DRAM) devices. As a result, conventional silicon RAMs are being challenged in certain IC storage applications, such as high-performance cache. This newsletter examines many of the recent developments in this technology.

THE IMPACT OF COST-EFFECTIVE GaAs VLSI

Until the late 1980s, highly reproducible GaAs ICs were confined to gates-per-chip counts below 5,000, limiting GaAs RAMs to low density.

Although one Japanese company proposed a 64K GaAs SRAM in the mid-1980s, the majority of chips produced today are at the level of 1 to 4 Kbits (Kb) per chip. In 1988, GaAs digIC chip complexity surged through the 10,000-gate-per-chip level, and in 1989 GaAs gate array pricing crossed below that of silicon ECL. At least one GaAs digIC supplier now promotes its GaAs gate arrays as performing 50 percent faster than the silicon ECL counterparts while consuming one-fifth of the power. Multisourced 30,000-gate GaAs chips now are offered on a production basis, and 100,000-gate GaAs arrays are expected by early 1991.

Such developments have pushed processing capability sufficiently to support the production of GaAs 16K SRAM and 64K DRAM designs. And, GaAs processing capability is by no means mature. Currently, GaAs VLSI arrays use processes resulting in a minimum FET gate length of 0.8 to 1.0 micron. ITT has developed a manufacturable 0.4-micron process, and almost all of the present GaAs IC fabrication processes are scalable on existing factory tooling. Thus, production of GaAs RAM ICs above 64Kb density should become feasible in the early 1990s.

THE CASE FOR GaAs DRAMs

The majority of silicon IC users and producers alike have disallowed the need for and in many cases the possibility of developing GaAs DRAMs. This bias arises from the fact that DRAMs represent the lowest cost-per-bit form of semiconductor read-write memory, and GaAs is not viewed as being potentially cost-competitive with silicon. Furthermore, some US-based GaAs IC producers have feared an onslaught of Japanese competition once the market for GaAs SRAMs grows into the $100 million range, and they do not wish to develop additional markets that would invite a repetition of the penetration of many of the existing IC memory markets by Japanese suppliers. Now that Fujitsu is constructing a ¥30 billion GaAs fab facility, such fears may become justified.

However, some organizations including the US Navy's Office of Naval Research (ONR) perceive sufficient need and merit to invest resources in this technology. Layered memory designs, such as those in 386- and 486-based personal computers on the low end and supercomputers on the high end, use small, fast caches backed by large (4MB and up) IC main storage and much larger (40MB to multigigabyte) disk storage.

*Note: The term RAM has been used for more than 30 years to denote read-write random access memory. The practice continues in today's jargon, although technically the various types of IC read-only and content-addressable memories also may be randomly accessed. Dataquest uses the same convention as others; thus, this report is confined to read-write RAMs.

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Additionally, a need is evolving for very fast (200ps to 2ns access time) chips in the 16- to 256Kb-per-chip capacity range to support the cache memory requirements of certain types of systems now on the drawing board. Silicon memory design effort is not expected to result in a viable approach to this requirement before the mid-1990s, if ever. GaAs DRAMs producible on existing GaAs fab lines offer a promising near-term solution to this particular problem.

PROGRESS IN GaAs DRAMs

Because GaAs SRAM designs require relatively high power per cell (silicon SRAMs need even more power during the operating state), GaAs DRAM cells have been developed as a possible alternative. To date, one-transistor GaAs DRAM cells have exhibited data retention times on the order of 15 minutes without refresh at room temperature, and acceptable data retention above 125°C has been projected from the test results. Power required to maintain storage was approximately two orders of magnitude below that of GaAs SRAM cells. Both MESFET- and JFET-accessed cell implementations using all-implant (no diffusion) processing have been examined.

Dataquest believes that a new niche market opportunity, which could quickly grow beyond $100 million annually, exists for fast, intermediate-density GaAs DRAMs. And, the availability of such devices would spur market growth for other GaAs and silicon ICs, increasing the IC TAM.

OPTOELECTRONIC RAMs

AT&T and Matsushita each have recently reported development activities involving the incorporation of photonic devices in memory storage arrays. The AT&T approach incorporates 2,048 multiple-quantum-well (MQW) devices called symmetric self electro-optic effect devices (S-SEEDs), each of which can function as an optical switch, a logic gate, or a storage element. The Matsushita design uses InP as the substrate material, which promises higher speeds than achievable on GaAs wafers. Dataquest is following this work and expects to publish a newsletter on these designs and related developments later this year.

GaAs SRAMs IN MID-1990

Several manufacturers including GigaBit Logic, McDonnell Douglas, Rockwell, Texas Instruments, and Vitesse now produce and market GaAs SRAMs at the 1- to 16K-density level. The GigaBit and Vitesse products are aimed primarily at the commercial market, with the other US suppliers supporting military/aerospace needs as top priority. Most of the designs were in response to requirements for characteristics other than raw speed, and none appear to have stretched the respective production technologies to the achievable limit of cycle time. Additionally, some Japanese and European companies, including Fujitsu, Hitachi, LEP (Philips), and Mitsubishi, have developed GaAs SRAMs, initially for R&D purposes, internal consumption, and/or technology exchanges.

An excellent example of a special-purpose SRAM chip design was recently reported by Texas Instruments. The TI chip, called a programmable delay line element (PDLE), contains 4,096 bits of SRAM and 750 gates of control logic. It is processed to 1.0 micron, recessed-gate, E/D MESFET design rules and incorporates two-layer metal interconnects. Chip I/O levels are ECL 50-ohm line compatible, and the ICs are cascadable to form as long a delay line as required for a given application.

Another example of a special-purpose GaAs IC containing a combination of RAM and logic gates is Vitesse's VSC20K8R, described as a 20,000-gate array with embedded 8K SRAM. The chip, based on Vitesse's Fury Series, has eight independently addressable 256- x 4-bit SRAMs, surrounded by approximately 20,700 2-input NOR gates. Gate delays (unloaded) are 90ps and SRAM cycle times are 3,500ps. The IC is packaged in a 344-pin leaded chip carrier and allows 256 signal I/Os that may be ECL, TTL, or GaAs compatible. Vitesse offers other SRAM-gate array combination options to the user, with embedded SRAM array sizes to 16Kb and gate counts to 30,000. Fujitsu has an alternate source agreement with Vitesse for all Fury Series devices, including the VSC20K8R.

Vitesse has also announced a 4K SRAM having a "clear-all-bits-to-zero" capability. The 28-pin, ECL-compatible device has a maximum cycle time of 5ns and dissipates less than one watt. The chip features registered inputs, latched outputs, and internal write-pulse generation, which simplifies system control logic.

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RECENT DEVELOPMENTS IN GaAs SRAMs

Recent development activity in GaAs SRAMs has largely been limited to refining previously announced products. Titles of papers to be presented in the near future include the following:

- "A GaAs Pin-for-Pin Replacement for the ECL 100474 4K SRAM" by A. Fiedler (GigaBit Logic)
- "Development of SRAMs Using Complementary HIGFET Technology" by D. Grider et al. (Honeywell)
- "A High-Speed GaAs 16Kb SRAM of 4.4ns/2W Using Triple-Level Metal" by H. Nakano et al. (Mitsubishi)
- "A Low-Power 16K GaAs HMESFET SRAM with Built-In Redundancy" by T. Tsen et al. (Rockwell)

DATAQUEST CONCLUSIONS

Progress in GaAs RAMs has been limited more by the extent of resources applied than by any particular technical problem or class of problems. Much inertia has resulted from some companies' fears of phantom competition, causing US GaAs suppliers to allow silicon RAM suppliers to continue dominating the high-performance end of the IC RAM marketplace.

Niche markets exist, notably in special-purpose SRAMs, fast medium-density DRAMs, and the emerging photonic and optoelectronic memory markets, for innovative GaAs RAM products. However, as is the case throughout the IC world, there is the attendant, ever-present risk of growing competition. As Douglas MacArthur said, "There is no security on this earth. Only opportunity."

Gene Miles

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Research Newsletter

RECENT EVOLUTION IN MMIC TECHNOLOGY

SUMMARY

GaAs microwave monolithic ICs (MMICs) are becoming more pervasive in commercial applications, and military insertions of this and related technologies are on the rise. Large-volume production is under way at several GaAs MMIC facilities, with major expansions either completed or in progress. This multitopic newsletter focuses on recent developments and trends in the increasingly important field of III-V compound MMICs, which are believed to be of significance to many of Dataquest's clients.

TREND TOWARD MULTIFUNCTION CHIPS

As MMIC process refinements continue, more multifunction, multiuse chips are emerging from the GaAs IC laboratories in reproducible form. Examples include MMICs and LSI chips recently built by ITT and NTT. Such ICs are finding their way into avionics hardware and will soon be applied to consumer products.

Radar Applications of Multifunction MMICs

The ITT GaAs Technology Center (GTC) recently reported test results on six types of multiuse GaAs ICs designed for radar and other applications. The chips were fabricated on ITT GTC's 0.4-micron multifunction self-aligned gate (MSAG) process. The chip set includes a redundant switch, broadband amplifiers, A/D converter, buffered prescaler, and sample-and-hold (S/H) circuits. Both low-noise and power MMICs and high-speed LSI-density logic are fabricated on the same chip. The overall RF yield achieved on a lot basis was 19 percent for the buffered prescaler. Chip yield for the sample-and-hold IC was 97 percent.

MMIC Ku-Band PLL Synthesizer

NTT's Radio Communication Systems Laboratory and LSI Laboratories have developed a MMIC and an LSI chip that together perform Ku-band frequency synthesis. The MMIC consists of a voltage-controlled oscillator (VCO), a dual-output buffer amplifier, a balun, and prescalers. The LSI chip contains a dual-modulus prescaler, programmable counters, and a phase/frequency comparator. The two chips are packaged in an 11 x 23mm flatpack. NTT expects this technology to be applied to personal wristwatch telephones, pocket-size satellite videophones, and other radiocommunication systems.

JAPAN'S SPACE PROGRAM USES GaAs MMICs

Japan has an aggressive space program under way, which ranges from communications satellites to plans for landing payloads on the moon. A recent report written by engineers of two NTT laboratories, ATR Research Labs and Japan's National Space Development Agency, describes a Ka-band (20 to 30GHz) MMIC receiver module.

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The module uses GaAs MESFET chips to implement trim-free 30-GHz receivers for transponders on the ETS-VI satellite, which Japan will launch in 1993. NTT's LSI Laboratories supplied the chips, which allowed a reduction in the weight of the module to 200 grams, a factor of six lower than the weight of the conventional hybrid approach.

MIMIC PROGRAM PROGRESS

The US Department of Defense (DOD) MIMIC program now is partially through Phase 1, which began in mid-1988. Four teams consisting of a total of 26 companies are participating in the program. By mid-1990, the teams reportedly were responsible for 79 chip types, 23 module assemblies, and 16 system brassboards.

Each of the teams has in place a pilot production facility that is capable of 100 3-inch wafer starts per shift per week. One MIMIC Phase 1 team, led by Hughes and GE, has validation work under way at five foundries: AT&T, GE, Harris, Hughes, and M/A-COM. Another team, led by Texas Instruments and Raytheon, had achieved production costs of less than $3 per square millimeter of chip area.

During the first 18 months of Phase 1, one of the MIMIC manufacturing teams experienced chip production cost reduction of a factor of six on small-signal amplifiers and a factor of 2.5 reduction for higher-output power circuits. Package costs and test costs are being vigorously attacked to improve overall system costs. Early in 1989, the HARM missile program started using 1,200 MIMICs per month, and commercial applications of MIMIC-type devices now are occurring in the automotive industry. Texas Instruments expects to produce about 80,000 MIMICs for the HARM missile program.

A parallel Phase 3 MIMIC program also is under way, with 12 critical technology developments in progress in such areas as GaAs epi growth, multichip ceramic packages, modeling, and testing. MIMIC Phase 2, which will follow Phase 1 completion, remains scheduled to start in September 1991.

FORD MICRO DESIGNS 20 MMICS FOR US NAVY

Ford Microelectronics Inc. (FMI), which has been developing GaAs ICs for more than six years, has completed first-pass designs of 12 custom and 8 ASIC MMIC chips for the US Naval Electronics Center. All of the designs are intended for use in navy system applications. The chips are to be fabricated at FMI's Colorado Springs, Colorado, fab facility.

ADVANCES IN PRODUCIBILITY

In addition to ITT's high yields and TI/Raytheon's joint venture progress described earlier, Sumitomo and others have reported excellent results in advancing the state of the art of GaAs wafer and chip production.

Sumitomo Refines Its Wafer Production

Sumitomo has developed a mass-production back-grinding technology for thinning GaAs wafers containing MMICs to less than 150 microns. The technique incorporates a chemical etch after the grinding operation to reduce wafer bow induced during the grinding operation. The use of this approach caused threshold voltage shift of less than 5mV. The technique was demonstrated on a 16x16 parallel multiplier IC as well as on SSI-density OEICs. Sumitomo now uses this technology in the production of raw wafers as well as in IC manufacture.

TREND TOWARD COMMERCIAL APPLICATIONS

Widespread commercial consumption of GaAs MMICs is now evident, a sure sign that this once-infant technology is growing up. The adoption of GaAs ICs into TV receiver downconverters, GPS receivers, and cellular telephones has accelerated commercial consumption of MMICs. While the US commercial consumer-oriented market for TVRO MMICs was virtually destroyed by the combined lobbying of TV program producers and cable companies, the Asian and European markets have developed very rapidly. ANADIGICS, Hitachi, and Mitsubishi are three major benefactors.

Besides the personal communications applications anticipated by NTT, other markets are emerging. These markets include MMICs for proximity detection devices (as demonstrated by General Motors in 1989), GaAs ICs for industrial and medical instrumentation, and GaAs integrated sensors for a variety of applications. The pocket-sized location devices and radio/telephones are also expected to become high-volume users of GaAs MMICs.

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ANADIGICS Producing 1 Million MMICs for British Application

The monolithic down converter, developed initially in GaAs MMIC form by Pacific Monolithics, finally is in mass production for the European marketplace. One of the largest commercial GaAs MMIC orders to date was placed by British Satellite Broadcasting with ANADIGICS, Inc. of Warren, New Jersey. ANADIGICS reportedly has achieved a run rate exceeding 70,000 ICs per month on the device, which is a MMIC downconverter used in home TV receiver antenna circuits. The 2 x 2mm die, which is of MSI complexity, is packaged in a modified TO-5 header. The average selling price (ASP) for the device on the approximately 1-million-piece contract is approximately $8.

Hitachi Plans 200,000 DBS MMICs per Month by Mid-1991

Hitachi began producing its DBS tuner ICs in June 1990. The chips were developed for cost and power reduction rather than performance improvement. The prescaler will sell for approximately $3 and the amplifier for less than $1. Hitachi plans to market the MMICs in the United States and Europe. The company expects production volume to exceed 200,000 per month by July 1991; the percentage committed for internal use was not disclosed.

Mitsubishi's GaAs IC Volume Approaches $3 Million per Month

Mitsubishi Electric Company reportedly has increased its GaAs IC production volume to more than ¥4.5 billion (more than $30 million). The company manufactures MMICs for satellite broadcasting, as well as GaAs ICs for other applications. An unspecified percentage of the production is for internal consumption.

IMPROVEMENTS IN SILICON MMICs CITED BY AVANTEK

Engineers in Avantek's Advanced Bipolar Products Group recently reported a semicustom array approach to silicon MMIC implementation, trademarked "star-CHIP-1" by Avantek. The 40x60 mil die contains 92 low-noise npn transistors, 394 thin-film resistors, and 24 bonding pads. The die can be housed in a 180-mil hermetic package.

Experience on two circuits developed using this approach indicates that the prototyping cycle can be reduced to seven weeks compared with five months or more for full-custom designs. NRE break-even volume of a full-custom design for either function has been estimated to be approximately 10,000 units. The engineers consider this approach to be more cost-effective than a GaAs implementation for devices requiring operation below 5 GHz.

INP ICs FOR MM-WAVE APPLICATIONS

GaAs ICs fabricated to 0.5 micron or greater process rules tend to reach a performance barrier in the neighborhood of 40 GHz. The millimeter-wave (mm-wave) frequency band ranges from 30 to 300 GHz. Thus, mm-wave ICs producible to early to mid-1990s design rules require a higher-mobility substrate such as indium phosphide (InP).

InP wafers have been used for several years to build certain types of optoelectronic chips. There are now several suppliers of high-quality InP wafers, and chip designers have gravitated toward this material for fabrication of mm-wave ICs. Examples of recently designed InP ICs include Rockwell's 62 GHz multistage HEMT amplifier and Varian's 100-GHz high-gain cascode amplifier.

More high-performance mm-wave ICs are expected to result from a recent innovation by Hughes scientists. The team at Hughes has fabricated 250-GHz HEMTs on InP, which is more than 60 percent faster than the reported IBM record for silicon. The Hughes device should lead to even higher frequency operation than reported by Varian.

DESIGN SOFTWARE

Another indication of relative maturation of GaAs MMIC products is the growing availability of software for IC circuit design. Table 1 lists representative software products, approximate costs (to single users), and North American suppliers. There is no apparent relationship between cost and number of circuit models included in the various software packages. More than 50 percent of the sources shown are based in the Silicon Valley, and another 20 percent are in other California locations.

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TABLE 1
MMIC Design Software Examples

Program	Approximate Cost	Supplier	Location
Contec Spice	To $10K	Contec Microelectronics	San Jose, CA
HaRPE	To $24K	Optim. Systems Assoc.	Dundas, Ont., Canada
H-Spice	To $90K	Meta-Software Inc.	Campbell, CA
Icap	$1.1K	Intusoft	San Pedro, CA
IC-CAP	To $69K	Hewlett-Packard	Palo Alto, CA
Libra	$24K	EESof Inc.	Westlake Village, CA
Mac Spice	$2K	Deutch Research	Palo Alto, CA
Micro-Cap III	$1.5K	Spectrum Software	Sunnyvale, CA
Microwave Harmonica	To $365K	Compact Software	Paterson, NJ
Microwave Spice	To $12K	EESof Inc.	Westlake Village, CA
MNS/MDS	To $45K	Hewlett-Packard	Palo Alto, CA
NANA/Agile	$2K	Sarnoff Res. Ctr.	Princeton, NJ
P Spice	To $30K	MicroSim Corp.	Irvine, CA
Precise	To $80K	Elec. Engrg. Software	Santa Clara, CA
RoMPE	NA	Compact Software	Paterson, NJ
Scout	$3.5K	Compact Soue tware	Paterson, NJ
Serenade	To $260K	Compact Software	Paterson, NJ
Spectre	$0.15K	UC Berkeley	Berkeley, CA
Spice	$0.15K	UC Berkeley	Berkeley, CA
Spice w/interactive graphics	$19K	A.B. Associates	Tampa, FL
S Spice	To $25K	Silvaco	Santa Clara, CA
Super Compact	NA	Compact Software	Paterson, NJ
Suxes 20	To $35K	Elec. Engrg. Software	Santa Clara, CA
Toast-TCSB	$25K	Caroline Hablgand	Montreal, Que., Canada
Turbo Spice	$1K	Deutch Research	Palo Alto, CA
Utmost II	To $60K	Silvaco	Santa Clara, CA
Xtract	To $28K	EESof Inc.	Westlake Village, CA

NA = Not applicable
Source: Dataquest (September 1990)

DATAQUEST CONCLUSIONS

Major advancements in the field of GaAs MMICs have occurred in the past several months. These events are not isolated; rather, they emphasize the growing acceptance of MMIC technology in a wide range of applications, similar to the silicon linear IC experience in the 1970s. The large investments of resources during the mid- to late 1980s have started to reward suppliers that had the staying power to continue their contributions to this technology.

Dataquest believes that the successes reported herein are just the "tip of the iceberg" and that consumer GaAs MMICs will become significant revenue generators by the mid-1990s. To date, Japan has taken the lead in high-volume commercial applications while continuing to follow American design expertise. Thus, IC shipment and market penetration history is again repeating itself, with more market position shifts to come. American and European consumer electronic equipment suppliers can expect another onslaught of Japanese hardware in their respective markets, made more competitive by the adoption of GaAs ICs.

Gene Miles

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Research Newsletter

GaAs ICs BOOST III-V COMPOUND SEMICONDUCTOR GROWTH RATE

SUMMARY

GaAs IC growth through 1994 is expected to exceed Dataquest's forecast of December 1989, primarily because of aggressive entry of several markets by Japanese suppliers. Optoelectronic semiconductor shipments continued to increase during the first nine months of 1990 and are forecast to grow nearly 5 percent in 1990 over 1989. The outlook through 1994 has improved over last year's forecast. This newsletter examines the updated forecast and includes, for the first time, regional data by major product groups.

DATAQUEST ANALYSIS

GaAs and related III-V compound semiconductor ICs and discretes became a $3 billion market in 1989, with GaAs ICs and microwave/millimeter-wave (mm-wave) discrete shipments constituting 20 percent of the total. The worldwide market compound annual growth rate (CAGR) for these devices is forecast at more than 16 percent through 1994 (see Table 1). The North American market will increase somewhat more slowly, at slightly less than 15 percent (see Table 2). Europe will experience double-digit growth also, at more

TABLE 1
Estimated Worldwide GaAs Semiconductor Merchant Consumption
(Millions of Dollars)

	1988	1989	1990	1991	1992	1993	1994	CAGR (%) 1989-1994
Total	2,723	3,012	3,242	3,874	4,661	5,536	6,430	16.4
Analog/Linear ICs	157	187	242	319	407	514	643	28.0
Devices	107	141	194	272	368	472	600	33.6
NRE	50	46	48	47	39	42	43	(1.3)
DigICs	86	117	168	264	425	586	725	44.0
Devices	51	88	140	236	391	545	682	50.6
NRE	35	29	28	28	34	41	43	8.2
Optoelectronics	2,237	2,417	2,535	2,973	3,484	4,060	4,652	14.0
Discretes and CCDs	2,179	2,340	2,434	2,826	3,292	3,795	4,304	13.0
OEICs	58	77	101	147	192	265	348	35.2
Microwave/mm-wave								
Discretes	243	291	297	318	345	376	410	7.1

Source: Dataquest (October 1990)
Note: Data include intracompany consumption for merchant suppliers and exclude intracompany consumption by full captives. Optoelectronics include silicon IR emitters, silicon photodetectors, and laser drivers.

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TABLE 2
Estimated North American GaAs Semiconductor Merchant Consumption
(Millions of Dollars)

	1988	1989	1990	1991	1992	1993	1994	CAGR (%) 1989-1994
Total	717	788	835	981	1,143	1,337	1,577	14.9
Analog/Linear ICs	137	159	183	218	266	322	389	19.6
Devices	89	116	141	182	240	295	361	25.5
NRE	48	43	42	36	26	27	28	(8.2)
DigICs	69	92	111	166	229	285	365	31.7
Devices	37	66	92	149	208	259	336	38.5
NRE	32	26	19	17	21	26	29	2.2
Optoelectronics	394	406	420	470	516	588	675	10.7
Discretes and CCDs	353	353	353	382	405	439	477	6.2
OEICs	41	53	67	88	111	149	198	30.2
Microwave/mm-wave								
Discretes	117	131	121	127	132	142	148	2.5

Source: Dataquest (October 1990)
Note: Data include intracompany consumption for merchant suppliers and exclude intracompany consumption by full captives. Optoelectronics include silicon IR emitters, silicon photodetectors, and laser drivers.

TABLE 3
Estimated Western European GaAs Semiconductor Merchant Consumption
(Millions of Dollars)

	1988	1989	1990	1991	1992	1993	1994	CAGR (%) 1989-1994
Total	351	386	415	477	544	650	746	14.1
Analog/Linear ICs	15	17	20	28	37	59	91	39.9
Devices	13	15	17	23	31	52	84	41.1
NRE	2	2	3	5	6	7	7	28.5
DigICs	8	11	13	17	34	59	73	46.0
Devices	6	9	11	14	31	55	69	50.3
NRE	2	2	2	3	3	4	4	14.9
Optoelectronics	309	336	359	409	449	507	557	10.6
Discretes and CCDs	306	331	351	394	428	472	511	9.1
OEICs	3	5	8	15	21	35	46	55.9
Microwave/mm-wave								
Discretes	19	22	23	23	24	25	26	3.4

Source: Dataquest (October 1990)
Note: Data include intracompany consumption for merchant suppliers and exclude intracompany consumption by full captives. Optoelectronics include silicon IR emitters, silicon photodetectors, and laser drivers.

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TABLE 4
Estimated Asia/Pacific GaAs Semiconductor Merchant Consumption
(Millions of Dollars)

	1988	1989	1990	1991	1992	1993	1994	CAGR (%) 1989-1994
Total	1,655	1,838	1,992	2,416	2,974	3,549	4,106	17.4
Analog/Linear ICs	5	11	39	73	104	133	163	71.5
Devices	5	10	36	67	97	125	155	73.0
NRE	0	1	3	6	7	8	8	51.6
DigICs	9	14	44	81	162	242	287	83.0
Devices	8	13	37	73	152	231	277	84.4
NRE	1	1	7	8	10	11	10	58.5
Optoelectronics	1,534	1,675	1,756	2,094	2,519	2,965	3,420	15.3
Discretes and CCDs	1,520	1,657	1,730	2,050	2,459	2,884	3,316	14.9
OEICs	14	19	26	44	60	81	104	40.5
Microwave/mm-wave								
Discretes	107	138	153	168	189	209	236	11.3

Source: Dataquest (October 1990)
Note: Data include intracompany consumption for merchant suppliers and exclude intracompany consumption by full captives. Optoelectronics include silicon IR emitters, silicon photodetectors, and laser drivers.

than 14 percent (see Table 3). The Asia/Pacific region is forecast to gain market share, growing more than 17 percent through 1994 (see Table 4).

The outlook for digital ICs (digICs) is that they will have a 50 percent growth rate worldwide for the next five years. Asia/Pacific is expected to lead this growth with an increase of more than 80 percent per year (see Table 4). Fujitsu will capture much of the worldwide market share, leveraging from its dominant positions in emitter-coupled logic (ECL) ASICs and ECL RAMs and its acquisition of ICL's computer and Vitesse's submicron E/D MESFET ASIC technologies.

Nonrecurring engineering (NRE) revenue has softened as major programs have moved from the development stage to various levels of volume production. Analog/linear NRE is forecast to decline through 1992, as the US Department of Defense (DOD) MIMIC program insertion activities evolve from R&D to production status.

Although discrete optoelectronic devices and charge-coupled devices (CCDs) will continue to provide the majority of the compound semiconductor market segment's revenue, their percentage of the total will decline from 80 percent in 1989 to less than 70 percent in 1994, at $4.3 billion. Japan's shipments will constitute approximately 80 percent of that total by 1994, up from 70 percent of the 1988 market.

Microwave and mm-wave discrete demand will continue modest growth through the mid-1990s. These devices provide users with the ability to exceed IC performance levels in special situations such as ultralow-noise amplifiers and, as a result, will enjoy ongoing niche markets.

Gene Miles

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Research Newsletter

COMMERCIALIZATION EVIDENT AT 1990 GaAs IC SYMPOSIUM

SUMMARY

The 1990 IEEE-sponsored GaAs IC Symposium, held October 7 through 10 in New Orleans, Louisiana, provided some of the best examples to date of the practical applications of GaAs IC technology. Authors from numerous companies discussed multimillion-dollar programs that are capitalizing on the advantages of GaAs rather than silicon, which now include raw cost in both analog/linear and digital hardware. This newsletter reviews many of the developments presented at the symposium.

EUROPEANS COMMERCIALIZE GaAs ICs

Many GaAs manufacturing projects and programs are now under way in Europe, at the company, country, and European Community (EC) levels. The ESPRIT program, established in 1984, accomplished the feasibility demonstration of such GaAs ICs as 1K and 4K SRAMs (Philips LEP), 4-Gbps MUX/DEMUX (Plessey), and eight-stage multiplication (STL). ESPRIT II is oriented toward high-volume applications such as 20- to 80-GHz communications and automotive hardware and L, X, and Ku-band receivers. The ESPRIT III program is planned for 1991 through 1994. It is likely to include advanced packaging, high-volume material growth, CAD technology, and sub-0.5 micron IC developments.

Individual country programs are under way in Germany, Greece, Italy, the United Kingdom, and others. The programs are supported by GaAs foundry facilities at Daimler Benz, Philips, Plessey, Selenia, Siemens, Telettra, and Thomson, as well as by US and Japanese companies. The largest-volume commercial application of GaAs ICs in Europe to date is the direct broadcast satellite (DBS) receiver. More than 200,000 X-band receivers are manufactured in the United Kingdom each month.

The national program in France is sponsored by several agencies and is believed to be of a similar magnitude as that of Germany. Spain has plans for a future national foundry. Table 1 delineates most of the country programs and EEC programs for GaAs and related development and applications and includes current funding levels.

JAPANESE GaAs ICs GO COMMERCIAL

Japan's GaAs IC developments have been coordinated by MITI since 1981. The careful focus has resulted in a functional GaAs supercomputer and broad applications of GaAs ICs in the communications, industrial, data processing, automotive, and consumer electronics segments. Last month, Dataquest reported that Mitsubishi's GaAs shipments now exceed $3 million per month.

Other GaAs IC suppliers in Japan include Fujitsu, Hitachi, Matsushita, NEC, Sony, Sumitomo, and Toshiba. Since 1989, Fujitsu has had a technology exchange agreement with Vitesse that gives it access to 0.6-micron E/D MESFET arrays of up to 1 million transistors per chip. Sumitomo, Japan's largest GaAs wafer supplier, has a working relationship with GigaBit Logic that is expected to lead to volume GaAs IC production capability at Sumitomo.

End-equipment applications supported by Japanese GaAs IC suppliers include the following:

- Instrumentation—Anritsu and Avantest
- EDP systems—Fujitsu, Hitachi, and others
- Satellite broadcast transmitters and receivers (including 30-GHz transceivers)—Hitachi and NTT

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- TV/VCR front ends—Hitachi and others
- Fiber-optic transceivers, microwave data links—NEC
- Cellular radio transceivers—Fujitsu, Matsushita, NEC, and others
- DSP—Fujitsu and Oki

Other applications include GPS receiver hardware and radar detection, engine speed sensing, and collision avoidance hardware for automobiles. Suppliers of GaAs ICs to Anritsu and Avantest include NEC, Oki, and Toshiba. NEC expects GaAs ICs to compete favorably against silicon in many computer and engineering workstation applications.

TABLE 1
Currently Funded GaAs IC Programs in Europe

Country	Nature of Program	Participating Companies	Funding ($M)
Germany	GaAs and related R&D and applications	Daimler, Siemens, others	90
France	GaAs and related R&D and applications	Alcatel, Thomson, CNET, LEP (Philips), others	(Approx. 90)
Italy	Development of GaAs ICs and discretes	Telettra, Selenia, Italtel, and Elettronica	28
United Kingdom	14 programs in materials and processes; HBT, HEMT, and MESFET applications	Plessey and 15 others	24
Spain	ALE and other materials growth, MMIC design, modeling, and testing	Telettra, Telefonica, University of Barcelona, University of Madrid, National Microelectronic Center	10
Greece	GaAs materials, MMICs, MBE wafers, HBTs, GaAs on silicon wafers	FORTH, Intracom, MITOS, University of Thrace, University of Patras	8
EC	"COSMIC" (MMICs to 23 GHz)	Siemens, Plessey, Telettra, Telefonica, FORTH, Jansen, ArguMens, University of Madrid, University of Rome, PT Torino	70 (Approx. total funding for 6 EC programs)
	"GIANTS" (GaInAs R&D)	Plessey, Thomson, LEP, STL, Picogiga, FORTH, Farran, University of Madrid, University of Lille	
	"PLANET" (MOCVD reactor)	Philips, Aixtron, Polyflow, Telefonica, University of Madrid	
	"MORSE" (MBE growth of HBT and HEMT layers)	Thomson, Riber, RSRE, CNET, FORTH, several universities	
	"AIMS" (20- to 80-GHz receiver front end)	Thomson, Daimler Benz, Alcatel, Electronik Centralen, University of Lille	
	"MONOFAST" (mm-wave design and fabrication techniques)	Alcatel, GaAsCode, Farran Technology, NMRC, others	

Source: Dataquest (November 1990)

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GaAs FUELS MEMORIES AND VLSI ARRAYS

GigaBit Logic described two of its GaAs memory ICs now in volume production, a 4Kb SRAM and an 8Kb masked ROM. The SRAM is a pin-for-pin replacement for the silicon ECL 100474, with worst-case cycle time of 2.3ns compared with 5ns for the silicon part. The ROM is a pipelined architecture with on-board translation logic, which allows functioning as a 650-MHz 4Kx8 sine lookup table. Sandia Laboratories funded the ROM chip development.

Other evidence of GaAs VLSI commercialization was provided by Mitsubishi and Rockwell, each reporting 16Kb SRAM availability, and by Sony, with engineers that have developed a 10,000-gate JFET sea-of-gates chip.

Although Vitesse did not make a formal presentation of its Fury gate array series, the company announced a 64x64 cross-point switch based on Fury technology, in parallel with the conference. At one of the panel sessions, a Vitesse representative stated that during the last six months, the company's die sort yields have averaged 55 percent for 5,000-gate E/D MESFET arrays, 35 percent for 15,000-gate chips, and 18 percent for 30,000-gate chips. (Author's note: On November 5, 1990, Vitesse announced availability of VGFX100K and 200K arrays offering 102,000 and 195,000 raw gates for immediate availability and VGFX350K arrays with 353,000 raw gates per chip for second quarter 1991 designs. A VGFX350K chip will contain more than 1,000,000 transistors).

HBT TECHNOLOGY PRODUCES COMBO ICs

Heterojunction bipolar transistor (HBT) AlGaAs/GaAs technology offers many advantages over its silicon counterpart. These advantages include higher cutoff frequency (f_t), higher speed, more efficient speed-power product, reduced base resistance, and semi-insulating substrate. Rockwell has developed a high-yield GaAs HBT process, which satisfies the requirements of Table 2. The potential of the process has been demonstrated in 27-GHz frequency dividers, 10.3-ps/stage ring oscillators, and 98-GHz common emitter transistors, all produced on the same wafer. Yield for the transistors, which have f_{max} of 218 GHz, was more than 90 percent. The company has also operated an HBT phase-detector chip containing 134 HBTs. Using this technology, Rockwell is developing a single-chip digital PLL with voltage-controlled oscillator.

Other groups represented at the conference reported progress in HBT technology. Those included CNET and Thomson (France), FORTH (Crete), Hughes, Pacific Monolithics, and TRW (United States), Plessey (United Kingdom), and Toshiba (Japan), as well as several universities.

TABLE 2
Requirements for Multifunctional HBT ICs

Parameter	Analog ICs	Digital ICs	Microwave Power ICs
f_t	Very high	High	Very high
f_{max}	Very high	High	Very high
R_b	Low	Low	Very low
C_c	Low	Low	Very low
C_{be}	Low	Very low	Low
Beta	10-30	20	10-20
BV_{ceo}	>10V	>2V	>10V
BV_{cbo}	>5V	>3V	>20V
V_{be}control	Good	Good	Good
Yield	High	Very high	High
Transistor Size	Moderate	Small	Large
Signal Level	Small	Small	Large

Source: Rockwell

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DATAQUEST CONCLUSIONS

The conferees confirmed that GaAs IC technology is gaining momentum throughout the world market and is well past the critical mass requirements for marketability and volume consumption. Although some participants question the viability of Vitesse's 1,000,000-transistor chips in the near term (i.e., mid-1991 production), there was no apparent doubt about the production worthiness of GaAs VLSI. The Fujitsu/Vitesse and Thomson/Vitesse alliances and the reported progress on the Japanese National Supercomputer project are good indicators that the days of United States dominance of the supercomputer marketplace now hinge on a major turnaround in the recent lackluster performance exhibited by the shutdown of Prisma and by CRAY, IBM, and the other US-based supercomputer system houses.

Evidence of the approaching threat of the superior performance of HBT technology to that of E/D MESFET and JFET is mounting. One wonders if the CRAY 4 should stick with the E/D MESFET approach or switch to HBT. However, Dataquest expects E/D MESFET to continue to grow rapidly into the mid-1990s because of its cost/performance advantages over silicon ECL and BiCMOS for mainstream EDP and digital communications designs.

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Research *Bulletin*

GaAs ICs PROPEL JAPAN'S NATIONAL SUPERCOMPUTER

SUMMARY

Hitachi recently described test results for the Japanese National Supercomputer Project. This bulletin reviews highlights of the presentation.

DISCUSSION

In 1981, Dataquest reported that Japan was embarking on a nine-year program to gain national advantage in the computing field. A major ingredient of this program was the Fifth-Generation Computer Project sponsored by Japan's Ministry of International Trade and Industry (MITI). Japanese government funding of approximately $120 million, supplemented with R&D by Fujitsu, Hitachi, Mitsubishi, NEC, Oki, and Toshiba, supported the effort. Objectives included a thousandfold improvement in computing speed and a hundredfold reduction in package volume.

To achieve system performance objectives, device technology requirements were set at 30 picoseconds per gate (ps/gate) at room temperature and 10 ps/gate at 77°K for logic LSI chips and at sub-10ns cycle time for 16K SRAMs at room temperature. The demonstration hardware consisted of a high-speed parallel processor with four processing elements, a distributed parallel processor, and a 4Gb high-speed storage unit. In January 1990, the demonstration unit was operated at 10.9 Gflops (billions of floating-point operations per second). GaAs IC applications in the demonstration system were as follows:

- Bus drivers for HPP—1.1K-gate logic LSI using 0.5-micron-gate AlGaAs/GaAs HEMTs (8 chips, supplied by Fujitsu)
- Pseudorandom number generator—3.3K-gate E/D DCFL HEMT LSIs operated at 77°K (8 chips, supplied by Fujitsu)
- System controller—1.3K-gate HEMT LSIs with 17ps gate delay, operated at 77°K (4 chips, supplied by Fujitsu)
- Data buffer—0.7-micron-gate HEMT-based 4Kb SRAMs with 0.5ns cycle time, operated at 77°K (8 chips, supplied by Hitachi)
- Cellular array processor—16Kb (4Kx4) SRAMs with 4.4ns access time, using buried-p-layer, lightly-doped-drain MESFETs and three-layer metal interconnects (64 chips, supplied by Mitsubishi)
- Variable pipeline processor—3,376-logic-gate and 76-bit dual-port register-file (8-bit bus logic) LSIs using 0.8-micron-gate MESFETs (48 chips, supplied by Toshiba)
- Display processor—100-gate and 700-gate, 0.5-micron inverted-HEMT MSIs, one each per chip set (6 chips)

The aforementioned chips were used to implement a demonstration system that transferred data from storage at 1.6 Gbytes per second (Gbps) and performed color signal processing at 400 MHz. The four-element parallel processor was operated at 10.9 Gflops, placing it near the high end of available supercomputing systems. Based on demonstrations already completed, Hitachi concluded that GaAs LSI is ready for the mainstream EDP marketplace.

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Research Newsletter

A GLIMPSE INTO THE WORLD OF ODP

OVERVIEW

Optical data processing (ODP) is a rapidly developing field of applied physics that is relatively untapped by the IC industry. A merging of several disciplines is occurring, the effects of which will continue to be revealed and felt well into the next century. This newsletter offers a brief look at the technologies involved and raises several issues warranting consideration by many of our clients.

WHAT IS IT?

ODP, often referred to as the field of fiber optics, has become an increasing part of our lives in recent years.

Because optical technology uses photons instead of electrons to move data through transmission media (which may include free space), communications are accomplished at much higher speed and lower cost than is physically possible through electronic media such as copper wire. (Electrons are much heavier and therefore more difficult and more costly to manipulate than photons.) The free-space transfer of photons over short distances allows elimination of large numbers of hardware interconnections, enhancing the speed and cost of data processing.

Photonic data buffering, switching, and storage offer the potential to lower computer internal connection costs and communications costs even further. Optical data lends itself to parallel processing, which fits well with the concept of neural networks. Also, optics technology permits efficient implementation of associative (content-addressable) memories, which are very powerful for parallel processing and cache storage.

These realities led to the application of photonic concepts to the data processing within computers and other hardware. Early in 1990, AT&T announced the world's first ODP system, and the company maintains the lead in the race to an all-photonic computer.

All of these factors are spurring interest in ODP, a term coined years ago to describe this emerging field. ODP includes a wide range of disciplines, including holography, liquid-crystal technology, microscopy and telescopy, and others, which will not be discussed herein. This newsletter is confined to ODP as it relates to active devices implemented on or within silicon or compound semiconductor substrates.

TERMINOLOGY

As with any technology, ODP is developing a unique jargon. Several abbreviations relating to this newsletter's discussion are defined as follows:

- BSOC—Bit-serial optical computer
- CAM—Content-addressable memory, a type of memory for which the input is the data and the output is all of the addresses at which the data occurs; also known as associative memory
- CCD—Charge-coupled device, a semiconductor element that stores and moves electron charge packets that are proportional to the photonic energy to which the device is exposed
- CdTe—Cadmium telluride, a compound semiconductor material that has higher photorefractive sensitivity than GaAs, InP, and others
- DSDLM—Digital synchronous delay line memory

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- LCD—Liquid-crystal display
- LCLV—Liquid-crystal light valve
- LED—Light-emitting diode
- $LiNbO_3$—Lithium niobate, a material used in certain photonic couplers
- OEIC—Optoelectronic integrated circuit
- OELE—Optoelectronic logic element
- PIC—Photonic integrated circuit
- PMMA—Polymethylmethacrylate, a material proposed for integrating three-dimensional structures containing lenses and PICs
- SEED—Self-electro-optic effect device
- SESQW—Surface-emitting strained-layer quantum well, a type of laser developed by AT&T
- SSL—Symbolic substitution logic

WHO IS DOING WHAT IN ODP?

Devices that convert photonic energy to electronic energy and vice versa are in mass production in many forms, including CCDs, lasers, LCDs, LEDs and LED arrays, optocouplers, photodetectors, and OEICs. These devices use silicon, GaAs, InP, or other semi-insulating or semiconducting substrates in the manufacturing process. All major, broad-line IC manufacturers have developed considerable expertise in one or more of these products, particularly in those devices that use silicon as the substrate. However, many of these suppliers have little or no R&D activity under way that is directed toward more advanced forms of ODP IC, such as optical (photonic) adders, multipliers, neural network chips, or read-write memories. The usual reason given is the focus on the near term, or next quarter's and this fiscal year's results at the expense of developing long-term survival capability.

Table 1 is a representative listing of organizations and projects involved in the field of ODP. It is by no means exhaustive and will be updated as necessary.

OPEN ISSUES

ODP and photonics-based designs offer many opportunities to make great strides in computing speed and efficiency. However, many issues must be dealt with before the full potential can be realized. The following are some examples of significant problems to be solved:

- Relatively little can be gained by adding photonic interconnections to electronic digital hardware implemented with electronic ICs compared with the approach of all-photonic computing. Thus, system architecture and software requires new approaches.
- Although optical storage systems can hold an order of magnitude more data per unit area than can magnetic disks, access time is relatively slow.
- Using multibeam reading can speed optical storage access by at least two orders of magnitude, which would overload almost all CPUs in existence today.
- No coherent infrastructure supports ODP; a variety of disciplines such as applied physics and applied optics are supporting fragments. Often, little or no dialog exists between ODP and EDP practitioners at any level, from basic materials through IC components to systems hardware and software.
- The first ODP ICs are still in the R&D stage at a few large companies. Very little venture capital has been entered into the race to support start-ups; much will be needed.
- Most CPU-based system architects are bound by thought processes developed around the constraints of electronic ICs. Few corporate management teams are even aware that this may present a long-term survival problem and fewer still really care.

Perhaps the most important issue facing both GaAs and silicon IC houses is this: Is it sufficient to maintain the status quo in electronic devices for EDP systems, or should the horizon be expanded to include all-photonic ICs for the emerging ODP equipment market?

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TABLE 1
Representative ODP Activities

Organization	Location	ODP Activity
APA Optics	Blaine, MN	GaAs intensity modulators
AT&T Bell Labs	Holmdel, NJ Naperville, IL Murray Hill, NJ	Developing SEED arrays, photonic cross-bar switches, all-photonic computers, and arrays containing the world's smallest galium arsenide SLSQW lasers
Call/Recall Corp.		3-D memory based on two-photon effect
Carnegie-Mellon University	Pittsburgh, PA	Fast algorithms for optical filter design
City College	New York, NY	CAM-based and other ODP hardware using symbol substitution algorithms
DARPA, USAFOSR, Honeywell, Boeing	Washington, D.C.	Massively parallel optical computer architecture studies
Delft University	Delft, Holland	Application of OELEs to multiprocessing
DSM Research	Geleen, Holland	Implementing OELEs in multiprocessors
Hamamatsu Photonics KK	Hamamatsu, Japan	Learning capability studies of photonic CAMs
Heriot-Watt University, RSRE, ECC; Boeing Aerospace; four other Scottish universities	Edinburgh, UK	Optically bistable filters using GaAs lasers and ZnSe nonlinear photon filters; optical computer storage
Kyushu University	Fukuoka, Japan	Design of laser diode modules with spherical and other lense types
Micracor, Inc.	Boston, MA	Developing the world's first 10¢ laser
MIT Lincoln Labs	Lexington, MA	Gbps board-to-board photonic interconnections
Nestor, Inc.	Providence, RI	Application of optical neural networks to pattern recognition
NTT Labs	Kanagawa and Tokyo, Japan	Developing ODP ICs; implementation of ODP hardware using SLMs in electronic host computer
Opticomp Corp.	Santa Fe, NM	16-bit optical computer architecture

Source: Aztek Associates

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TABLE 1 (Continued)
Representative ODP Activities

Organization	Location	ODP Activity
Osaka University	Osaka, Japan	Optoelectronic parallel processing logic
PA State University	ARL State Coll., PA	Optical tunnel applications in computing
Shanghai Institute	Shanghai, PRC	Optoelectronic implementation of cellular logic with polarization coding
Sony, CAL Tech	Tokyo, Japan; Pasadena, CA	ODP hardware development using WORM disk and GaAs neurons
UCLA	Los Angeles, CA	IR neurons implemented in CdTe
University of California/United States Navy Office of Naval Research (USNONR)	La Jolla, CA	3-D memory based on two-photon effect
University of Colorado	Boulder, CO	Building GHz-rate BSOC using $LiNbO_3$ gates and DSDLM storage technologies
University of Neuchatel	Switzerland	ODP hardware R&D using LCLVs and SLMs
USSR Academy of Science	Novosibirsk, USSR	Integrated optical digital computer R&D
University Phys. Institute	Erlangen, FRG	H^+ proton-beam formation of PMMA structures
USAFOSR, Carnegie-Mellon University	Washington, D.C.	Optical computing architectures and algorithms
United States National Science Foundation (USNSF), University of Arizona	Washington, D.C.	SSL algorithm development
USNONR, University of Alabama, Georgia Institute of Technology	Washington, D.C.	Development of ODP algorithms for CAM storage applications
Yonsei University	Seoul, South Korea	R&D of coding algorithms for logic operations in photorefractive crystals

Source: Azriel Associates

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DATAQUEST CONCLUSIONS

Dataquest believes that optical data processing is on its way to the marketplace, as exhibited by AT&T's commitment to this technology. The promise of ODP is that it offers major improvements in computing, storage speed, and efficiency, and lower-cost massively parallel data processing systems. As with any technology that has the potential for huge financial rewards for its practitioners, there appears to be a worldwide movement toward accomplishing the R&D needed to generate marketable products. Many significant problems are posed to the eventual participants in this infant industry; the next century will arrive before some of these are solved.

Gene Miles

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Research Newsletter

ASIAN ACTIVITIES IN COMPOUND SEMICONDUCTORS IN 1990

SUMMARY

Annually, Dataquest prepares a summary of significant activities involving GaAs and related compound ICs and discrete semiconductors in Japan and other Asian countries. This newsletter highlights Asian companies' progress in this field during 1990. It includes information about the performance of GaAs ICs used in Japan's National Supercomputer Project. For the first time, particular focus is placed on GaAs ICs and related devices for optical data-processing applications.

JANUARY

Honda began captive pilot production of GaAs ICs for engine control sensors. Expansion of the facility, which is located in Hoga, Japan, will cost $14 million before its completion in 1992. Toyota and Nissan also have in-house IC capability, but Honda was first to produce GaAs ICs.

Fujitsu Ltd. announced that it will build a GaAs 4-inch wafer fab facility in Yamanashi Prefecture at its wholly owned subsidiary, Fujitsu Yamanashi Electronics Ltd. The plant is part of Fujitsu's five-year plan to boost its communications equipment sales through intelligent communications and information-processing services, in which GaAs ICs are positioned as strategic devices.

Hitachi Ltd. and Mitsubishi Electric Corp. completed the prototype development of 4K GaAs SRAMs and demonstrated system operation as a part of the National Supercomputer Project. This program is sponsored by the Agency of Industrial Science and Technology, a division of MITI.

Engineers at Hitachi's Consumer Products Research Center have developed a compact GaAs tuner for use in 12-GHz satellite communications. The tuner uses a downconverter IC and an amplifier IC to reduce unit size by 50 percent to 40cc; Hitachi contends that it is the most compact tuner in the world.

Shizuoka University (Hamamatsu City, Japan) and Swiss Federal Institute scientists reported the first photovoltaic IR sensors fabricated in PbS layers on Si wafers. The design uses a stacked CaF_2-BaF_2 buffer layer to overcome the large lattice and thermal-expansion mismatches between the PbS and the Si.

Scientists at Academy Sinica (Beijing, China) performed photoluminescence studies in an effort to better understand the radiation mechanisms in heavily doped n-type and p-type GaAs materials. Silicon and beryllium were used as dopants in the studies.

NTT's Optoelectronic Laboratories reported operating relatively stable GaInAs single-quantum well lasers at 30mW CW and pumping Er (erbium)-doped fiber amplifiers with maximum signal gain of 37.8dB at 1.536-micron wavelength. The use of Er-doped fiber in communication links has previously been demonstrated by AT&T as a means of eliminating regenerator circuits in undersea cables, greatly enhancing reliability.

FEBRUARY

Mitsubishi Electric Corp. has plans to build a GaAs semiconductor facility at an expected cost of ¥5 billion ($34.5 million) to support its satellite communications business. Monthly capacity will be 500,000 ICs, using a 4-inch fabrication process.

In a paper presented at the ISSCC in San Francisco, Fujitsu Ltd. reported developing a high-speed random-number generator using high electron mobility transistor (HEMT)-based ICs. The three types of ICs used were a system controller LSI, a data buffer LSI, and a 3319-gate shift register/logic chip. The subsystem operates at liquid nitrogen temperature at 1.6 GHz and has

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4.5W power consumption. The development was part of the National Supercomputer Project.

NEC developed a 0.5-micron-gate metal-insulator semiconductor field-effect transistor using AlGaAs layered onto a GaAs substrate. The transistor, referred to by NEC as a doped-metal transistor, allows a gate-switching speed of 4.8ns in a 25-stage ring oscillator. A 5-stage shift register using the device was operated at 5 Gbps while consuming 45mW of power. NEC plans to apply the technology to optical communications systems.

Toshiba began marketing samples of its TOLD9220, a semiconductor (InGaAlP) index-guided CW laser operating at 660nm wavelength. Priced at approximately $200, the device is intended to replace 670nm models and surpass helium-neon gas lasers in many applications. Toshiba expects to market 638nm diode lasers within a few years.

MARCH

Major Asian chipmakers plan to increase production of GaAs HEMTs used in downconverters for satellite broadcast receivers. The market in Japan for satellite antennas grew 40 percent in 1989 to 650,000 units and was expected to triple in 1990. Mitsubishi doubled its HEMT production to approximately 300,000 units per month, and Sony tripled its output to 100,000 units per month. Other manufacturers were expected to follow these moves.

Hamamatsu Photonics engineers fabricated metal-semiconductor-metal photodiodes for use in ultrafast optical impulse detection applications. The photodiode area is 10 microns on each side. Measured rise and fall times were each less than 10ps.

Mitsubishi's Central Research Lab (CRL) (Amagasaki, Hyogo) built and characterized quantum well wires (QWWs) on GaAs by MBE. The 7nm-thick-by-90nm-wide wires were spaced on 220nm centers. The structures will be applied to photonic ICs. Mitsubishi's CRL also reported demonstrating ultrahigh gain HBTs (gain values ranging from 112,000 to 141,000) of InGaAsP-on-InP substrates.

NEC scientists (Fundamental Research Labs, Tsukuba, Ibaraki) achieved atomic layer epitaxy (ALE) growth of InGaP/GaAs alternating layers on GaAs with monolayer control. The process, more precisely defined than is possible with metal-organic CVD or MBE, supports ultrafine IC fabrication.

NEC Corp. has reached an agreement with the Chinese government (People's Republic of China) to build an IC plant in Beijing for production of ICs for communications systems. The joint-venture agreement follows the lifting of economic sanctions by the Japanese government and relaxation of COCOM regulations.

APRIL

Fujitsu Ltd. planned to boost its production of HEMTs to 3 million units per month by the end of 1990, tripling its rate. As many as five HEMTs are in each satellite broadcast receiver antenna, and more than 1 million such antennas will be consumed by the Japanese market in 1990.

NEC announced a 20-year plan to invest ¥30 trillion ($200 billion) to connect every household and office in Japan through a digital fiber-optic network. The plan includes development of terahertz transmission-rate hardware and HDTV service and is expected to place large additional demand on the compound semiconductor IC industry infrastructure.

A U.S. District Court ruled that Sumitomo Corporation infringed on Corning Inc.'s optical waveguide patents. Sumitomo was ordered to pay $25 million in settlement.

Toshiba America began marketing 5mW visible laser diodes (VLDs) that use index guiding to reduce astigmatism by a factor of three. The VLDs have threshold current of 50mA versus the industry standard of 80mA, making the devices suitable for battery operation.

A research group at Toyohashi University of Technology built a prototype optical-calculating chip. The device uses a laterally variable refractive film as a light switch. By processing photons instead of electrons, the chip performs arithmetic literally at the speed of light. Expected applications include computers, pattern recognition, and artificial intelligence systems.

Hewlett-Packard Company established a research laboratory in Tokyo, which will focus on applied research in photonics. The staff will work with other HP scientists as well as visiting scientists and professors on projects of interest to HP and its joint venture, Yokagawa Hewlett-Packard.

MAY

Mitsubishi Electric Corporation, a major supplier of semiconductors including GaAs and related

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compound semiconductor ICs, lasers, and other discretes, launched a major market expansion initiative in Southeast Asia. The company set up a technical support center in Singapore, adding to its current sales and marketing bases in Taiwan, Hong Kong, and South Korea.

NTT's Optoelectronic Laboratory (Atsugi, Japan) achieved 40ps response times on photodiodes fabricated by the MBE growth of AlGaInAs/InAs MQW structures on GaAs substrates. Intended applications include detection of 160nm wavelength signals.

Scientists at the Indian Institute of Technology and the Tata Institute of Fundamental Research, Bombay, India, fabricated and analyzed OPFETs (photo-metal semiconductor FETs), which are capable of detecting 100ps light pulses at a 2-GHz rep rate. They found that the light-energy level above the bandgap of the transistor is detected by band-to-band excitation, and light energy below the bandgap of the transistor is detected by internal photoemission. In each case, the MESFET gate Schottky barrier is acting as a photodiode.

Japan's Optoelectronic Industry Trade and Development Association reported that Japan's production of optoelectronic detectors and sensors grew by 13 percent, from ¥26.2 billion to ¥29.5 billion ($187 million to $210 million) for the year ended March 31, 1990, versus fiscal year 1988 ended March 31, 1989.

JUNE

Toyohashi Institute of Technology (Aichi, Japan) students proposed a photodiode/4-FET cell for application in neural networks as an OEIC synaptic-connection circuit with variable analog weights. This work is supported by the Japan Ministry of Education, Science, and Culture.

Scientists at the Tokyo Institute of Technology completed characterization studies of CuInSe and other II-VI compounds for solar-cell applications. A conversion efficiency of 8.16 percent was achieved for cadmium sulfide on CuInSe by optimizing the structures using Raman scattering spectrometry.

Toshiba's Kawasaki R&D Center reported using a KrF excimer laser to grow GaAs epitaxial layers over the range of 470 to 530°C, enabling volume production by the ALE method. The allowable temperature spread without laser irradiation was so narrow that it prevented highly repeatable results.

NTT's Yokosuka Electrical Communication Laboratories (Kanagawa, Japan) developed a digital mobile transceiver containing the following chips:

- GaAs MSI quadrature modulator IC
- GaAs LNA, frequency divider, and detector IC
- Si CMOS LSI waveform generator, coherent demodulator, codec, and framing circuit

JULY

Matsushita built and operated a 32 x 32 array of optoelectronic bistable switches, with each cell consisting of an HPT and an LED. Optical feedback from the LED to the HPT causes latching. The chip is called a photonic parallel memory.

Engineers at NEC's Optoelectronic Research Labs, Ibaraki, Japan, reported building and testing MBE-grown matrices of vertical-to-surface transmission electrophotonic device structures. The devices have optical-switching energy of 2pJ when biased at 1.9 volts. By using a laser diode light beam through an optical-mask pattern, the parallel operation functions of optical pattern writing, memory retention, optical regeneration, and erasing were performed. NEC plans to integrate the functions into larger arrays for use in optical data-processing systems.

Sumitomo fabricated a GaAs 16 x 16 multiplier IC using electron-cyclotron resonance CVD (ECR-CVD). Yields were at the 50 percent level, using 0.45u gate FETs, which demonstrated 39-GHz cutoff frequency.

Researchers at Sophia University (Tokyo, Japan) demonstrated what they reported to be the first emission of yellow light using MQW lasers grown by GS-MBE. The lasers consist of GaInP/AlInP layers on InP substrate, emitting at 576nm wavelength.

NEC introduced an optical hand-held range finder based on an Er-doped fiber amplified (EFDA) laser emitting at 2.8-micron wavelength, considered "eye-safe" by the manufacturer. Resolution is 5 meters over a working range of 100 to 10,000 meters.

Researchers at Fujitsu and KDD reported that EFDAs could be cascaded up to 100 stages without restricting 2.5-Gbps optical signals. The limit for semiconductor laser amplifiers was considered to be 20 stages at a 2.5-Gbps transmission rate.

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AUGUST

Recent III-V device work by Asia/Pacific organizations is described in Table 1.

SEPTEMBER

Sumitomo developed a mass-production, back-grinding technology for thinning GaAs wafers containing MMICs to less than 150 microns. The technique incorporates a chemical etch after the grinding operation to reduce wafer bow. The use of this approach caused threshold voltage shift of less than 5mV. The technique was demonstrated on a 16 x 16 parallel multiplier IC as well as on SSI-density OEICs. Sumitomo now uses this technology in the production of raw wafers as well as in IC manufacturing.

Matsushita developed a microbump bonding method for assembling GaAs LED array modules. The first modules were functions containing LED chips and LSI driver chips, mounted on a glass substrate.

NTT reported a new method of measuring strain distribution within an optical fiber, in contrast to previous methods, which were limited to measuring average strain over the entire cable length. The method involves using laser-induced pump and probe beams to measure back-traveling power over time.

OCTOBER

Hitachi described test results for the Japanese National Supercomputer Project at the 1990 GaAs IC Symposium. Japanese government funding of approximately $120 million, supplemented by R&D support from Fujitsu, Hitachi, Mitsubishi, NEC, Oki, and Toshiba, supported the project. Objectives included a thousandfold improvement in computing speed and a hundredfold reduction in package volume.

To achieve system performance objectives, device technology requirements were set at 30ps per gate at room temperature and 10ps per gate at 77°K for logic LSI chips and sub-10ns cycle time for 16K SRAMs. The demonstration hardware consisted of a high-speed parallel processor with four processing elements, a distributed parallel processor, and a 4-Gbyte high-speed storage unit. In January 1990, the demonstration unit was operated at 10.9 Gflops. GaAs IC applications in the demonstration system were as follows:

- Bus drivers for HPP—1.1K-gate logic LSI using 0.5-micron-gate AlGaAs/GaAs HEMTs (8 chips, supplied by Fujitsu)
- Pseudorandom number generator—3.3K-gate E/D DCFL HEMT LSIs operating at 77°K (8 chips, supplied by Fujitsu)

TABLE 1
Recent III-V Semiconductor Developments in Asia/Pacific

Organization	Location	Topic
National Defense Academy	Yokosuka, Japan	Properties of AlGaAs
National Cheng Kung University	Tainan, Taiwan	MBE-grown AlGaAs
Nagoya Institute of Technology	Santa Clara, California	MOCVD of GaAs on Si wafers
NTT Opto-Elec. Lab	Kanagawa, Japan	Ar laser-assisted epi growth of GaAs, GaP, GaAsP
Osaka University	Osaka, Japan	MBE-grown GaAs on Si wafers
Mitsubishi Opto and Microwave R&D Lab	Hyogo, Japan	AlGaAs laser diode fabrication techniques
Japan Broadcasting Corp.	Setagaya, Japan	Bistable laser diode operation
Sony Corp. Research Center	Yokohama, Japan	Modeling and characterization of GaAs JFETs and MESFETs
KAIST (Korea Advanced Institute of Science and Technology	Seoul, South Korea	HFETs using GaAs
NEC R&D Laboratories	Kawasaki, Japan	Sidegating in GaAs MESFETs

Source: Aztek Associates

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- System controller—1.3K-gate HEMT LSIs with 17ps gate delay, operating at 77°K (4 chips, supplied by Fujitsu)
- Data buffer—0.7-micron-gate HEMT-based 4Kb SRAMs with 0.5ns cycle time, operating at 77°K (8 chips, supplied by Hitachi)
- Cellular array processor—16Kb (4Kx4) SRAMs with 4.4ns access time, using buried-p-layer, lightly doped-drain MESFETs, and three-layer metal interconnects (64 chips, supplied by Mitsubishi)
- Variable pipeline processor—3,376-logic gates and 76-bit dual-port register file (8-bit bus logic) LSIs using 0.8-micron-gate MESFETs (48 chips, supplied by Toshiba)
- Display processor—100-gate and 700-gate, 0.5-micron inverted-HEMT MSIs, one each per chip set (3 sets or 6 chips)

These chips were used to implement a demonstration system, which transferred data from storage at 1.6 Gbps and performed color signal processing at 400 MHz. The four-element parallel processor was operated at 10.9 Gflops, placing it near the high end of available supercomputing systems. Based on demonstrations already completed, Hitachi concluded from this work that GaAs LSI is ready for the mainstream EDP marketplace.

NOVEMBER

KDD and AT&T planned a new transpacific cable system, which will connect Japan and the U.S. mainland by 1996. The 2.4-Gbps system will employ Er-doped fiber repeaters rather than optoelectronic repeaters, eliminating the need for reconfiguration when bit rates or modulation schemes change.

Matsushita's Semiconductor Research Center (Osaka, Japan) has generated 12.3mW of second-harmonic blue light from a semiconductor laser source. This was done by using a $LiNbO_3$ proton-exchanged waveguide doped with MgO, driven by an AlGaAs laser.

NTT's Lightwave Communications Laboratory (Tokai, Japan) engineers accomplished 180-250fs (femtosecond) optical pulse generation with peak power of 260W and average power of 32mW using a gain-switched DFB laser diode, erbium-doped amplifiers, and three-stage soliton compression. NTT operated a 40-Gbps time division cell multiplexer for a photonic asynchronous transfer mode switch. By using MQW lasers, NTT hopes to raise the bit rate to several hundred Gbps.

NTT LSI Labs (Kanagawa, Japan) reported building high-gain, carbon-doped MOCVD-grown AlGaAs/GaAs HBTs. The transistors demonstrated current gain of 100. NTT is developing AlInAs/InP HEMTs and has demonstrated 0.8u-gate devices with f_{max} of 65 GHz and f_T of 22 GHz. The company claims these to be the best results reported to date.

DECEMBER

NTT Optoelectronic Labs (Kanagawa, Japan) reported improved InAlAs/InGaAs on InP HBTs, achieving gain of 200 at I_c of 10mA and f_T of 96 GHz. Potential applications involve integrating the HBTs onto OEICs along with 1.3- to 1.55-micron-range optical sources and detectors.

Engineers at Hamamatsu Photonics KK have designed a dynamic optical memory cell consisting of two photodiodes and a laser diode. The cell, measuring 100 x 100 microns, requires minimum speed-power products for set and reset operations of 5 and 35pJ, respectively. Applications will include optical data-processing (ODP) systems.

Other ODP developments under way at various Asia/Pacific organizations include those shown in Table 2.

DATAQUEST CONCLUSIONS

As 1990 ended, Japan maintained its lead among Asia/Pacific competition in the compound semiconductor arena, particularly in GaAs digital and linear ICs and in semiconductor lasers. Among Asia/Pacific companies, NTT continues to lead in basic compound semiconductor device R&D, particularly in those areas expected to result in more efficient optical communications and switching systems. In fact, on a worldwide basis, NTT appears to be second only to AT&T's Bellcore.

Although much effort has been directed toward optical computing and data processing, the rewards to date have been few. The primary benefits so far have appeared in digital communication systems within Japan. The technology required to build an all-optical computer still appears a few years away from critical mass in Japan, with other Asian countries behind Japan in this technology.

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TABLE 2
Representative ODP Activities

Organization	Location	ODP Activity
Hamamatsu Photonics KK	Hamamatsu, Japan	Learning capability studies of photonic CAMs
Kyushu University	Fukuoka, Japan	Design of laser diode modules with spherical and other lens types
NTT Labs	Kanagawa and Tokyo, Japan	Developing ODP ICs; implementation of ODP hardware using SLMs in electronic host computer
Osaka University	Osaka, Japan	Optoelectronic parallel processing logic
Shanghai Inst.	Shanghai, PRC	Optoelectronic implementation of cellular logic with polarization coding
Sony, Cal. Tech	Tokyo, Japan; Pasadena, California	ODP hardware development using WORM disk and GaAs neurons
Yonsei University	Seoul, South Korea	R&D of coding algorithms for logic operations in photorefractive crystals

Source: Aztek Associates

Following NEC's lead, Fujitsu and Hitachi are helping to bring IC technology into the consumer household, finding applications in portable radiotelephones, TV front-end hardware, and satellite TV downconverters. With expansion under way at Honda, the automotive industry now has a Japanese supplier capable of producing its own GaAs chips for engine control and other applications.

Perhaps most disconcerting of the 1990 developments to U.S. and European computer makers alike, is this: The Japan National Supercomputer Project is running (at 10.9 Gflops) on GaAs LSI chips. Cray and others are letting huge opportunities slip away as yet another U.S.-invented industry yields to growing Japanese competition.

Gene Miles

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Research *Bulletin*

TRIQUINT/GBL MERGER STRENGTHENS U.S. GaAs INDUSTRY

The January 24 letter of intent to merge, released by TriQuint (Beaverton, Oregon) and GigaBit Logic (GBL) (Newbury Park, California), will result in the world's largest GaAs IC house. Japanese competition grew rapidly in 1990; this move will add significant power to the two companies' respective marketing forces, positioning the new TriQuint Semiconductor, Inc., as the dominant supplier of both digital and analog/linear GaAs ICs.

An office of the president has been established, consisting of Al Patz, president of TriQuint, and Spencer Brown, president of GBL, to finalize details of the intended merger, which will be consummated by March 31, 1991. Until that date, the two companies will maintain separate operations. The combined companies have a population of 265 employees and a run rate of approximately $2.5 million per month. Dataquest expects the new company to ship well in excess of $40.0 million in 1991 to a base of customers exceeding 500; combined sales in 1990 were approximately $30.0 million.

TRIQUINT

TriQuint is a 1985 start-up and a subsidiary of Tektronix (Beaverton, Oregon) specializing in analog/linear GaAs ICs and high-frequency IC packaging. The company is the leading supplier of GaAs ASICs produced on multiproject 4-inch GaAs wafers and is the major foundry for Pacific Monolithics and Gazelle. TriQuint received a $2.65 million MIMIC Phase 3 award in November of 1990 and is the prime contractor for the Wright-Patterson Air Force Base Aeronautics Systems Division ASD award.

GIGABIT LOGIC

GBL was founded in 1981 to specialize in digital GaAs ICs, including ASICs. It has the industry's only extensive catalog of GaAs digICs, including SRAMs, logic, MUX/DEMUX chips, and interface circuits for optoelectronic systems. GBL also operates a major GaAs IC foundry and was the first company to convert to 4-inch GaAs wafer production. Initially, Cray Research was GBL's largest customer, with peak shipments of custom digICs to Cray (for the CRAY-3 supercomputer) exceeding an estimated $5 million annually. In 1990, GBL supplied Cray with a complete fab capability, which was transferred to Cray's Colorado Springs, Colorado, facility without disrupting GBL's work with its other 300 customers.

INVESTORS

Investors in the new company include Amoco (via Analog Devices), Canaan Venture, DFC (New Zealand), Digital Equipment Inc. (DEC), Intervene Partners, NKT (Denmark), and Tektronix (sole owner of TriQuint). The five-member board of directors of the new company was not announced.

DATAQUEST ANALYSIS

Dataquest expects the merger of TriQuint and GBL to present strong competition to the GaAs IC supplier base for the foreseeable future. No other company has this concentration of expertise, experience, and base of more than 600 GaAs IC customers.

Gene Miles

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Research *Newsletter*

THE IMPENDING BATTLE OF THE GaAs HETEROSTRUCTURES

INTRODUCTION

GaAs technology is maturing; E/D MESFET gate arrays are available in volume from three suppliers at densities of 30,000 gates per chip. The next generation of logic families is now being chosen by various industry participants. The decision to use some form of heterojunction transistors for gate and latch structures already has been made. The remaining decisions, regarding circuit form, are much more difficult because they involve relative volumes of emerging applications. Each major player has a unique perspective of end uses and must avoid tunnel vision. To assist our client base, this newsletter examines the heterostructure issue.

THE CONTENDERS

The participants in the heterostructure war of the early 1990s are the vertically integrated electronic systems houses and their compound semiconductor materials and equipment supplier base. These companies will determine their future viability in many end-equipment markets by their choice of technology for multi-GHz digital hardware. Affected applications include almost every electronics market segment from spaceborne systems and electronic warfare to microwave-frequency personal communications and future notebook computers.

THE ISSUES

The primary points of contention are similar to those in most of the silicon logic wars of the past. They include the following:

- Gate delay—translating to logic speed
- Power/gate—setting the level of integration and driving packaging cost
- Process complexity (manufacturability)—limiting chip (and therefore, system) cost
- Market viability—the ultimate determinant of practicality

THE APPROACHES

Currently, three basic transistor structures are contending for leadership as technologists strive to develop the successor to E/D MESFET technology for high-performance applications. They are high electron-mobility transistors (HEMTs), complementary heterostructure transistors (C-HFETs), and heterojunction bipolar transistors (HBTs). Each offers advantages for specific applications, as summarized later.

HEMTs

Dr. Raymond Dingle and others at Bell Laboratories invented selectively doped heterostructure transistors (SDHT, later labeled HEMT by Bell's competitors) and reported structures using this approach in 1978. The 64K SRAM (1.2ns access time) and 45K gate array devices announced by Fujitsu on February 12, 1991, are representative of the current state of the art of HEMT. Fujitsu is obviously "doing its homework" in preparation for bringing its $200 million GaAs fab facility on-line next year. Table 1 describes major details of the Fujitsu devices.

C-HFETs

Notable work has resulted from IBM's efforts in C-HFET logic structures. Others (notably Honeywell) are pursuing this approach because of its inherent similarities to silicon CMOS, which include lowest attainable logic power for complex

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functions and because of its radiation hardness. Sources at Boeing and other companies believe that C-HFET is the logical alternative to E/D MESFET logic, just as silicon CMOS displaced NMOS.

HBTs

Theoretical work on HBTs traces to 1957, and GaAs HBTs were functional by 1972. However, until recently, HBT ICs were limited to low-LSI-density functions fabricated on an R&D basis (measured by silicon standards). In mid-1990, AT&T reported a carbon-doped process sustainable in economic high-volume production. A joint effort of IBM and Rockwell accomplished the integration of 5,090 transistors on a 1,100-gate equivalent logic array, reported in 1990. An October 1987 paper describes a TI/CDC GaAs RISC microprocessor chip containing 13,000 HBT transistors interconnected to perform I^2L logic.

The DARPA MIMIC program includes sponsorship of development of millimeter-wave (mW) (>30 GHz) ICs, and at least one MIMIC contractor has produced 25,000 HBT ICs with excellent yields. Companies such as AT&T, Hughes, Pacific Monolithics, Rockwell, TI, and TRW now have considerable expertise in HBT IC design and fabrication.

THE TRADE-OFFS

Table 2 summarizes major advantages of the three types of GaAs heterostructure ICs and indicates approximate levels of speed, power, and

TABLE 1
Fujitsu HBT ICs Described at 1991 ISSCC

Feature	SRAM	Gate Array	Notes
Complexity	8,192 x 8 bits	45,600 gates	
Power	5.9 watts	11 watts	GA power at 80% gate usage
Supply Voltages	-1.0,-2.0,-3.6V	-1.4,-2.0V	
Speed	1.2ns typical	35ps (DCFL) 50ps (BDCFL)	Gate array delays do not include interconnect C
I/Os	ECL-compatible	ECL-compatible	
Die Size	7.4mm x 6.5mm	9.8mm x 9.8mm	Produced on 3-inch wafers
Cell Size	17.5u x 13.5u	30 x 66	
Transistors	E/D HEMT	E/D HEMT	38 GHz cutoff frequency
Gate Length	0.6u	0.6u	AlGaAs/GaAs dry-etched
Metal Pitch	2.4u	3.0u	
Linewidth	1.2u	1.2u	L1 = Al; L2 = Ti/Pt/Au

Source: Fujitsu Ltd.

TABLE 2
GaAs Heterostructure ICs
(State of the Art, 1990)

IC Type	Advantage	Speed/Power Product	Reported Level of Integration	Representative IC Suppliers
HEMT	Lowest cost	5.8ps x 1.8mW per gate	64K SRAM	Fujitsu, Philips, Thomson, TI, TRW
C-HFET	Lowest power	100ps x 0.1uW per MHz per bit	1K SRAM	Honeywell
HBT	Highest speed	1.9ps x 40mW per gate	13,000 transistors/chip	Hughes, Pacific Monolithics, Rockwell, Thomson, TI, Toshiba, TRW

Note: At least 53 companies, universities, and other organizations are active in internal research and development of one or more of these circuit forms.
Source: Aztek Associates

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density achievable in volume production in 1991 and 1992.

WHAT'S NEXT?

The technologies discussed in this newsletter and the suppliers investing in them are arrayed in a battle for supremacy in heterostructures. The stakes involved in betting on the winning technology are increased by the fact that the costs of production facilities are in an upward spiral. As a result, Dataquest believes that the days of the $30 million GaAs start-up are over, particulary in light of the fact that some vertically integrated suppliers have failed to make as much as a $30 million dollar profit in a bad year.

However, in spite of the risks, the failure of any company to place its bets will surely amount to conceding a market share victory to its competitors—missing the time-to-market window can be just as disastrous as backing the wrong technology.

Gene Miles

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Research Newsletter

GaAs ADVANCES INTO THE MILLIMETER-WAVE REGIME

INTRODUCTION

GaAs technology continues to evolve to higher-frequency operation. Recent advances in production processes make possible the fabrication of transistors and ICs suited for operation above 30 GHz. This newsletter examines some of the recent developments and potential applications of millimeter-wave GaAs semiconductors.

WHAT IS THE MILLIMETER-WAVE REGIME?

Because energy radiates at approximately 186,000 miles per second in free space, energy fluctuating at a frequency of more than 30 GHz has a wavelength of less than one centimeter. The wavelength becomes one millimeter at approximately 300 GHz. Hence the name "millimeter-wave" is used to refer to frequencies in the range of 30 to 300 GHz.

For comparison, the "microwave" range of frequencies extends from 3 to 30 GHz, which is about 1,000 times higher than the clock rates of today's personal computers (4.77 to 33 MHz). Although very high, the millimeter-wave frequency range is 10,000 times slower than the visible (human eye response) range of frequencies, which have wavelengths of approximately 400 to 800 angstroms.

IMPORTANCE OF MILLIMETER-WAVE TECHNOLOGY

For many years, the microwave range of frequencies has been used for such applications as radar and radio communications, initially in military equipment and more recently in commercial hardware. As the frequency bands allocated for the various applications have become more crowded, equipment design constraints have increased. The semiconductor industry responded at first by improving silicon technology and later by introducing GaAs substrate material.

As a result of recent advances in GaAs and other compound semiconductor technologies, it is now feasible to produce transistors and SSI- to MSI-density ICs capable of processing millimeter-wave signals. Extending the available frequency range for applications from 30 GHz up to 300 GHz and adding the millimeter-wave bands to the existing bands (which range through the microwave regime) increases available bandwidth by a factor of nine. This element is critical in enabling future portable personal communications, which will be required to operate in an environment containing many times today's channel traffic.

Another important aspect of millimeter-wave technology is physical in nature. The earth's atmosphere attenuates energy propagation at most frequencies above 3 GHz and into the lower infrared spectrum (10 THz) by at least 0.1dB per kilometer; this increases to as much as 100 to 1,000dB per kilometer at certain frequencies. This property enables highly localized transmission and reception of signals for such applications as collision-avoidance radar, which Detroit sources prefer to refer to as "proximity detection" for fear of legal consequences of implying that collision avoidance is a problem with today's vehicles. Because this attenuation is characteristic of the oxygen, water vapor, and other gases in the earth's atmosphere, space communications at millimeter-wave frequencies are much more efficient. The attenuation characteristics also allow local earthbound communications to occur with less interference with each other and with other equipment, and they enable certain forms of secure communications.

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MILLIMETER-WAVE SEMICONDUCTOR DEVELOPMENTS

GaAs and InP are compound semiconductor substrate materials that allow electrons to be switched much more efficiently than silicon, hence enabling higher-frequency operation at a given minimum device feature size. Scaling semiconductors to smaller feature sizes increases potential operating frequency until materials limitations or geometric tolerances become excessive. Table 1 describes recent device developments by four companies, all indicating millimeter-wave range operating capability. All of the devices in Table 1 use AlGaAs layers in their construction.

The U.S. DOD MIMIC Program includes provision for development of millimeter-wave ICs for defense applications. Other companies working in this regime include TRW and Alpha Industries. TRW has developed GaAs power transistors capable of 94-GHz operation. Several European and Japanese companies, including Thomson, Siemens, Fujitsu, NEC, and Plessey, are developing millimeter-wave ICs for government and commercial applications.

MILLIMETER-WAVE IC APPLICATIONS

In addition to space communications, radar, and military applications, potentially large volumes of mm-wave ICs will be required to support vehicular traffic control and collision avoidance systems. In Germany, the AEG Verkehrs Erfassungs (AVES) system, operating at 61.5 GHz, has been tested under actual traffic conditions. This system uses radar transmitter and sensor units mounted on signboard bridges above the roadway, coupled with hardware algorithms, to determine vehicle speeds, lengths, and spacings. The German Bundesanstalt has approved the system, and a production order for 1,000 units is in process. Similar systems are in use in Tennessee and other U.S. states, as well as in Japan.

DATAQUEST CONCLUSIONS

The potential commercial applications for millimeter-wave ICs are growing in number. Microwave semiconductor applications originated in the military and aerospace sectors and migrated to the commercial arena, and millimeter-wave chips are expected to experience similar evolution. In addition to the radar, automotive, and communications markets already described, Dataquest expects many niche markets to develop in the early to mid-1990s for mm-wave GaAs and InP transistors and ICs. Only a small number of IC houses are now adequately positioned to take advantage of the emerging opportunities in this field of applications. A major obstacle today is the relative lack of microwave/mm-wave engineering talent at the IC houses influencing the selection and development of new IC products.

Gene Miles

TABLE 1
Some Recently Developed Millimeter-Wave Low-Noise Transistors

Company	Substrate Material	Gate Size (Microns)	F_{max} (GHz)	Noise Constant (K/GHz)	Achievable NF at: 44 GHz (dB)	60 GHz (dB)	94 GHz (dB)
Linear Monolithics	GaAs	0.1x100	113	2.4	2.0	2.9	6.4
GE	GaAs	0.08x50	270	2.7	2.0	2.6	3.9
COMSAT Labs	GaAs	0.35x60	107	7.1	4.1	5.6	11.4
GE	InP	0.25	380	1.9	1.6	2.1	3.1
Hughes	InP	0.2x50	173	0.9	1.0	1.4	2.4

Source: Martin Marietta

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Research *Bulletin*

CONVEX C3800 SUPERCOMPUTERS USE 45,000-GATE GaAs ASICs

CONVEX Computer Corporation has announced its 3C Series of supercomputers, which includes the industry's first all-GaAs IC supercomputer family. This announcement further confirms the general industry acceptance of GaAs ICs for high-performance electronic data processing (EDP) applications, already in use at Cray Computer Corporation and several Japanese computer houses. Classed as "enterprise"-level machines, the air-cooled C3800 Series features implementation of one to eight CPUs using 45,000-gate GaAs ASICs, up to 4GB of physical memory, and 2 gflops (billions of floating point operations per second) peak performance. CONVEX plans to beta-site the C3800 in the third quarter of 1991. Additional C3800 shipments are scheduled for the fourth quarter of 1991.

Vitesse Semiconductor Corporation is believed to be the major supplier of 45,000-gate GaAs ASICs to CONVEX, although Fujitsu and other suppliers are capable of producing the chips. In 1990, Vitesse announced GaAs ASICs with gate densities to 350,000 gates and transistor counts of up to 1 million per chip. In February 1991, Fujitsu announced GaAs HEMT-based ICs with a density of 45,000 gates, as well as GaAs HEMT 64K SRAMs. Vitesse has alternate-sourcing agreements on its FURY series of GaAs ASICs with both Fujitsu and Thomson. CONVEX and Vitesse share two board members, Pierre Lamond and Robert Paluck.

The CONVEX C3 Series also comprises the C3400 family of 150,000-gate BiCMOS ASIC-based "departmental" supercomputers and the C3200 family of ECL and CMOS IC-based "server" machines. Maximum physical memory for either of the families is 2GB. Peak performances are 0.8 gflops and 0.2 gflops, respectively. Announced price ranges are $2 million to $8 million for the C3800s, $650,000 to $2 million for the C3400s, and starting at $350,000 for the C3200s.

CONVEX developed the C3 family to address the demands of supercomputer users for relatively low-cost, air-cooled, interactive open systems supported by a wide range of third-party application software. More than 1,000 UNIX-based software applications are available on the C3 Series. All CONVEX machines are upward and downward binary compatible.

At press time CONVEX, which was founded in 1982 and introduced its first supercomputer in 1985, had sold more than 850 systems to nearly 500 customers in at least 36 countries. The company markets its products primarily to scientific, engineering, and technical users worldwide. The pervasiveness of supercomputers in the worldwide marketplace is well illustrated by a sampling of CONVEX's customer base. CONVEX customers as of December 31, 1990, included the following:

- Government/aerospace—Aerospatiale (France); British Aerospace plc (U.K.); Canadair (Canada); Daimler-Benz (Germany); Joint Electronic Warfare Center, Lockheed, McDonnell Douglas, NASA (Ames, Langley, and Lewis Research Centers), Naval Ocean Systems Center, Naval Research Lab, Naval Surface Warfare Center, Rockwell, Texas Instruments, and TRW (United States)
- Computer-aided engineering—Air Liquide, ESI, GEC ALSTHOM, and Hutcheson (France); AVL List (Germany); DSM Research (The Netherlands); Nissan Motor Co., Sanyo, and Taisei (Japan); Jaguar Cars Ltd. (U.K.); Saab-Scandia (Sweden); AT&T, 3M Company, EDS/General Motors, and Ford Motor Company (United States)
- Computational chemistry—Biomolecular Research Institute (Australia); Pasteur Institute and Roussel UCLAF (France); Bayer AG and Boehringer Ingelheim (Germany); Institute of

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Fundamental Chemistry and Sekisui Chemical Co. (Japan); Cambridge University (U.K.); Agouron Pharmaceuticals, Amgen, Eastman Kodak, Johns Hopkins University, Mount Sinai Medical Center, National Institutes of Health, Scripps Clinic, and Schering-Plough (United States)

- Petroleum—Commonwealth Scientific and Industrial Research Organisation (Australia); Compagnie Generale de Physique, French Petroleum Institute, and Total (France); Telefunken Systemtechnik and Preussag (Germany); Delft Geophysical, Jason Geosystems, and Royal Dutch/Shell Group (The Netherlands); CogniSeis Development, Inc. (U.K.); ITA (Canada); Allied Geophysical Labs, Mobil, PT Caltex Pacific Indonesia, Seismograph Service, and Texaco (United States)
- Advanced research—University of Bielefeld and University of Marburg (Germany); Labein Industrial Research Laboratory (Spain); Exeter University (U.K.); University of Odense (Denmark); University of Utrecht (The Netherlands); NTT and Sony (Japan); GE, Los Alamos National Labs, National Center for Supercomputing Applications, and these universities—Arizona, California, North Carolina, Princeton, and Rice (United States)
- Environmental—Alfred Wegener Institute, DKRZ, IFU, and Polarstern research vessel (Germany); Catania Observatory and Institute of Radio Astronomy (Italy); Natural Environment Research Council (U.K.); Ministry of Health and Environment (Belgium); Royal Netherlands Meterological Institute (The Netherlands); Korean Aerospace Research Institute (Korea); Air Force Geophysics Lab, Naval Oceanographic Research and Development Agency, and Woods Hole Oceanographic Institution (United States)
- Emerging Markets—Center for Scientific Computing (France); Erasmus University and Gasunie (The Netherlands); India Institute of Technology (India); Acer Sertek (Taiwan); NKK, Ricoh, and Schimizu (Japan); Dow Jones & Company, E-Systems, and the following universities—Notre Dame, Texas (three locations), and Wisconsin (United States)

DATAQUEST CONCLUSIONS

The displacement of silicon ECL ICs by GaAs ICs at VLSI density levels is well under way. CONVEX's C3800 products are encroaching on markets once dominated by the silicon current-mode architectures of CDC, Cray, and other companies, further ensuring rapid growth of the GaAs VLSI chip marketplace. Although the C3800 line is priced at $2 million or more, it is substantially below the expected $10 million to $20 million CRAY 3 price tag and reflects the cost efficiencies provided by air-cooled GaAs VLSI ASICs and memories. Dataquest expects a growing number of EDP houses to announce the adoption of GaAs ICs in their hardware designs as they increasingly compete in high-performance niches.

Gene Miles

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Research Newsletter

GaAs INDUSTRY SURVEY REVEALS OPPORTUNITIES

A Dataquest survey of the GaAs IC industry infrastructure, performed during June and July 1991, shows a range of opportunities for participants in this growing marketplace. A record 48 percent of the sample contacted responded in depth to the question set rather than the expected 20 to 30 percent for this type of survey. This newsletter reports significant results and summarizes key findings of the analysis to date.

ISSUES CONSIDERED

Many of Dataquest's clients and potential clients have indicated high interest in acquiring more information about the following:

- The extent of GaAs penetration of the high-performance end of the silicon IC market and whether this penetration will continue
- Potential for growth in usage of existing GaAs IC chip types
- Plans for future usage of GaAs ICs, including potential demand for GaAs charge-coupled devices (CCDs)
- Changes in competitive positions of industry participants, including potential impact of the recent merger of TriQuint, GigaBit Logic, and Gazelle
- Future needs for additional GaAs IC chip types, engineering software, test equipment, and related product functions and parameter improvements
- Recommendations for additional improvements in products and services offered by the GaAs industry

The question set used in this survey was designed to elicit response in sufficient depth to address these issues and allow collection of additional detail about the perceptions of the industry participants regarding industry shortcomings, competition, and several other relevant factors.

SURVEY POPULATION, SAMPLE SET, AND METHODOLOGY

For purposes of this newsletter, the following terminology is used to distinguish major subsets of the population:

- Group B denotes members of the "bottom" of the food chain, supplying raw or epi wafers, chemicals, processing equipment, CAD/CAM/CAE hardware and/or software, and related goods and services to GaAs IC suppliers.
- Group M denotes the GaAs IC suppliers ("middle" of the food chain).
- Group T denotes actual or potential users of GaAs ICs that build equipment for sale or system integration, not including those company divisions surveyed as suppliers of equipment for GaAs IC processing, production, and/or test.

Dataquest chose the following sample from the industry population, comprising primarily companies that have offices in North America, regardless of country of origin. Thus, virtually all of the Europe- and Asia/Pacific-based companies participating in the GaAs IC industry infrastructure were surveyed. They include:

- 8 GaAs wafer suppliers (a group B subset)
- 15 other GaAs materials producers (a group B subset)
- 18 GaAs IC processing/production/test equipment manufacturers (a group B subset)

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- 5 GaAs IC development software suppliers (a group B subset)
- 31 GaAs IC suppliers (group M)
- 28 actual/potential GaAs IC users: computer/EDP/workstation manufacturers (a group T subset)
- 25 actual/potential GaAs IC users: communication equipment manufacturers (a group T subset)
- 28 actual/potential GaAs IC users: military/aerospace equipment manufacturers (a group T subset)
- 25 actual/potential GaAs IC users: all other electronic equipment manufacturers (a group T subset)

The initial selection for sampling was performed using random numbers to select from several alphabetized lists, except the GaAs IC supplier list, which consisted of all the GaAs IC merchant market suppliers known to Dataquest (excluding distributors and stocking representatives). Selected names within the companies were then contacted by Dataquest's Survey Group to verify qualifications as potential respondents. The incentive offered to potential respondents was a copy of this newsletter summarizing survey results. The Survey Group used telephone interviews to collect the data, which were entered into a Dataquest computer database for summarization.

SURVEY RESULTS

A total of 87 respondents participated from a sample of 182 potential candidates. Breakdowns of the sample and respondent data are presented in Table 1. The wafer suppliers, software suppliers, and GaAs IC producers indicated the highest interest levels (80 to 100 percent) in cooperating in this survey effort, as the table illustrates. GaAs IC users and potential users showed a much lower interest level, varying by subgroup from 20 to 48 percent.

Table 2 describes industry material/equipment/software, GaAs IC supplier, and GaAs IC user companies' perceptions of relative competitor positioning among the GaAs IC suppliers. Interestingly, 75 percent of GaAs IC suppliers and 50 percent of GaAs IC users perceive TriQuint as the top-ranked GaAs IC competitor compared with 35 percent of those that supply major goods and services to GaAs IC houses.

CURRENT AND FUTURE GaAs IC PRODUCT NEEDS

Eighty-eight percent of the respondents identified which types or functions of the GaAs ICs now produced by the suppliers are considered most important. Of these, 27 percent identified digital functions as most important, with 7 percent specifically naming gate arrays. Ten percent stated that amplifiers were most important.

TABLE 1
GaAs Survey Respondent Group

Group/Subset	Sampled	Respondents	Percent of Sample Subset	Percent of Responent Group	Percent of Total Respondents
B/Wafer Suppliers	8	8	100	28	9
B/Other Materials Suppliers	15	10	67	34	11
B/Equipment Suppliers	18	7	39	24	8
B/Software Suppliers	5	4	80	14	5
M/GaAs IC Producers	31	28	90	100	32
T/Computer/EDP/Workstations	28	6	21	20	7
T/Communication Equipment	25	5	20	17	6
T/Mil/Aero	28	7	25	23	8
T/Other Users	25	12	48	40	14

Source: Dataquest (August 1991)

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TABLE 2
Perceived Ranking of "1, 2, and 3" GaAs IC Suppliers

GaAs IC Company (Number/Percent)	Ranked as #1 by Respondents (Number/Percent)	Ranked as #2 by Respondents (Number/Percent)	Ranked as #3 by Respondents (Number/Percent)
TriQuint	54/60	16/18	4/4
Vitesse	13/15	27/31	2/2
Anadigics	2/2	2/2	6/7
Texas Instruments	3/3	4/4	2/2
Avantek	2/2	1/1	0/0
Harris Microwave	0/0	2/2	2/2
Pacific Monolithics	0/0	2/2	1/1
Fujitsu	0/0	2/2	1/1
M/A-COM	0/0	0/0	5/5

Source: Dataquest (August 1991)

When questioned about future GaAs IC needs and industry opportunities, 92 percent of the respondents described specific application opportunities, and 65 percent of the participants identified specific types or characteristics of circuits they require. Eleven percent of the respondents want more and better communication circuits, some describing chips for fiber-optic applications. Personal communications and cellular communications were most frequently mentioned (39 percent) as the greatest opportunity for the GaAs IC industry during the next five years, followed by computer applications (26 percent).

Respondents among the sample of 106 companies that are GaAs IC users or potential users (group T) were asked if they currently use GaAs ICs. Thirty percent of respondents said they are using GaAs ICs in designs that are currently under way, and 20 percent are using GaAs ICs in production. Thirteen percent of group T respondents refused to answer these questions.

When asked about the percentage mix of GaAs and silicon ICs used by themselves and by the industry, respondents indicated a mean usage of 5.7 percent GaAs ICs for themselves and 6.8 percent for the overall industry in 1990, forecast to grow to 15 and 14 percent, respectively, by 1995 and remaining at about the same percentages through 1999. Twenty-seven percent of group T respondents stated that they now use GaAs optoelectronic ICs. Of those not now using OEICs, less than half stated that they will not be using OEICs in 1993 and only 20 percent of group T respondents foresee no needs for OEICs through the next decade. The respondents indicated virtually no interest in GaAs CCDs.

Regarding the GigaBit and Gazelle mergers with TriQuint, 81 percent of respondents expect no impact on their company activities and half of the remainder expect a positive impact.

FOR FURTHER INFORMATION

Dataquest clients may use the normal inquiry procedure to obtain further information resulting from this survey. Non-Dataquest clients may contact the nearest Dataquest office for additional assistance.

DATAQUEST CONCLUSIONS

Overall growth in the GaAs IC industry is assured for several years to come, as the participants respond to user demands for a greater variety of GaAs ICs in a broadening range of applications. However, some participants will not benefit from this increasing demand unless their images change significantly from what is currently perceived by their potential client base. This still-young industry faces heavy competition in the years ahead because of the desire of all participants to maintain rapid growth, decreasing military budgets, consolidation in the computer and communications industries, and other factors.

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Research *Bulletin*

III-V SEMICONDUCTOR ICs MAY BOOST MACHINE VISION

A recent study shows that approximately half of a human's brain cells are associated with visual activity. Computers, particularly PCs in ever-growing numbers, are increasingly used to relieve people of complex, highly repetitive mental tasks. To date, computers have not been applied very well to replacing human visual routines. The necessary speeds of the algorithms required for all but the most rudimentary real-time machine vision are above those speeds attainable using state-of-the-art silicon ICs. However, GaAs ICs have achieved system-operating speeds above 30 giga operations per second (GOPS) and complexities of 1 million transistors per chip, and ZnSe/GaAs chips are capable of extending OEIC operation into the blue area of the visible spectrum. Furthermore, production-worthy InP chips routinely operate in the millimeter-wave range. Thus, machine vision represents a huge potential for growth in applicable III-V ICs.

WHAT IS BEING DONE THAT III-V ICs COULD DO BETTER?

Two examples show the potential for GaAs and other III-V compound ICs in the field of machine vision: scanners used as OCR input devices for PCs and video cameras.

Scanners for PCs

PC-compatible hand-held scanners, supported with crude recognition software, are capable of scanning and recognizing the majority of characters in a column of newsprint. Such scanner subsystems have been on the market for less than $200 since early 1991. Color page scanners also are available for desktop PCs, priced below $1,100 each (single quantity). However, the recognition time and overall character recognition rate on a document basis appear to be unacceptable for anything other than limited academic use. The primary limitations are use of relatively slow silicon ICs for recognition (hardware) and crude learning algorithms (hardware and software). Although some speedup will be achieved with software improvements, the hardware problems must also be solved before a viable solution is attained.

Many PC owners' near-term needs will not be satisfied until page scanning at a level supportable by an automatic spelling-checker becomes a routine method of data entry, priced in the $200 to $300 range. The need exists for a self-contained, easily trainable, scanner-recognition package that can read, recognize, and enter mixed-font characters several times faster than an expert human typist. GaAs linear CCD and parallel DSP chips based on currently available processes could be developed to perform these functions. The unit demand probably exceeds 60 percent of all PCs in use today, representing a GaAs IC market niche of several hundred million dollars. As occurred with the desktop PC, once a several-chip solution is accomplished, cloners will ensure that affordable pricing follows.

Video Minicams

A miniature video camera (minicam) uses a silicon CCD front end to convert photonic data to electronic data. The electronic signals are processed through silicon ICs, either to drive recording electronics that store images on magnetic film, or to be amplified and transmitted for broadcast, or both. In low-level light, rapidly changing light, fast panning, and other normal visual conditions, the use of silicon results in streaking, blooming, and several other undesirable effects. Battery duration between recharges is also a major performance factor in

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some law enforcement and other applications. GaAs ICs for the CCD "retina," A/D conversion, signal processing, and data transmission chips would greatly enhance sensitivity and speed, allowing at least an order of magnitude improvement in image quality over that of present minicams while simultaneously extending battery time between charges.

DOES MAJOR POTENTIAL EXIST FOR SYSTEMS INNOVATION?

The future for systems innovation appears bright for entrepreneurs and enterprises alike. To avoid compromising sensitive development activity already under way, the following hypothetical example serves as an available technology within two years.

Little imagination is required to combine a high-performance minicam function such as that of the Magnavox CVM710 with a cellular radio, a small color display, or both, to build a highly portable, receive-only or transceiver videophone capability. GaAs IC technology has already been applied individually to high-volume-production cellular phones, video displays, and VCRs for subsystem cost and power reductions.

Applications for such a device occur in every facet of life where there is a need to enhance personal communication. Examples include law enforcement, news reporting, and emergency services. A volume production cost well below $600 per unit is achievable with available IC and other hardware technology.

Although bandwidth requirements coupled with frequency allocation constraints prevent real-time application of portable color video transceivers to mass usage, a lower-cost black-and-white version and a still-picture color version could become consumer products before the mid-1990s. (Note that ultralightweight, 6-inch black-and-white video receivers can now be produced at a volume cost below $12.) And, bandwidth limitations could be relieved by allocation of higher communications frequencies, allowing application of InP IC technology to the transceiver.

Dataquest believes that the first company to produce such equipment for professional use is likely to enjoy initial unit pricing in the several thousand dollar range because of the value perceived by the initial user markets. This is but one example of the rapidly growing potential for increasingly pervasive GaAs technology.

Gene Miles

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Research *Bulletin*

MIMIC PHASE II CONTRACTORS SELECTED

Three teams of companies have been selected by DARPA, and awards totaling approximately $228 million have been made by three United States military services for Phase II of the MIMIC hardware program. The awards are summarized in Table 1.

The MIMIC program is a DARPA initiative aimed toward the economic insertion of microwave and millimeter-wave (3GHz to >100GHz) GaAs ICs into military systems. Phase II objectives include addressing the needs of the military services by continuing the technology and product developments started in Phase I, further demonstrating affordability, pursuing new technology approaches, and demonstrating system use and foundry support of MIMICs. Phase III activities, conducted in parallel with Phases I and II, address additional special issues. System applications for MIMIC program technology include military communications, radar, electronic warfare, smart munitions, smart fuzes, and missiles. The advanced technology fighter (ATF) and many other military platforms and systems will benefit from MIMIC technology insertion.

Gene Miles

TABLE 1
MIMIC Phase II Awards

Prime Contractor	Team Members	Service	Award Amount ($M)
Hughes Radar Systems Group	Alliant, AT&T, Cascade Microtech, EEsof, General Electric, Litton, M/A-COM, Rockwell	U.S. Air Force	78.9
Raytheon/Texas Instruments	Aerojet, Airtron, Cadence, Consilium, General Dynamics Hewlett-Packard, Hittite, Lockheed-Sanders, Teledyne	U.S. Navy	83.4
TRW Electronic Systems Group	Alliant, Avantek (acquired by Hewlett-Packard), COMSAT, EEsof, General Dynamics, Hercules, Mentor Graphics, Texas Instruments, Westinghouse	U.S. Army	65.7

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Research *Bulletin*

HDI FOR GaAs AND OTHER IC MODULES

A new hybrid microcircuit high-density interconnection (HDI) technique dramatically reduces IC subsystem size and boosts performance. HDI has been applied to GaAs RAM modules and at least 20 other applications. This bulletin describes the development of the methodology by General Electric Company (GE), some of its applications, and implications for the GaAs IC industry.

WHAT IS HDI?

As its name implies, HDI accomplishes high-density IC interconnections on a dielectric material using laminates, sputtered metal, and laser drilling. A typical HDI process flow starts with a ceramic substrate, which is selectively milled to accommodate IC chips of various thicknesses and layouts. Aluminum pads are then deposited, and chips are bonded to the pads. Kapton laminate is overlayed; via holes are laser-drilled. Metallization is achieved by sputtering a thin film of titanium and copper. Next, photoresist is applied, laser-exposed, and etched to form conductors that range from 1-1/2 to 3-1/2 thousandths of an inch wide. Application of a dielectric layer allows repeating laser-drilled via holes, metallization, photoresist, etch, and dielectric steps in this order to achieve multilayer interconnections. After the last dielectric layer, passivation is applied and provision is made for external connections. The module is then packaged and tested. Repairability has been demonstrated by removing and replacing chips and HDI layers numerous times on the same substrate.

HDI was developed at GE's corporate R&D center in Schenectady, New York, with funding by GE, the Defense Area Research Project Agency (DARPA), the United States Air Force, and the United States Office of Naval Research. GE has licensed HDI to Texas Instruments Inc. (TI), and TI expects to be on the Pentagon's qualified manufacturer's list (QML) with its HDI facility by mid-1992. TI will produce HDI modules for DARPA's evaluation by fourth quarter 1992, in a company-funded facility supplemented by a $9 million DARPA contract. TI expects to offer what it describes as turnkey service to both government and industry customers, requiring only that a customer supply a circuit schematic, parts list, and required module dimensions.

HDI APPLICATIONS

HDI is ideally suited to many GaAs IC applications, because GaAs is often applied to achieve more power-efficient, higher-performance circuit operation than is possible with silicon. The precision layers of HDI allow construction of transmission lines with carefully controlled characteristic impedance, essential to subnanosecond microwave and millimeter-wave operation of GaAs ICs. However, HDI also provides higher-density packaging of silicon chips than is possible with most other hybrid approaches, so it will find application in all-silicon IC systems as well. The variable chip height provision enables mixing active and passive, GaAs and silicon, analog and digital, electronic and photonic ICs on a single substrate. Because pads interior to a chip can be used for interconnection, overall chip sizes may be made smaller. The use of topside metal for connections eliminates "flip-chipping," enhancing repairability. The laser steps eliminate mask layers, which reduces turnaround time from weeks to days.

GE has demonstrated the HDI technology with a module containing nine GaAs SRAM ICs and having a module access rate above 100 MHz.

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Use of HDI in a signal processor allowed a 30-fold reduction in module size. Another application achieved interconnection of 36 ICs, which operate at 90 MHz or about 50 percent improvement in speed, in an area less than two inches on a side. GE has fabricated a static RAM module containing 20 silicon ICs, which has a substrate area of only 11 percent greater than the silicon chip area. In many applications, the chips may be spaced only 0.01 inches apart.

DATAQUEST CONCLUSIONS

As already demonstrated, continued application of HDI technology will eliminate the need for printed circuit boards in many hardware designs. Dataquest perceives HDI as a technology whose time has come and expects rapid acceptance in the high-performance segments of the electronic equipment marketplace.

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Dataquest Perspective

Gallium Arsenide Semiconductors *Worldwide*

Vol. 1, No. 1 **December 16, 1991**

Market Analysis

The Impact of GaAs Semiconductors on Communications Markets

This article analyzes major segments of the telecommunications markets and identifies emerging opportunities for GaAs discrete and IC chip and module suppliers. Segments include spaceborne telecommunication, terrestrial wireless communication, and fiber-optic systems. The impact of developments such as Motorola Incorporated's Iridium system on global, including communist-controlled, markets is considered.

By Gene Miles

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Product Analysis

A Cornucopia of GaAs ICs for Communication

This article reviews current GaAs IC product offerings from a sampling of suppliers to the previously mentioned market segments. Products include GaAs laser drivers, detectors, clock and data regenerators, decision circuits, crosspoint switches, multiplexer/demultiplexer sets, low-noise amplifiers, power amplifiers, and gain blocks.

By Gene Miles

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Company Analysis

Major Producers of GaAs Chips for Communication

This article lists supply sources of GaAs and related compound semiconductors for communications applications, by geographic area, accompanied by brief analyses of several suppliers.

By Gene Miles

Page 9

News and Views

Major Issues Facing GaAs IC Suppliers

No longer are technology barriers the limiting factors in GaAs IC market development in the communications sector. The current stumbling blocks are political in nature.

By Gene Miles

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Market Analysis

The Impact of GaAs Semiconductors on Communications Markets

The traffic requirements of communications systems applications are measured in quadrillions of bits (10^{15}bits) per year (see Table 1, which lists typical statistics for the U.S. market for communications electronics). Systems traffic for European applications are approaching similar levels, and the potentials for Asia (including the Soviet Union) are even greater within this decade. Such traffic levels have led to implementation of microwave electromagnetic and lightwave photonic communications systems. These systems are supported by GaAs and related compound semiconductor component sales, which now exceed $250 million annually into this market segment.

Three distinct communications equipment market segments have evolved for GaAs and related compound semiconductors: spaceborne wireless; terrestrial wireless, including personal; and optical fiber.

Each application places unique demands on semiconductors. For example, long distances involved in spaceborne geosynchronous satellite links (typically 22,800 to 27,000 miles) and a high-radiation environment dictate noise, power efficiency, and radiation hardness specifications unattainable with silicon component technology.

Table 1
U.S. Information Volume Estimates

Annual Traffic /10^{15}15 bits	Application
14,000	Telephone conversations
1,400	Video telephone systems
1,200	Digital data file transfers
1,000	Electronic newspapers
300	Information age labor force
200	Motion picture distribution
47	Network TV distribution
7	Personal data (for example, credit)
1	Periodicals distribution
0.3	Airline reservation systems

Source: Institute of Electrical and Electronics Engineers

GaAs and related semiconductor ICs provide the only practical solutions to such system problems.

The nature of mass communication makes the market subject to political control. Thus many of the applications are national or regional in nature. The market discussion that follows repeatedly reveals this characteristic.

Spaceborne Telecommunication

Spaceborne wireless communication represents one of the earliest applications for GaAs semiconductors, dating from Telstar and other applications in the late 1960s. Since then, more than 160 communications satellites have been placed in orbit and are still operational. This number includes all countries, communist-controlled and otherwise. Geosynchronous satellites using GaAs discrete and microwave monolithic IC (MMIC) chips in transmitters, receivers, switching and relay functions and operating at microwave frequencies (3 to 30 GHz) play an indispensable role in today's hundreds of worldwide telecommunications networks, such as the one operated by Cable News Network. Combined revenue for these semiconductors is measured in tens of millions of dollars, and accumulated experience of vendors supplying this market has proven invaluable in terms of spinoff applications such as personal cellular radio-telephones for terrestrial use.

Terrestrial Wireless Communication

Microwave towers became a familiar part of the landscape in the 1970s. For over 15 years, they carried a major part of North American and European intracontinental line-of-sight (LOS) traffic. The links, with repeater towers spaced at 20- to 40-mile intervals, typically operated at one or more of the frequency bands shown in Table 2. Because GaAs components typically feature cutoff frequencies of more than 30 GHz (several times higher than silicon circuits), GaAs is very important for microwave link operation.

North American Wireless Applications Boost GaAs

Cellular radio-telephone service was inaugurated in North America in 1983. Today more than 300 metropolitan service areas are in operation, and the Federal Communications Commission (FCC) is awarding rural service areas as well. Almost 8 million cellular subscriber units are now in service in the United States, many of which use GaAs ICs for the receiver preamplifier, prescaler, mixer, filter, and output amplifier circuits. Although silicon comprises the majority of the revenue, cost-effective GaAs often replaces silicon in new designs.

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Table 2
Typical Commercial Communications Frequencies

Frequency Band (GHz)	Application
0.824 to 0.848	Cellular mobile transmitters
0.868 to 0.894	Cellular mobile receivers
0.928 to 0.932	Private carrier paging
0.945 to 0.953	Studio to transmitter links
2.110 to 2.140	Common carrier LOS
3.70 to 4.20	Commercial LOS C-band
5.925 to 6.425	Commercial LOS C-band
6.425 to 7.125	Common carrier LOS
10.55 to 10.68	Electronic news-gathering
11.0 to 12.0	Mobile satellite service feeders
12.75 to 13.25	Electronic news-gathering
17.7 to 20.2 and SQ 27.5 to 30.0	Private commercial LOS and interoffice (K-band)
18.0 to 30.0	Ka band satellite

Source: Aztek Associates

Additional applications for GaAs ICs are emerging in the pager, personal communications network (PCN), and digital cellular segments of this market. PCN, already implemented in the United Kingdom, has been granted experimental licenses by the FCC to a Millicom Inc. subsidiary—PCN America—and to BellSouth Corporation, Graphic Scanning Inc., Motorola Incorporated, and NYNEX Corporation. FCC licenses are pending for American Information Technologies, GTE Corporation, McCaw Inc., and others. We expect the PCN equipment market to exceed $5 billion for the United States by the year 2000.

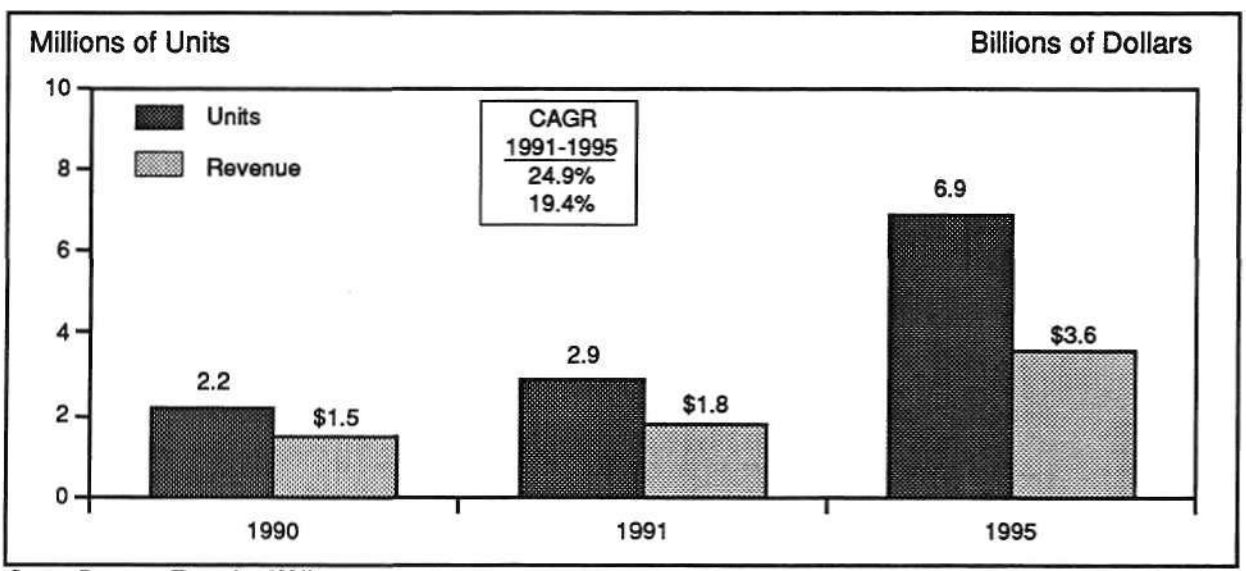
Figure 1 summarizes the market for new cellular sets in the United States, and Figure 2 shows Dataquest's estimate of growth of services associated with this market. More than 20 percent of 1990 units are thought to contain GaAs discretes and ICs; this share is forecast to exceed 40 percent by 1995. Units operating above 12 GHz will contain GaAs ICs.

European Cellular Units Use GaAs ICs

More than 3 million cellular telephones were in Europe by 1991; the number was growing at about 60 percent per year. Market penetration varies significantly by region, from 60 users per 1,000 capita in the Scandinavian countries to 20 per 1,000 in the United Kingdom to less than 10 per 1,000 in Germany, Italy, and France. The systems all use analog modulation at frequencies of 450 or 900 MHz.

Digital systems such as Telepoint Ltd. (United Kingdom), Birdie GmbH (Germany), and Pointel (France) are based on 900-MHz carrier frequencies and have been in operation since 1989. The requirements of these systems are satisfied

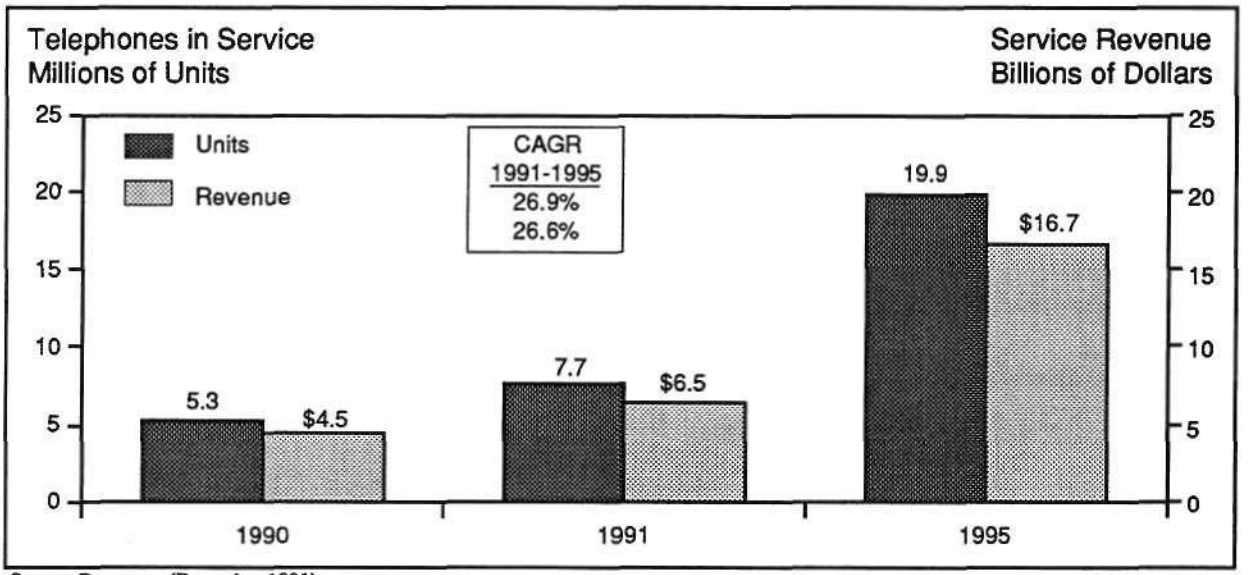
Figure 1
Estimated U.S. Market for Cellular Telephones



Source: Dataquest (December 1991)

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Figure 2
Estimated Growth of the U.S. Cellular Services Market



Source: Dataquest (December 1991)

with either silicon or GaAs front-end circuits, although GaAs provides two to three times longer battery life per charge at a slightly higher unit cost. Companies such as Fujitsu Ltd. and NEC Corporation have capitalized on this GaAs MMIC market, shipping millions of low-noise amplifiers and prescalers for such applications.

Since 1987, 17 European countries have worked on market development initially based on a unified European personal digital communications system called global system mobile (GSM), establishing standards in 1990 and starting pilot network experiments earlier this year. Commercial operation of GSM is set for mid-1992. Other planned systems are Digital European Cordless Telephone (1992), Personal Communications Network (1994), and Universal Mobile Telecommunications System (UTMS) (1998).

UTMS is planned to operate initially at 1.9 GHz and later at 62 to 66 GHz with 1-GHz bandwidth. The European Economic Community Research in Advanced Communication in Europe project is working toward a unified approach to interface all other European cordless and wireless systems by the year 2000. Given the cultural differences among European countries, time will determine whether the unified approach succeeds.

Figures 3 and 4 show Dataquest's forecasts of unit consumption and semiconductor revenue for European wireless handsets, by standard, for the decade. At least 20 percent of GSM and more than 40 percent of DCS1800 semiconductor consumption revenue will be for GaAs and related compound semiconductors.

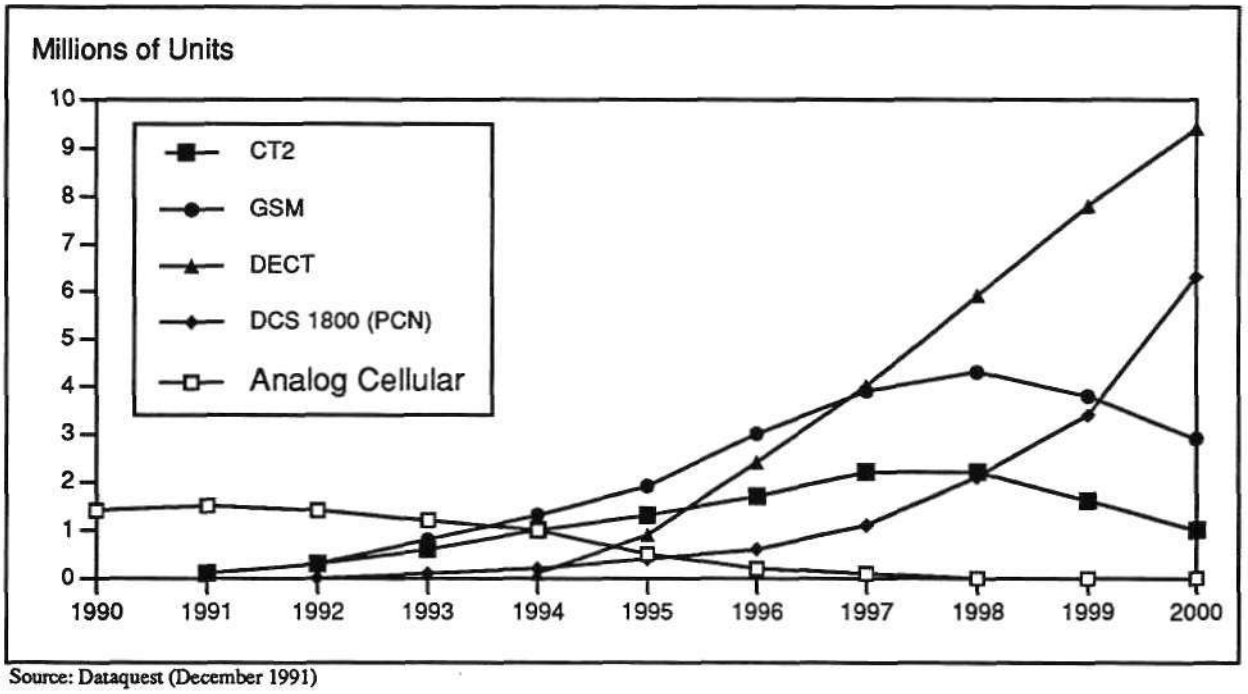
GaAs MMIC requirements for the European portable digital radio-telephone market are estimated by Thomson Composants Microondes to create a demand for consumption of several thousand 4-inch GaAs wafers per year by 1995. We expect European demand to be even higher if current continental systems standardization efforts succeed.

Wireless Telecom Market Evolution

Motorola's Iridium system vividly portrays directions for future evolution of the worldwide wireless telecommunications market and resultant dramatic growth in demand for GaAs communications ICs. Iridium uses a combination of satellite-based and terrestrial microwave stations to enable portable cellular radio-telephone communication between any points on earth. A constellation of 77 satellites, 7 each in 11 polar low orbital planes, communicate with one another via 23-GHz crosslinks and with a network of 70 gateway ground stations via 30-GHz uplinks and 20-GHz downlinks. The ground stations tie into existing communications systems. Links between satellites and portable cellular sets operate at 1.6 GHz.

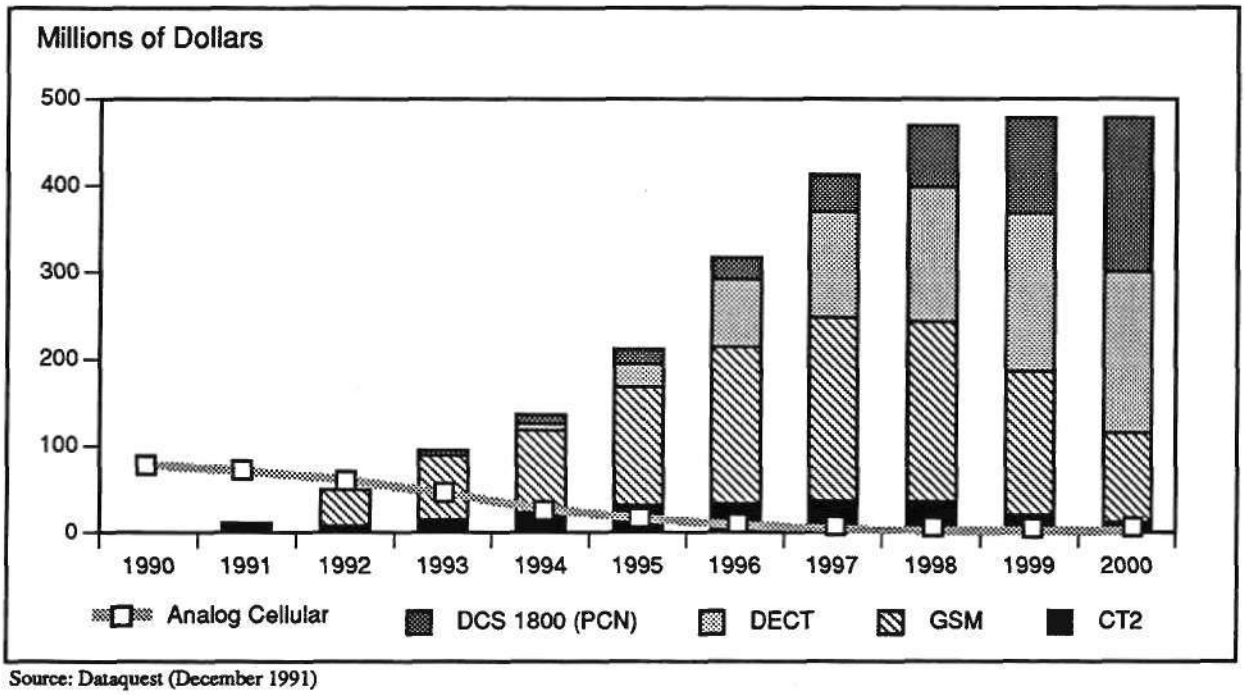
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Figure 3
Forecast European Handset Consumption by Wireless Standard



Source: Dataquest (December 1991)

Figure 4
Forecast Semiconductor Consumption by European Handset Standard



Source: Dataquest (December 1991)

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Each Iridium satellite has four crosslink transceiver modules, each using six different GaAs MMIC chip designs, high electron mobility transistor (HEMT) K-band transistors, and supporting silicon circuitry. Each satellite has four gateway transceiver modules, using a GaAs chip mix similar to the crosslink transceivers. Thus a full GaAs MMIC die complement for the satellites, including spares, is about 5,000 space-qualified pieces. Seven L-band phased array (beam-steering) antennas are used on each satellite, each using 80 modules containing five GaAs MMIC designs and several silicon support chips. This adds about 200,000 space-qualified MMIC chips to the satellite requirements.

Each earth station has three gateway transceiver modules requiring about 18,000 MMIC chips. Each hand-held cellular transceiver uses three GaAs MMIC ICs for front-end requirements, creating potential for more millions of chips as a direct function of the number of public subscriber units. The reality of this emerging market is demonstrated by rapid growth in the existing 800- to 900-MHz GaAs and silicon IC-based cellular radio-telephone marketplace.

In preparation for this market growth, Motorola is investing more than $100 million in a 42,000-square-foot state-of-the-art Class 10 submicron GaAs IC fabrication facility in its Tempe, Arizona, semiconductor complex. Starting with 4-inch GaAs wafers, Motorola plans to switch to 6-inch wafers as soon it is economically viable. This is the largest investment in a GaAs fab facility by a U.S. company so far, equalled only by Fujitsu's investment in GaAs.

QUALCOMM Inc. and other companies are working on a global network for personal communication. The network is planned to use 48 satellites and associated ground stations. Such a system would compete with Iridium but demand similar quantities of GaAs ICs for successful implementation.

GaAs Essential in Fiber Optics

In the last several years, the communications industry has put into operation hundreds of thousands of miles of fiber cable. At AT&T, fiber has replaced more than 85 percent of microwave LOS traffic in North America. Bit rates for these systems are typically 0.62, 1.7, or 2.5 Gbps. A typical system may multiplex 64,000 voice channels onto a single fiber, along with digital data streams. Fiber-optic systems require transmission at wavelengths approaching 1 micron. Two most frequently used wavelengths are 1.3 and 1.55 microns.

Transmitter functions must convert electrons to photons to accomplish efficient operation at such frequencies, so lasers are required. Semiconductor lasers based on GaAs or AlGaAs structures on GaAs substrates routinely are used for this task; prices for such devices have fallen in the last three years from over $1,500 to under $400 each. Such lasers are usually customized for a particular system, and a 5,000-piece order is considered large because of the dollar cost involved.

Fiber-optic systems require thousands or tens of thousands of cross-connections at each switching center. This function used to be performed with relatively slow-speed, high-voltage, dielectrically isolated silicon technology, which presents major cost problems at the interface. Companies such as TriQuint Semiconductor Inc. and Vitesse Semiconductor Corporation developed GaAs crosspoint switch matrices in response to a need for higher-performance, lower-power, compatible-interface chips. Typical densities are 16 × 16 to 64 × 64 arrays per chip. A single switching center needs thousands of such chips to accomplish networking, which presents a major opportunity for innovation in GaAs crosspoint switches.

Dataquest Perspective

Dataquest expects the communications applications market for GaAs ICs to expand for decades to come. Consumer market penetration by GaAs is still very low, compared with silicon. Frequency crowding prevents further significant growth below microwave frequencies, dictating increased demand for GaAs and other compound semiconductor ICs to support continued consumer market growth.

Eastern European and Asian market penetration in present applications categories represents additional potential, which we believe will spur growth in both GaAs and high-performance silicon semiconductors. Dataquest foresees emergence of global networks incorporating satellites and both wireless and fiber earth-based links as a catalyst for the largest potential growth area of communications semiconductors, particularly GaAs ICs, in the late 1990s and into the next century. ■

By Gene Miles

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Product Analysis

A Cornucopia of GaAs ICs for Communication

Semiconductor suppliers are actively engaged in the development, marketing, and production of GaAs ICs and discrete products in response to rapidly developing markets and applications. This article gives a brief overview of a few of the communications industry's GaAs chip and module suppliers' product offerings. The discussion is intended to provide Dataquest clients with insight into the types of GaAs product opportunities that exist and are emerging in the communications arena.

FORCE 2.5 Family

AT&T markets a set of GaAs ICs for operation in systems with data rates to 3.0 Gbps called FORCE 2.5 Fiber Optic Regenerator Chip Ensemble. This chip family includes laser drivers, clock and data regenerators, decision circuits, preamplifiers, a limiting amplifier, and a transition detector. AT&T offers compatible test fixtures to support development and incoming inspection activities. Table 1 summarizes the FORCE 2.5 GaAs IC family.

Each transimpedance amplifier features a GaAs IC die that provides variable transimpedance to a 5-Gbps data rate, followed by additional gain stages and a 50-ohm output buffer. Typical usage in an optical communications system is immediately following an avalanche photodiode (APD) or a positive-intrinsic-negative (PIN) detector stage in a receiver or repeater.

Table 1
FORCE 2.5 GaAs IC Family

AT&T Part No.	Function
LG1094C	Transimpedance Amplifier
HG1210AXA	Transimpedance Amplifier
LG1600AXD	Clock and Data Regenerator
HG1601AXA	Clock and Data Regenerator
LG1602	Decision Circuit
HG1604AXA	Enhanced Decision Circuit
LG1605	Limiting Amplifier
LG1606	Transition Detector
LG1608	Laser Driver (to 3 Gbps)
LG1609	Laser Driver (to 622 Mbps)
LG1622A	622 Mbps Transimpedance Amplifier
LG1624A	2.5 Gbps Transimpedance Amplifier
TF100X Series	FORCE 2.5 Test Fixtures

Source: Dataquest (December 1991)

The clock and data regenerator (CDR) devices are SONET-compatible and used for clock recovery and data retiming. The CDR assemblies contain two chips: a GaAs frequency and phase-locked loop high-sensitivity decision IC; and a silicon bipolar loop filter, acquisition, and detector IC.

The LG1602 Decision Circuit is available in a 16-pin package or in die form. It contains a high-gain, broadband amplifier; a D-type flip-flop; and complementary data output buffers. The HG1604AXA Enhanced Decision Circuit provides signal output proportional to the phase difference between clock and data. It is typically used in nonreturn to zero (NRZ) digidata streams.

The LG1605 GaAs Limiting Amplifier provides constant output signal swing and constant output skew over a wide range of varying input signals. It features complementary 50-ohm outputs and comes in 16-pin package or die form.

The GaAs LG1606 Transition Detector extracts transition pulses from an NRZ data stream; the pulses can be filtered to extract the original clock from the data stream. The circuit includes a high-gain input amplifier, delay generator, mixer, and complementary buffered outputs.

The LG1608 and LG1609 Laser Drivers each contain a GaAs IC with four cascaded differential stages operated from a single 5.2V (ECL-compatible) supply. The drivers accept standard emitter-coupled logic (ECL) 100K-level inputs. One version of LG1608 allows users to control the input switching point. Either driver is available in 16-pin package or die form.

AT&T has accumulated reliability data on GaAs circuits for more than 20 years, starting with devices used in the Telstar satellite. The Telstar chips have accumulated more than 5 million device hours in space without failure. Reliability analyses of test results for preamplifier and laser driver ICs show a failure rate of less than one per billion device hours for a 100°C junction temperature and 10-year system life, which is consistent with field returns experienced by AT&T. Additional analysis on hybrid ICs using GaAs circuits in AT&T's 1.7-Gbps lightwave system confirms these results.

BT&D Optoelectronic Components

BT&D, a joint venture of British Telecom plc and E.I. du Pont de Nemours and Company, markets a family of optoelectronic components based on GaAs and $LiNb_3$ (lithium niobate) technologies. Table 2 shows examples of BT&D's extensive product line.

NEC Optical Transmitter/Receiver Modules

NEC produces and markets a set of module assemblies for use in 2.4-Gbps fiber-optic

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Table 2
BT&D Optoelectronic Components

Part No.	Function
LSC1300	1.3-micron laser module (6-pin)
XMT1300	"Logic to Light" 1.3-micron, -10dBm transmitter
LSC2110	1.3-micron BH laser (cooler)
LSC2300	1.3-micron BH laser (no cooler)
PDH0104	InGaAs PIN photodiode
PDH0804	InGaAs 250-micron area PIN photodiode
PDC2201	InGaAs PIN diode and FET amplifier transmitter, 2.4 Gbps
LST0X0X Series	Connectorized ELEDs and lasers
PDT0412	Connectorized PIN photodiode
DLT1000	1.3-micron FDDI transmitter
DLR1000	Data receiver, light to ECL
DLX2000	FDDI full-duplex transceiver
IOCXXXX Series	$LiNbO_3$ phase modulators, switches, and couplers

Source: BT&D

transmission systems. The company has targeted SONET digital networks as one of the intended applications for these devices. Both 1.3- and 1.55-micron single-mode fiber pigtailed versions of the modules are available. The NEC circuits are summarized in Table 3.

NEC's transmitter modules use distributed feedback lasers incorporating a double-planar buried heterostructure design for increased stability. Receiver modules use indium gallium arsenide (InGaAs) APDs for high sensitivity and a wide dynamic range. The NDL5522P also contains a preamplifier IC for increased sensitivity.

TI's Communications MMICs

Texas Instruments Inc. (TI) introduced several low-noise amplifiers (LNAs) and power amplifiers suitable for space-based and terrestrial microwave communication and other applications. Each offers wideband operation (see Table 4).

Figure 1, a die layout of the TGA8810, shows the complexity of this type amplifier. Die size is 74 × 65 mils; die thickness is 6 mils. It operates from a single 5V supply. Processing of the chip

Table 3
NEC Optical Transmitter/Receiver Modules

Part No.	Function
NDL5803P	1.3-micron DFB laser diode module
NDL5853P	1.55-micron DFB laser diode module
NDL5520P	1.3-micron InGaAs APD module
NDL5522P	1.55-micron InGaAs APD module

Source: Dataquest (December 1991)

Table 4
Texas Instruments' MMIC Amplifiers

Part No.	Function
TGA8310	2- to 20-GHz LNA
TGA8320	DC to 8-GHz—L, S, C band gain-block amplifier
TGA8031	Dual-gate driver amplifier
TGA8061	100- to 3.5-GHz LNA
TGA8161	500- to 3-GHz general-purpose amplifier
TGA8810	2- to 10-GHz C, S, X band amplifier

Source: Dataquest (December 1991)

is ion-implanted submicron metal-etch semiconductor field-effect transistor (MESFET) on semi-insulating GaAs wafers. The square at upper right of the layout is a bonding pad, and the long curved lines are controlled impedance interconnection paths. TI offers this device in chip or packaged form.

TriQuint GaAs ICs for Communication

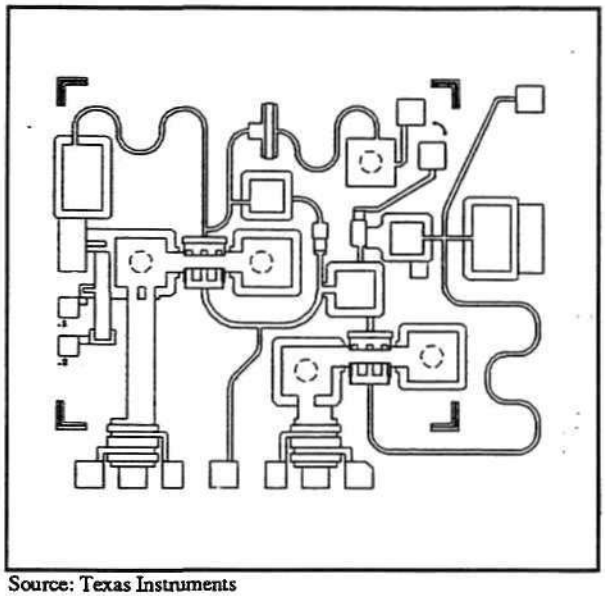
TriQuint has developed GaAs ASICs for almost all segments of the GaAs IC marketplace and is a strong supplier to the communications market. In mid-1990, TriQuint announced the first GaAs ASIC in a plastic package, for use in a cellular telephone receiver. Also in 1990, TriQuint described a 2.4-Gbps, 32 × 32 crosspoint switch based on its QLSI standard-cell source-coupled field-effect transistor (FET) logic (QLSI) ASIC process. The company demonstrated the concept by fabricating 8 × 8 chips that functioned above 3 Gbps. TriQuint produces for the communications and other markets a TQ91XX series of wideband amplifiers, switches, dividers, and related circuits; a TQ6XXX series of line drivers, receivers, and digital-to-analog converters; and a TQ1XXX series of MUXs and deMUXs.

Vitesse Communications ICs

Vitesse has developed and is shipping several types of communications multiplexer (MUX) and demultiplexer (deMUX) ICs in 52-pin leaded chip carrier (LDCC) packages (see Table 5). The ICs range in function from 4- to 12-line multiplexer complexity and operate at SONET network frequencies to 1.25 or 2.5 Gbps. Vitesse also offers a 64 × 64 crosspoint switch in a 344-pin LDCC. As with other crosspoint switches, the use of four devices expands interconnectivity to 128 × 128, 16 chips achieve 256 × 256 connections, and so on; the number of chips used is an exponential function of increased complexity of interconnections. Vitesse uses a 0.6-micron E/D MESFET GaAs process offering functional density of more than 1 million transistors per chip to produce these products at cost-per-function levels below those of equivalent silicon ICs.

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Figure 1
TGA8810 Die Layout



Source: Texas Instruments

Table 5
Vitesse GaAs ICs for Communication

Part No.	Function
VS8001	1.25-Gbps 12:1 MUX
VS8002	1.25-Gbps 1:+12 deMUX
VS8004	2.5-Gbps 4:1 MUX
VS8005	2.5-Gbps 1:4 deMUX
VS8010	1.25-Gbps 8-bit MUX/deMUX with SONET frame detection
VS8011	1.25-Gbps 8-bit MUX
VS8012	1.25-Gbps 8-bit deMUX with SONET frame detection
VS8021	2.5-Gbps SONET 8-bit MUX
VS8022	2.5-Gbps SONET 8-bit deMUX
VSC864	GaAs 200-Mbps crosspoint switch

Source: Dataquest (December 1991)

Dataquest Perspective

The foregoing discussion confirms that GaAs technology has been brought to bear on some of the communications industry's most pressing performance problems. Dataquest believes that product evolution in GaAs ICs is accelerating, and that future generations of communications hardware will benefit directly from such enabling functions as single-chip or two-chip GaAs transceivers, microwave-frequency digital phase-locked loops, and similar innovative ICs. ■

By Gene Miles

Company Analysis

Major Producers of GaAs Chips for Communication

ICs and discrete components for the high-speed communications equipment market have been developed by a new breed of suppliers. Although they are a mixture of long-established companies and start-ups, the names may surprise some semiconductor users. Each supplier has focused on market niches, and the vertically integrated suppliers have developed major product sets for in-house use (see Table 1).

Four suppliers are examined in this article. To illustrate the variety of market strategies that have been successfully applied, two start-ups and two vertically integrated multinational companies are reviewed. The companies treat their

Table 1
Merchant Suppliers of GaAs Semiconductors for Communication

North America	Europe	Asia/Pacific
Alpha Industries	Alcatel	Fujitsu
Anadigics	BT&D	Hitachi
AT&T	GEC-Marconi	Mitsubishi
COMSAT Labs	Italtel	NEC (including
Epitaxx	LM Ericcson	California
Harris	Philips	Eastern Labs)
Siemens	Oki	Toshiba (Matcom)
Hughes	Telefunken	
ITT GTC	Thomson	
Lytel	Composants	
M/A-COM		
Motorola		
Optek Technology		
Optotek Ltd.		
Ortel		
Pacific Monolithics		
Raytheon		
Rockwell		
Telcom Devices		
Texas Instruments		
TriQuint		
TRW		

Source: Dataquest (December 1991)

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external sales and internal consumption of specific GaAs and related compound semiconductor products as proprietary data, so only a few very general estimates are shown here.

AT&T

AT&T provides long distance communications hardware and services throughout approximately 200 countries worldwide. Company sales exceed $35 billion annually. AT&T Bell Laboratories, a subsidiary of AT&T, is the world's leader in basic and applied communications research and has pioneered the evolution of GaAs and related compound semiconductors for microwave and lightwave communication. The company holds extensive patents in this technology, many of which are cross-licensed with other companies worldwide. AT&T manufactures compound semiconductors in large volume at its 34,000-square-foot Reading, Pennsylvania, GaAs facility, which includes five modules of Class 3 or better 2,000-square-foot clean rooms.

In October, AT&T Microelectronics and Mitsubishi Electric Corporation announced a five-year agreement to work together in developing GaAs ICs for selected wireless communications products. The agreement allows for joint development, product exchange, private label, and mutual alternate-sourcing of GaAs ICs, as well as consideration of exchange of GaAs IC design, process, and product information. Products manufactured by AT&T Microelectronics as part of the agreement will be fabricated at the Reading GaAs production facility, using a 0.6-micron metal-etch semiconductor field-effect transistor process on molecular beam epitaxy GaAs wafers. One product, a 1.9-GHz dual modulus prescaler, will be produced with AT&T technology to Mitsubishi specifications by AT&T, starting in mid-1992.

Nippon Electric Corporation

Nippon Electric Corporation (NEC) was founded in 1899 to manufacture telephone sets and switchboards. Initial capitalization came from a group that later became Western Electric Company, for many years the manufacturing arm of the Bell Telephone Companies. NEC is the number-one manufacturer of semiconductors worldwide and one of the top five world suppliers of communications and computing equipment and systems.

NTT, the research arm of NEC, has closely followed the work of Bell Laboratories and other communications pioneers and developed lasers, detectors, microwave ICs, and other compound semiconductor components for spaceborne and terrestrial communications systems. NEC began offering GaAs prescalers in 1986, after a long history of supplying discrete microwave GaAs transistors for low-noise and power applications.

In the United States, California Eastern Laboratories (CEL) is the exclusive agent for NEC microwave semiconductors, which now include GaAs field-effect transistors (FETs), GaAs high-electron mobility transistors, diodes, low-noise amplifiers (LNAs), prescalers, other microwave monolithic ICs (MMICs), and microwave hybrid circuits. CEL ships more than $35 million per year of NEC products into the U.S. marketplace.

NEC has technology exchange agreements with AT&T, Hewlett-Packard Company, Matra-Harris Semiconducteurs (France), Oki Electric Industries Company Ltd., Sharp Corporation, Sony Corporation, Toshiba Inc., Tektronix Incorporated, Texas Instruments Inc., and others. NEC has developed GaAs computer and communications ICs for the Japan National Supercomputer Project jointly with Fujitsu Ltd., Hitachi Ltd., Mitsubishi Electronics Corporation, Oki, and Toshiba.

NEC is a major international supplier of prescalers and other semiconductors for cellular radio-telephone applications, and of fiber-optic transmitter and receiver modules. It has supplied GaAs discretes and ICs for space applications on U.S., Japanese, and European satellites.

TriQuint Semiconductor Inc.

TriQuint designs, develops, manufactures, and markets microwave, linear, and multi-GHz digital GaAs IC components for communications and other high-performance IC markets. The company also operates a full-service foundry. TriQuint evolved from research on GaAs ICs that began in Tektronix Laboratories in 1978. Several of TriQuint's founders were leaders of the Tektronix research team. In 1984, TriQuint was formally established as a majority-owned subsidiary of Tektronix and given entrepreneurial freedom to pursue a portfolio of long-term manufacturing contracts.

In 1991, TriQuint acquired GigaBit Logic of Newbury Park, California, and Gazelle Microcircuits of Santa Clara, California. Both acquisitions added communications ICs to the product portfolio. TriQuint has 35,000 square feet of administration, engineering, and manufacturing areas and 15,000 square feet of clean room

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facilities in Beaverton, Oregon, and additional facilities in Santa Clara. The company has about 270 employees.

TriQuint has been a leader in developing microwave CAD tools. In 1986, the company teamed with EEsof Incorporated to incorporate TriQuint's custom GaAs MMIC foundry models into EEsof's Touchstone workstation-based CAD system for MMIC development. For more than three years, TriQuint's MMIC library of foundry design models has been used in Hewlett-Packard's microwave CAE design system.

TriQuint is an approved supplier to Motorola's Government Electronics Division. It received a Defense Advanced Research Projects Agency MIMIC award for Phase 3 and has been a major foundry for Pacific Monolithics, a pioneer in the TV receiver downconverter business.

In July 1991, following the Gazelle acquisition, TriQuint announced major organization changes including setting up three market-oriented business units: computing/networking, digital communication and digital signal processing, and microwave communication. TriQuint shipped about $30 million of product in 1990, and 1991 revenue is expected to exceed $40 million. Its market base is more than 1,200 customers worldwide.

Vitesse Semiconductor Corporation

Vitesse designs, manufactures, and markets cost-effective digital GaAs ICs for the high-performance marketplace and offers foundry services on a contract basis. The company's first products were commercial GaAs ICs including gate arrays, SRAMs, and logic products such as 2.5-Gbps SONET-compatible communications ICs.

Vitesse's GaAs ICs compete favorably with silicon emitter-coupled logic (ECL) devices. Its H-GaAs III, 0.6-micron process introduced in 1989 offers better performance and higher integration levels than currently available silicon ECL, at per-gate costs below silicon bipolar. The all-implant (no diffusion) process allows up to four layers of metal interconnections.

Vitesse has 45,000 square feet of administration, marketing, engineering, production, and test facilities in Camarillo, California, including 12,000 square feet of clean rooms (about half of which is Class 10) for producing GaAs E/D MESFET wafers. The company has about 190 employees.

Dataquest estimates that Vitesse has already shipped more than $7 million in GaAs communications ICs in 1991 and that this business is growing at more than 60 percent per year. We expect total sales of Vitesse GaAs ICs to exceed $30 million in 1991. Sales in 1990 were about $18 million, with profit of $1.7 million. The company has apparently been profitable since the first quarter of 1990.

Vitesse has alternate-sourcing and technology exchange agreements with Advanced Micro Devices Inc., Fujitsu, Thomson Composants Microondes, TRW Incorporated, and others. TRW's agreement involves Class S logic, memory, and ASIC products for space applications.

On October 25, Vitesse announced the filing of a Registration Statement with the Securities and Exchange Commission relating to the company's proposed initial public offering of 3.2 million shares of common stock at an anticipated initial price of $8 to $9 per share. Vitesse plans to use the funds to reduce indebtedness and to purchase equipment. The underwriting group is managed by Robertson, Stephens and Company and Prudential Securities Incorporated.

Dataquest Perspective

Dataquest believes that the agreement between AT&T and Mitsubishi, which builds on previous agreements, could strengthen both their market positions. AT&T should enjoy increased penetration of the personal wireless communications market in Japan, and Mitsubishi will benefit from acquisition of more AT&T technologies.

The complement of suppliers in the GaAs IC product arena is a mixture of start-ups and vertically integrated companies. Either can be successful if funded consistently at appropriate levels and if managed well; lack of either ingredient has proven disastrous. Dataquest believes that a new start-up must now invest at least $50 million to enter the GaAs IC market and that if a silicon IC company or a vertically integrated company has not already entered the GaAs IC arena, an investment of more than $100 million will be required to do so. ■

By Gene Miles

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News and Views

Major Issues Facing GaAs IC Suppliers

Although such issues as user acceptance of unfamiliar technology and conservatism of traditional silicon IC houses continue to constrain rapid growth of GaAs ICs, the limitations through the mid-1990s are primarily political in nature. Government allocation of frequencies is one political tool used to control the flow of wealth in this industry. This article illustrates the nature of nontechnical problems facing the industry in the next few years.

Political Constraints on Market Evolution

High financial stakes involved in mass communication cause evolution of markets to be manipulated by lobbyists and political leadership. Thus, most public communications systems continue evolving on a geopolitical basis, and semiconductor suppliers to these markets must learn to cope.

One example of how politics has affected market evolution is seen in the contrast between AM and FM radio and cable TV. In the United States, radio receivers are not individually charged fees for receiving information and companies such as General Electric Company, Motorola, Philco Corporation, and RCA Corporation were able to develop mass markets for radio receivers rapidly without government interference. However, companies such as Anadigics Inc., M/A-COM Inc., and Pacific Monolithics Inc. were unable in the late 1980s to develop a similar mass market for television receive-only (TVRO) downconverters because of political lobbying by entertainment and cable industries and the resulting territorial licensing and fee structures imposed by Congress via the Federal Communication Commission. This has not been the case in Japan and Europe, where downconverter applications emerged rapidly. The first commercial order for 1 million GaAs MMICs was supplied by Anadigics to a European customer.

Dataquest believes that GaAs IC suppliers must become more sensitive to the political nature of control of their end markets and must form mutually beneficial partnerships with customers that have governmental lobbying strength in order to enjoy rapid growth throughout the 1990s.

Export Controls Restrict World Market Growth

Potential markets for GaAs ICs and discretes to support fiber-optic and wireless communications equipment in Eastern Europe, the Soviet Union, and China are enormous because of the broad geographic areas (more than 33 million square kilometers) and huge population sizes (more than 1.3 billion people in Eastern Europe and Asia) to be served. However, present Coordinating Committee for Multilateral Export Controls (CoCom) regulations prevent exporting single-mode fiber and related electronics to the Soviet Union, and data rates of electronics are restricted to 45 Mbps maximum. Eastern Europe exports may include 1.5-micron lasers, single-mode fiber, and 565-Mbps hardware for civilian customers. People's Republic of China exports can include 140-Mbps electronics and 1.3-micron lasers for civilian applications.

Relaxing any of these restrictions will open additional markets. However, the inherent security and resistance to tapping of fiber systems present national security concerns to the United States, United Kingdom, and other Western governments, making it unlikely that major relaxations will be quickly forthcoming. Because of national security concerns, Dataquest believes that the growth potential for wireless systems such as Motorola's Iridium network of satellites and ground stations appears greater than does that of fiber systems, at least through the mid-1990s, in the communist-controlled markets. ■

By Gene Miles

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Dataquest Perspective

Gallium Arsenide Semiconductors *Worldwide*

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In This Issue...

Market Analysis

GaAs and Related Compound Semiconductor Shipments and Consumption Examined

This article analyzes the historical shipment data for GaAs and related compound semiconductors and reviews some of the major market opportunities for GaAs chip suppliers. Dataquest also looks at progress in and problems of GaAs IC market development and provides a five-year forecast.

By Gene Miles *Page 1*

Product Analysis

Vitesse Production GaAs IC Contains 1.5 Million Transistors

Vitesse Semiconductor Corporation's VGFX350K GaAs ASIC chip contains a total of 1.5 million transistors. Announced last year, the chip is now in the production sampling phase of its development. The sea-of-gates architecture offers basic gate delays of 60ps, which is up to four times the speed performance of BiCMOS arrays. This article examines the VGFX350K and two other GaAs gate arrays recently announced by Vitesse.

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News and Views

Motorola's Altair Eliminates Cables in Office Communication

A "wireless ethernet" system of 18-GHz communication hardware, developed by Motorola, simplifies in-building networks.

By Gene Miles *Page 8*

Recent Developments in Blue LED Lasers

Blue lasers will allow increased throughput over fiber-optic communications links. Brown University and Purdue University researchers have reported progress in this technology.

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Market Analysis

GaAs and Related-Compound Semiconductor Shipments and Consumption Examined

In this article, Dataquest examines recent shipment and consumption data for GaAs and related-compound semiconductors. Some of the major market opportunities for GaAs chip suppliers are reviewed. We also take a look at progress in and problems of GaAs IC market development and provide a forecast of expected GaAs semiconductor consumption over the next five years.

GaAs Analog/Linear IC Shipments

In 1991, GaAs analog/linear IC shipments grew to $308 million, an increase of 27.3 percent over 1990 (see Table 1). Two primary factors helped boost this segment. First, the successful insertion of GaAs ICs in major weapons systems in North America and Europe required production quantities of many types of GaAs ASICs. Second, commercialization efforts resulted in significant growth in consumption of GaAs microwave monolithic ICs (MMICs) by producers of satellite communications, fiber communications, and cellular radiotelephone systems, as well as TV receivers and video recorders, navigation

Table 1
Estimated Worldwide Merchant Shipments, GaAs Analog/Linear ICs (Millions of Dollars)

Category	1990	1991	Percent Change
GaAs Analog/Linear ICs	242	308	27.3
NRE	48	47	- 2.1
MMIC Amps	42	54	28.6
ASICs	114	164	48.9
Others	38	43	13.2

Source: Dataquest (March 1992)

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receivers (particularly portable GPS types), traffic control, and security systems.

North American shipments of GaAs analog/linear ICs increased 19.4 percent over 1990, to $215 million in 1991 (see Table 2). From 1990 to 1991, Western European shipments grew by 40 percent and Japanese shipments by almost 60 percent (see Tables 3 and 4).

Table 2
Estimated North American Merchant Shipments, GaAs Analog/Linear ICs (Millions of Dollars)

Category	1990	1991	Percent Change
GaAs Analog/Linear ICs	180	215	19.4
NRE	38	35	- 7.9
MMIC Amps	27	29	7.4
ASICs	88	123	51.1
Others	27	28	3.7

Source: Dataquest (March 1992)

Table 3
Estimated Western European Merchant Shipments, GaAs Analog/Linear ICs (Millions of Dollars)

Category	1990	1991	Percent Change
GaAs Analog/Linear ICs	30	42	40.0
NRE	6	7	16.7
MMIC Amps	5	7	40.0
ASICs	14	22	57.1
Others	5	6	20.0

Source: Dataquest (March 1992)

Table 4
Estimated Japanese Merchant Shipments, GaAs Analog/Linear ICs (Millions of Dollars)

Category	1990	1991	Percent Change
GaAs Analog/Linear ICs	32	51	59.4
NRE	4	5	25.0
MMIC Amps	10	18	80.0
ASICs	12	19	58.3
Others	6	9	50.0

Source: Dataquest (March 1992)

GaAs DigIC Shipments

Although an estimated 17.8 percent increase occurred in GaAs digital IC (digIC) shipments in 1991, results were disappointing to many manufacturers, primarily because of weak market acceptance of GaAs SRAMs and standard products including programmable devices. The impact on commercial suppliers of Cray's decision to captively produce GaAs ICs is estimated at $6 million to $10 million in 1991, figures that will grow throughout this decade.

Table 5 summarizes 1990 and 1991 GaAs digIC shipments by product category, and Table 6 shows regional GaAs digIC shipments.

GaAs ASIC Shipments

Because GaAs IC products are predominately ASICs, Dataquest has prepared a summary for this category. Worldwide GaAs ASIC shipments in 1991 were 27.5 percent greater than in 1990. The analog/linear category grew faster than did the digital, 30 percent versus 24 percent. Table 7 summarizes this data, showing NRE charges as separate line items.

Table 5
Estimated Worldwide Merchant Shipments, GaAs DigICs (Millions of Dollars)

Category	1990	1991	Percent Change
GaAs DigICs	163	192	17.8
NRE	46	45	- 2.2
Standard Logic	13	10	-23.1
SRAMs	10	8	-20.0
ASICs	94	129	37.2

Source: Dataquest (March 1992)

Table 6
Estimated Regional Merchant Shipments, GaAs DigICs (Millions of Dollars)

Region	1990	1991	Percent Change
Worldwide GaAs DigICs	163	192	17.8
North America	107	125	16.8
Western Europe	18	22	22.2
Japan	19	23	21.1

Source: Dataquest (March 1992)

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Tables 8, 9, and 10 show 1990 and 1991 GaAs ASIC shipments for each major geographic region.

Table 7
Estimated Worldwide Merchant Shipments, GaAs ASICs (Millions of Dollars)

Category	1990	1991	Percent Change
Total GaAs ASICs	302	385	27.5
Digital GaAs ASICs	140	174	24.3
Devices	94	129	37.2
NRE	46	45	- 2.2
Analog/Linear GaAs ASICs	162	211	30.2
Devices	114	164	43.9
NRE	48	47	- 2.1

Source: Dataquest (March 1992)

Table 8
Estimated North American Merchant Shipments, GaAs ASICs (Millions of Dollars)

Category	1990	1991	Percent Change
Total GaAs ASICs	220	278	26.4
Digital GaAs ASICs	94	120	27.7
Devices	66	94	42.4
NRE	28	26	- 7.1
Analog/Linear GaAs ASICs	126	158	25.4
Devices	88	123	39.8
NRE	38	35	- 7.9

Source: Dataquest (March 1992)

Table 9
Estimated Western European Merchant Shipments, GaAs ASICs (Millions of Dollars)

Category	1990	1991	Percent Change
Total GaAs ASICs	37	50	35.1
Digital GaAs ASICs	17	21	23.5
Devices	9	12	33.3
NRE	8	9	12.5
Analog/Linear GaAs ASICs	20	29	45.0
Devices	14	22	57.1
NRE	6	7	16.7

Source: Dataquest (March 1992)

Table 10
Estimated Japanese Merchant Shipments, GaAs ASICs (Millions of Dollars)

Category	1990	1991	Percent Change
Total GaAs ASICs	45	57	26.7
Digital GaAs ASICs	29	33	13.8
Devices	19	23	21.1
NRE	10	10	0.0
Analog/Linear GaAs ASICs	16	24	50.0
Devices	12	19	58.3
NRE	4	5	25.0

Source: Dataquest (March 1992)

GaAs Discrete Microwave/Millimeter Wave Shipments

The GaAs discrete microwave and millimeter wave product category includes small-signal transistors, power transistors, Hall-effect elements, and high-frequency diodes. Shipments were boosted in 1991 as more types of high-electron mobility transistor (HEMT) and heterojunction bipolar transistor (HBT) devices displaced metal-etch semiconductor field-effect transistor (MESFET) devices in this market, slightly exceeding Dataquest's May 1991 forecast. Worldwide consumption rose to an estimated $331 million in 1991 (see Table 11), led by the increase in the North American market. Tables 12, 13, and 14 detail consumption in the North American, European, and Japanese regions.

Optoelectronic Semiconductor Shipments

Optoelectronic semiconductors include active circuits produced on silicon, GaAs, or other compound semiconductor substrates. The devices combine photonic and electronic functions in a single discrete or IC chip. The worldwide market for such devices now exceeds $3 billion.

Tables 15 through 19 summarize 1990 and 1991 shipment data for this category, by product grouping and by region. Double-digit growth occurred in the worldwide charge-coupled device/optoelectronic IC (CCD/OEIC), laser/transmitter, and LED/LED display segments, led by high demand in the video minicam, fiber-optic communications, and associated equipment markets.

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Table 11
Estimated Worldwide Merchant Shipments, GaAs uWave/mmWave Discretes (Millions of Dollars)

Category	1990	1991	Percent Change
Other GaAs Discretes	305	331	8.5
Small-Signal Transistors	188	199	5.9
Power Transistors	98	110	12.2
Hall Elements, Others	19	22	15.8

Source: Dataquest (March 1992)

Table 12
Estimated North American Merchant Shipments, GaAs uWave/mmWave Discretes (Millions of Dollars)

Category	1990	1991	Percent Change
Other GaAs Discretes	136	154	14.1
Small-Signal Transistors	60	69	15.0
Power Transistors	73	80	9.6
Hall Elements, Others	3	5	66.7

Source: Dataquest (March 1992)

Table 13
Estimated Western European Merchant Shipments, GaAs uWave/mmWave Discretes (Millions of Dollars)

Category	1990	1991	Percent Change
Other GaAs Discretes	22	24	9.1
Small-Signal Transistors	11	11	0.0
Power Transistors	8	10	25.0
Hall Elements, Others	3	3	0.0

Source: Dataquest (March 1992)

Table 14
Estimated Japanese Merchant Shipments, GaAs uWave/mmWave Discretes (Millions of Dollars)

Category	1990	1991	Percent Change
Other GaAs Discretes	147	153	4.1
Small-Signal Transistors	117	119	1.7
Power Transistors	17	20	17.6
Hall Elements, Others	13	14	7.7

Source: Dataquest (March 1992)

Table 15
Estimated Worldwide Merchant Shipments, Optoelectronic Semiconductors (Millions of Dollars)

Category	1990	1991	Percent Change
Total Optoelectronics	2,687	3,072	14.3
LEDs and LED Arrays	669	791	18.2
Optocouplers, Isolators, Interruptors	552	593	7.4
Lasers and Transmitters	557	643	15.4
Detectors	156	160	2.6
Photovoltaic Cells	162	170	4.9
Others (Including CCDs and OEICs)	591	715	25.2

Source: Dataquest (March 1992)

Table 16
Estimated North American Merchant Shipments, Optoelectronic Semiconductors (Millions of Dollars)

Category	1990	1991	Percent Change
Total Optoelectronics	457	541	18.4
LEDs and LED Arrays	98	96	- 2.0
Optocouplers, Isolators, Interruptors	112	116	3.6
Lasers, Transmitters, Detectors, Photovoltaics, Others	247	329	33.2

Source: Dataquest (March 1992)

Table 17
Estimated Western European Merchant Shipments, Optoelectronic Semiconductors (Millions of Dollars)

Category	1990	1991	Percent Change
Total Optoelectronics	267	272	1.9
LEDs and LED Arrays	152	153	0.7
Optocouplers, Isolators, Interruptors	41	42	2.4
Lasers, Transmitters, Detectors, Photovoltaics, Others	74	77	4.1

Source: Dataquest (March 1992)

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Table 18
Estimated Japanese Merchant Shipments, Optoelectronic Semiconductors (Millions of Dollars)

Category	1990	1991	Percent Change
Total Optoelectronics	1,935	2,227	15.1
LEDs and LED Arrays	405	526	29.9
Optocouplers, Isolators, Interruptors	391	427	9.2
Lasers, Transmitters, Detectors, Photovoltaics, Others	1,139	1,274	11.9

Source: Dataquest (March 1992)

Table 19
Estimated Asia/Pacific Merchant Shipments, Optoelectronic Semiconductors (Millions of Dollars)

Category	1990	1991	Percent Change
Total Optoelectronics	28	32	14.3
LEDs and LED Arrays	14	16	14.1
Optocouplers, Isolators, Interruptors	8	8	0
Lasers, Transmitters, Detectors, Photovoltaics, Others	6	8	29.0

Source: Dataquest (March 1992)

GaAs Semiconductor Market Share Estimates

Dataquest has prepared preliminary 1991 market share estimates for most of the GaAs and related-compound semiconductor manufacturers, including the top 20. The results are shown alphabetically by company for each geographic region in Tables 20, 21, and 22.

Hewlett-Packard is clearly the leading North American supplier; its position was recently strengthened by its acquisition of Avantek. Texas Instruments is second, and Optek third among North American suppliers. The companies rank 5th, 12th, and 13th, respectively, among the world's producers of compound semiconductors. Among makers of GaAs ICs only, TriQuint ranks first and Vitesse second, closely followed by Rockwell and TRW.

Table 20
GaAs Semiconductor Market Share, Preliminary Estimates for North American Companies (Millions of Dollars)

Company	1990	1991	1991 Share (%)
Alpha Industries	22	22	0.6
Avantek[1]	27	NA	NA
GigaBit Logic Inc.[2]	12	NA	NA
Harris (Including HMS)	24	21	0.5
Hewlett-Packard	255	310	7.9
Honeywell	28	28	0.7
Hughes	28	31	0.8
Litton	25	33	0.8
M/A-COM	36	35	0.9
MicroWave Technology	11	12	0.3
Motorola	30	38	1.0
Optek	66	52	1.3
Quality Technologies	34	35	0.9
Rockwell	25	27	0.7
Texas Instruments	45	82	2.1
TriQuint[3]	18	35	0.9
TRW	17	26	0.7
Vitesse	17	28	0.7
Others	160	NA	NA
Total	880	1,035	26.5

NA = Not available
[1]Acquired by Hewlett-Packard in 1991.
[2]Acquired by TriQuint in 1991.
[3]Acquired GigaBit Logic and Gazelle Microcircuits in 1991.
Source: Dataquest (March 1992)

Table 21
GaAs Semiconductor Market Share, Preliminary Estimates for Western European Companies (Millions of Dollars)

Company	1990	1991	1991 Share (%)
Philips	38	45	1.1
Siemens	138	177	4.4
Telefunken Electronic	87	93	2.3
Thomson CSF	33	45	1.1
Others	41	10	0.3
Total	337	370	9.2

Source: Dataquest (March 1992)

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Table 22
GaAs Semiconductor Market Share, Preliminary Estimates for Japanese Companies (Millions of Dollars)

Company	1990	1991	1991 Share (%)
California Eastern Labs (NEC)	35	45	1.2
Fujitsu	144	171	4.4
Hitachi	85	94	2.4
Matsushita	335	412	10.6
Mitsubishi	62	NA	NA
NEC	149	180	4.6
Oki	43	47	1.2
Rohm	105	NA	NA
Sanken	19	21	0.5
Sanyo	170	236	6.0
Sharp	339	432	11.1
Sony	270	339	8.7
Toshiba	317	367	9.4
Others	79	NA	NA
Total	2,152	2,476	63.4

NA = Not available
Source: Dataquest (March 1992)

Siemens is the only European company ranked within the top 10 compound semiconductor producers worldwide, and it is the largest of the European manufacturers of these devices. Among Japanese producers of GaAs and related-compound semiconductors, Sharp, Matsushita, Toshiba, and Sony rank first through fourth, both in Japan and worldwide. All four companies are vertically integrated with significant internal demand; all have strong positions in the chip markets for LEDs, LED displays, CCDs, and MMICs.

GaAs Semiconductor Market Forecast

Dataquest has prepared a preliminary forecast of worldwide GaAs and related-compound semiconductor consumption for 1992 through 1996. This forecast uses the 1991 shipment data already discussed and additional data as the starting point. It is based on the following assumptions:

- No global military conflicts and no conflicts resulting in combat within the territories in which the GaAs device manufacturing facilities are based, between now and 1997
- Gradual economic recovery in the United States, accompanied by major cuts in more than 200 defense programs and the continuing lack of a positive national technology policy

Table 23
Worldwide GaAs Semiconductor Merchant Consumption Preliminary Forecast (Millions of Dollars)

Category	1991	1992	1996	CAGR (%) 1991-1996
Total	3,903	4,280	6,347	10.2
GaAs Analog/Linear ICs	308	387	732	18.9
Devices	261	338	670	20.7
NRE	47	49	62	5.7
GaAs DigICs	192	241	563	24.0
Devices	147	201	528	29.1
NRE	45	40	35	- 4.9
Optoelectronics	3,072	3,298	4,574	8.3
LEDs, CCDs, Others	2,988	3,201	4,380	7.9
OEICs	84	97	194	18.2
uWave/mmWave Discretes	331	354	478	7.6

Note: Data include intracompany consumption for merchant suppliers and intracompany consumption by full captives; optoelectronics include silicon IR emitters, detectors, and laser drivers.
Source: Dataquest (March 1992)

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- Minimal predatory pricing among GaAs ASIC competitors
- Continuing favorable cost/performance of GaAs VLSI ASICs over silicon ECL and BiCMOS counterparts
- Accelerating acceptance of GaAs MMICs for commercial communications applications, and expansion of microwave communication into Eastern markets

Dataquest expects the worldwide market for GaAs and related-compound semiconductors to experience overall growth of more than 10 percent through 1996, led by the growth in analog/linear shipments, which are now expected to remain ahead of GaAs digICs through 1996. The market will approach $6 billion in 1995. Table 23 summarizes the forecast by product category, and shows the compound annual growth rate for each.

Dataquest Perspective

The year 1991 marked a major shift in the trends in GaAs IC industry evolution, as reflected in the shipment and forecast data cited in this article. Several Japanese companies strengthened their positions in the worldwide market for these components, leveraging from lessons learned by supplying their internal needs.

GaAs digIC shipment levels will remain below those of GaAs analog/linear ICs for the foreseeable future. The demise of such companies as GigaBit Logic Inc. and Gazelle Microcircuits Inc., due partly to the failure of the majority of large-scale computer mainframe houses to capitalize on the favorable cost/performance of GaAs over silicon ECL and BiCMOS, portends a long-term market shift in favor of the analog/linear GaAs IC producers. This trend is enhanced by the rapid growth of microwave communication in the commercial sector, with its resultant increased demand for low-noise, highly efficient GaAs MMICs.

As the GaAs IC market matures, Dataquest expects vertically integrated producers of GaAs ICs to grow their GaAs IC market shares by using their broad lines of semiconductor products, including silicon semiconductors, as leverage against the specialty (GaAs IC-only) houses. More merger activity will be a likely result of this pressure.

By Gene Miles

Product Analysis

Vitesse Production GaAs IC Contains 1.5 Million Transistors

For many months, Vitesse Semiconductor Corporation (Camarillo, California) endeavored to achieve a production-worthy GaAs chip density equivalent to that used in leading silicon microprocessors. It has succeeded with the VGFX350K gate array, which accomplishes the task easily.

Vitesse is a major producer of digital GaAs ICs and has been a leader in the practical application of silicon interconnection methodology and other production cost-reduction techniques to the manufacture of enhancement/depletion (E/D) mode GaAs ICs, including very large scale integration (VLSI).

The VGFX350K gate array has a transistor count of 1.14 million active of a total of 1.44 million available sites. This matches the complexities of the Intel i486 and Motorola 68040 silicon microprocessors. In contrast, the popular Intel 80386 microprocessor, the CPU of many IBM PC clones shipped last year, contains about 275,000 transistors, or one-fourth as many as the VGFX350K.

The VGFX350K has 378 ECL I/O signal buffers. The interfaces are configurable to a mixture of emitter-coupled logic (ECL) and transistor-transistor logic (TTL), if needed by the user. Industry-standard power supplies are used. The package is a 557-pin, plastic pin grid array (PGA). A master-slice option provides for such combinations as standard-cell SRAM blocks, multiport register files, sea-of-gates, and I/Os.

The performance of the Vitesse FX architecture is superior to that of available BiCMOS families by a factor of 4 to 10. A two-input NOR (Not OR) gate, unloaded, has a speed-power product of 60ps times 180mW, or 11 femtojoules. This allows construction of a 32-bit adder with a 2.3ns delay at 110mW power consumption and SRAM arrays with cycle times of 3.5ns. Thus, read-modify-write cycles can be performed at a rate of 100 MHz, several times that implemented in presently available high-end PCs.

Recent product announcements by Vitesse include the FX20K and FX40K arrays, which contain about 10,000 and 20,000 usable gates,

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respectively. These devices, produced on the same 0.6-micron H-GaAs III process as the VGFX350K, are aimed at the large-volume gate array markets at the lower end of the complexity range. Bandwidths exceeding 1 GHz are achievable with these arrays, suitable for fiber-optic systems, cache control, high-speed digital signal processing (DSP), and similar applications.

To support customers during the development process, Vitesse's software tools package supports Synopsys logic synthesis and Verilog mixed-mode simulation environments. This allows the synthesis of high-level logic descriptions directly into simulated netlists, thus reducing the difficulty of schematic capture.

Dataquest Perspective

A GaAs IC startup company has moved from concept to production along a progress curve that spans the gap from small-scale integration (SSI) density to the intercept of silicon complexity, a feat considered by many to be impossible, in just eight years. This in and of itself is a major milestone in GaAs IC technology.

Silicon technology already competes with itself in the sense that silicon ECL is experiencing encroachment of its market niche by silicon BiCMOS. Availability of GaAs ICs at BiCMOS density and four times the performance efficiency, at comparable cost/performance pricing, assures that silicon ECL will experience further erosion of market potential.

Dataquest believes that GaAs VLSI is having a growing impact on the viability of silicon ECL and, to a lesser extent, BiCMOS, and that those IC users involved in new CPU designs should carefully weigh the trade-offs of GaAs versus silicon before proceeding. The message to ASIC producers is: Make sure the customers' intentions are well understood and carefully studied, and act accordingly to determine if it is reasonable to continue spending capital on silicon gate array technology, whether it be ECL or BiCMOS.

By Gene Miles

News and Views

Motorola's Altair Eliminates Cables in Office Communication

In-building communication requires wiring and cabling that present significant physical, financial, and logistical problems to businesses and other office operations. In response, Motorola's Altair wireless LAN system (named after the brightest star in the Milky Way) was developed to replace cables and wires with 18-GHz microcells.

Altair uses 10-MHz channels to achieve 15-MBps throughput through small 18-GHz FM transceiver nodes, each about the size of a PC modem. Each microcell uses control modules connected to ethernet servers, wired LANs, and other networks, and user modules that are connected to PCs, printers, and other peripheral devices. The control modules route data among the various system components.

Extensive testing has confirmed that the 18-GHz carrier signal diffuses well inside buildings and yet attenuates well outside, which permits carrier reuse in another system located more than 40 meters away. Less than 1W of effective radiated power is needed for successful operation of Altair.

Another advantage of operation at 18 GHz is that this frequency is now nearly interference-free, much more so than are other frequencies both below and above 18 GHz. The frequency band near 18 GHz was not available for such applications until the Federal Communications Commission (FCC) made rule modifications in April 1990, which added provision for the digital termination service (DTS) band to include low-power wireless communication within buildings.

Early in 1988, a Motorola design team set out to make major reductions to the size, weight, and cost of available 18-GHz radios. A major factor in the success of their effort was the decision to adapt GaAs ICs to the task. Motorola at that time had already accumulated several years of

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experience with GaAs microwave monolithic IC (MMIC) technology and had interfaced with at least eight different GaAs foundries.

Motorola developed an MMIC subassembly for Altair that comprises the following:

- S-band amplifier die
- X-band amplifier die
- Transmitter die
- Receiver die
- Discrete ×4 step recovery diode (SRD) multiplier
- P-type intrinsic N-type (PIN) diode double-pole, six-throw switch
- Teflon/fiberglass substrate
- Gold-plated housing

Movement of people and equipment within a building causes multipath-induced fading effects in FM radio communication at this and other frequencies. Altair uses a six-sectored antenna and DP6T switch, selecting the best transmit and receive antenna sectors on the fly, to overcome this obstacle.

The GaAs MMICs for Altair were developed on a multiproject or "pizza" mask methodology, which allowed cost-effective experimental device and circuit modeling. The process chosen uses 0.5-micron minimum transistor gate length, ion implantation, on-wafer radio-frequency probing, and other advanced techniques for producing high-quality, cost-effective dice. Die yield was averaging 65 percent by the end of 1991, and further cost-reduction and yield improvements were under way.

Dataquest Perspective

Dataquest believes that the Altair system portends a new trend in telecommunications. Users of this technology will experience increased flexibility in organization evolution and will save time and therefore reduce costs as a result of improved logistics. However, the user must cope with a new set of security constraints if fiber is traded for wireless links. Solutions exist or can readily be developed; they will add to overall system cost and therefore should not be ignored in the decision-making process.

By Gene Miles

Recent Developments in Blue LED Lasers

Researchers at Brown University (Providence, Rhode Island) and Purdue University (West Lafayette, Indiana) recently reported progress in blue laser technology, where lasers emit near the high end of the visible range. Blue lasers will allow increased throughput over fiber-optic communications links.

In June 1991, researchers at 3M Company (St. Paul, Minnesota) reported achieving blue lasing (490nm) at room temperature. More recent research at Brown and Purdue universities resulted in emission of 600mW total power at 490nm wavelength, in pulsed operation at 77 Kelvin. Achieved quantum efficiency was about 28 percent.

GaAs substrate materials continue to offer exciting prospects for product innovation.

Blue lasing has been achieved in zinc selenide (ZnSe) on GaAs at 28 percent quantum efficiency. The lasing action occurs in zinc- and cadmium-doped selenium multiple quantum well (MQW) structures within ZnSe heterostructures fabricated on a GaAs substrate. ZnSe material has been lattice-matched to GaAs substrates by the researchers, and dislocation density is being decreased to improve efficiency and reliability of the devices for continuous operation at room temperature. Further refinements are under way to improve heat dissipation and electrical contact efficiency. Brown University will present additional results of this research as they are completed.

Dataquest Perspective

GaAs substrate materials continue to offer exciting prospects for product innovation. This research is but one example of how progress can be made by leveraging with the unique photonic and electronic properties of this material. Dataquest believes that future communications systems will take advantage of ultraviolet laser potential for increased frequency of operation.

By Gene Miles

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1992 Conference Schedule

North America

Forecast '92: Technology Briefing	March 19	San Jose
Ledgeway Service Trends	April 6-7	Boston
Document Management	April 29-30	San Francisco
Computer Storage	June 8-9	San Jose
SEMICON/West	June 17	San Francisco
Semiconductor	October 5-6	Monterey

Europe

Computer Storage	January 22	Munich
Regional Computer	March 31	Milano
	April 2	Munich
	April 7	London
	April 9	Paris
Pan-European Computer	April 3	Munich
Semiconductor	June 3-5	Dublin
Document Management	September 16-17	Paris
Colour	September 18	Paris
Telecommunications	October 29-30	Munich
Ledgeway Service Trends	November 3-4	Amsterdam

Japan and Asia

Semiconductor	April 13-14	Tokyo
Computer, CSAD, & Telecommunications	June 1-3	Tokyo
High-Technology Electronics	September 17	Seoul
Strategic Industry	September 21-22	Taipei
Peripherals	September 28-30	Tokyo

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Dataquest Perspective

Gallium Arsenide Semiconductors *Worldwide*

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In This Issue...

Market Analysis

The Impact of GaAs Semiconductor Foundries

This article examines the role of GaAs IC foundries in today's rapidly changing electronic equipment marketplace and reviews some major market opportunities for foundries. Progress and problems of GaAs foundry market development also are examined.

By Gene Miles *Page 1*

Company Analysis

Overview: Major GaAs IC Foundries and the Market Today

This article provides brief analyses of most of the foundries that supply GaAs and related compound semiconductor ICs to the merchant marketplace. Dataquest's perspective on the foundry situation is included. No longer are technology or device costs the barriers limiting GaAs IC market development. Current stumbling blocks include customer apathy and politics.

By Gene Miles *Page 2*

News and Views

Recent Developments in the GaAs IC Industry

These brief articles provide some insight into the nature of the rapidly changing markets for GaAs and related compound semiconductor ICs. The GaAs IC market segments are increasingly global in nature, and foundry management teams need to be responsive to this development.

By Gene Miles *Page 11*

Market Analysis

The Impact of GaAs Semiconductor Foundries

Gallium arsenide (GaAs) IC foundry activity intensified throughout the 1980s and into this decade, enabling major new hardware applications. Commercialization of GaAs digital ICs (digICs) and microwave monolithic ICs (MMICs) including 2ns cycle-time vary large scale integration (VLSI) SRAMs, sub-100-picosecond gate arrays, and millimeter-wave ICs became a reality as an average of 15 foundries simultaneously offered their services to the free-world marketplace. Today, at least 19 merchant GaAs foundries support the electronic industry infrastructure. Some shrink, while others grow at rates greater than 50 percent per year.

Supercomputers developed by Cray Computer Corporation, Convex Computer Corporation, and the Japanese government now contain GaAs IC CPUs, cache memories, and support circuits to push the speed of some of these systems to well beyond 10 billion operations per second. Communications systems such as TRW's private network in Southern California routinely operate in the 20-GHz realm at lower costs than do fiber-optic systems. Satellite-based systems will support personal communication at similar frequencies before the end of this decade.

However, such progress is not made without problems. Several foundries, including MSC (acquired by Siemens), GAIN Electronics, Ford Microelectronics, and Tachonics, exited the business during the last few years. Others, notably Adams Russell, GigaBit Logic, and Varian, were acquired by competitors seeking to grow market share. As the 1990s unfold, each GaAs IC foundry continues its struggle against foreign government support, customer apathy, and internal problems in the face of a weak economy and shrinking military programs.

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Dataquest Perspective

President Bush announced $50 billion in defense spending reductions over the next five years in his state-of-the-union address, including limits on the B2 bomber to 20 aircraft and curtailment of other programs. Thus the already-soft defense market is becoming depressed, which will definitely take its toll upon those GaAs foundries that have become too dependent on this segment. Although our view is tempered somewhat by the fact that GaAs is a leading-edge technology required for future systems, Dataquest expects more GaAs foundry layoffs, shutdowns, mergers, and acquisitions as 1992 continues.

The tremendous potential for using GaAs MMIC hardware to enhance vehicle safety is being ignored by the U.S. government and Detroit.

Most U.S. computer manufacturers that support the worldwide data processing industry (only Convex and Cray are the notable exceptions to this) have failed to capitalize on the increased availability of cost-effective GaAs VLSI. This has caused many GaAs foundries either to refocus and pursue MMIC applications in personal communication, instrumentation, and global positioning systems and other position location hardware, or to sell out or shut down. However, captive foundries, particularly those of Fujitsu, Hewlett-Packard, and Motorola, are or will become the primary sources for the majority of GaAs ICs required for these applications.

The tremendous potential for using GaAs MMIC hardware to enhance vehicle safety is being ignored by the U.S. government and Detroit.

The demise of the U.S. television industry created a significant void in the MMIC marketplace that has been filled by internal sources of supply from Hitachi and other Japanese TV makers. Apathy in the U.S. Congress and in Detroit has delayed, if not destroyed, the potential for U.S.-based suppliers to the U.S. market of GaAs MMICs for vehicular collision avoidance equipment, leaving yet another opportunity open for non-U.S.-based suppliers.

By Gene Miles

Company Analysis

Overview: Major GaAs IC Foundries and the Market Today

This article provides a concise analysis of each GaAs foundry that participates in the worldwide merchant marketplace. Company background, location, brief history of foundry evolution, strategic alliances, major contracts, and other available data are included on a company-by-company basis. The format necessitates brevity; Dataquest offers additional information on these and other IC companies in other Dataquest products and services (please refer to the last page for contact information). Table 1 summarizes the present merchant market GaAs foundries and gives brief descriptions of device technologies, minimum gate lengths, and the general product focus of each company.

ANADIGICS Inc.

A privately owned company, ANADIGICS Inc. was founded in January 1985 by Ronald Rosenzweig, George Gilbert, and Dr. Charles Huang. The company uses its foundry to pursue a strategy of producing GaAs analog and digital ICs for niches in the high-frequency defense and communications equipment markets.

ANADIGICS has a full-service foundry at its Warren, New Jersey, headquarters. Process capabilities include 1.0- and 0.5-micron gate-length GaAs metal-etch semiconductor field-effect transistor (MESFET) technology, including low-power option. Fabrication facilities include 10,000 square feet of Class 100 or better clean rooms.

ANADIGICS and Thomson Composants Micro-ondes (France) have a technology agreement whereby Thomson is the sole representative and only supplier of ANADIGICS products in Europe. The agreement was announced in March 1990.

In 1990, ANADIGICS achieved a shipment rate exceeding 70,000 millimeter-wave monolithic ICs (MMICs) per month on a contract with Continental Microwave Technology Ltd. (CMT) of Luton, Great Britain. The September 1989 order called for delivery of 1 million MMICs. ANADIGICS developed the chip for British Satellite Broadcasting under contract with CMT.

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ANADIGICS also offers standard catalog GaAs ICs to the merchant market. These include operational amplifiers, high-gain amplifiers, dividers, phase splitters, laser drivers, and other MMICs and digital ICs (digICs).

AT&T Microelectronics

AT&T's GaAs Center of Excellence is located at the company's Reading, Pennsylvania, facilities. The GaAs Center has the benefit of AT&T's 106 years of experience in electrical, electronic, and photonic communication. This includes the extensive basic and applied research of Bell Laboratories and Bellcore, work that is closely monitored by Japanese and other companies.

AT&T's GaAs process capabilities include submicron and nanoscale (sub-0.1 micron) fabrication expertise. The Reading foundry uses molecular-beam epitaxy (MBE) and other advanced equipment to support both in-house and merchant market requirements.

AT&T's Reading operations incorporate at least 34,000 square feet of production area, including five highly automated 2,000-square-foot clean room modules. The modules have achieved much better than Class 10 operation. Foundry production processes feature GaAs MESFET gate lengths to less than 0.5 microns.

AT&T has electronic technology (including GaAs ICs) agreements with many companies including Hughes, Mitsubishi, and M/A-COM. The Hughes agreement relates to foundry and other GaAs IC work on Defense Advanced Research Projects Agency (DARPA) contracts. The formal relationship with Mitsubishi involves GaAs ICs for various communications applications. Under the agreement with M/A-COM, AT&T provides MBE and other processing of MMICs.

Table 1
Merchant Market GaAs Foundries

Company	Processes	Geometries (Microns)	Products
ANADIGICS	D-MESFET	1.0, 0.5	MMICs, digICs
AT&T	E/D MESFET, others	Submicron	MMICs, digICs
COMSAT Labs	MESFET, HEMT	0.2	MMICs
Fujitsu	E/D-MESFET, HEMT	Submicron	Vitesse's Fury ASICs
GEC-Marconi	MESFET, HEMT, HBT	0.7,0.5, others	MMICs
Harris uWave	MESFET	1.0, 0.5, 0.25	MMICs
Hughes	MESFET, HEMT	To 0.25	MMICs
ITT GTC	E/D-MESFET	0.5, others	MMICs, digICs
Litton	HEMT, MESFET	0.25	MMICs
M/A-COM	MESFET	0.8, 0.5, 0.25	MMICs
OPTOTEK	MESFET	0.5	MMICs
Philips	MESFET, HEMT	0.7, others	MMICs, digICs
Raytheon	D-MESFET	0.9, 0.5, 0.25	MMICs
Rockwell	MESFET, HBT	0.5, 1.4	MMICs, digICs
TI	MESFET	0.5, 0.25	MMICs
Thomson	MESFET, HEMT	0.8, 0.7, 0.5, 0.25	MMICs, digICs including Vitesse's Fury ASICs
TriQuint	E/D-MESFET	1.0, 0.5	MMICs, digICs
TRW	HBT, HEMT, MESFET	2.0, 0.5, 0.2	MMICs, digICs
Vitesse	E/D-MESFET	0.6 to 1.25	digICs including gate arrays

Source: Aztek Associates

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COMSAT Laboratories

Established 1963 in Clarksburg, Maryland, COMSAT Laboratories is the research and development center of the Communications Satellite Corporation. The company offers foundry services including custom MMIC design, analysis, prototype fabrication, and testing to government and military standards including Class S.

COMSAT's device expertise covers the range from 1 to 94 GHz. Process technology incorporates 0.2-micron gate-length MESFETs as well as high-electron mobility transistor (HEMT) structures. Foundry wafer processing takes place in a 5,000-square-foot Class 100/10 facility equipped with MBE, direct-write e-beam and other advanced fabrication equipment.

COMSAT is a member of TRW's team on Phase 2 of DARPA's MIMIC program. The company is a foundry for Pacific Monolithics and other companies.

Fujitsu Ltd.

Fujitsu Ltd., a spinoff of Fuji Electric Company in 1935 and a member of the powerful Fuji zaibatsu, was founded to produce automatic telephone exchange and related equipment. Later the company added carrier transmission and radio communications equipment to its portfolio. By 1990, Fujitsu's companywide R&D budget was $1.89 billion.

Fujitsu has become a world leader in the field of telecommunication including microwave systems; thus a GaAs foundry is a key ingredient in its market strategy. The company established its GaAs activities in 1979. Initial expertise was developed on such efforts as the nine-year Japan National Supercomputer Project, under which Fujitsu, Hitachi, Mitsubishi, NEC, Oki, and Toshiba jointly developed and demonstrated (in 1990) a GaAs-based supercomputer system, including the GaAs ICs used in the hardware.

Fujitsu produces GaAs chips at its plants at Aizu, Kawasaki, and Yamanashi. The 125,000-square-foot Yamanashi plant includes 3- and 4-inch GaAs wafer fab for production of GaAs discretes, ICs including MMICs and digICs, and optoelectronic devices including lasers. The company is expanding its GaAs IC capacity to support a run rate in excess of $200 million annually by 1993.

In mid-1990, Fujitsu entered a technology exchange agreement with Vitesse Semiconductor Corporation on the Fury Series of GaAs E/D-MESFET very large scale integration (VLSI) ASICs, which requires significant foundry support. The details of Fujitsu's foundry plans were unavailable at press time.

GEC-Marconi Materials Technology Ltd.

The GaAs foundry at the GaAs Division of GEC-Marconi Materials Technology Ltd. originated with the production of the first GaAs devices in 1965 at Plessey plc. Later the effort evolved into Plessey Opto Microwave Ltd., which was restructured into three groups in 1989. Subsequent merger and acquisition activities resulted in the April 1991 combination of Plessey Research Caswell Ltd., Plessey Microwave Materials Ltd., and Hirst Research Centre into the GaAs Division of GEC-Marconi.

Plessey produced the first commercial GaAs FET in 1970. Plessey invested more than £50 million sterling to upgrade its GaAs facilities from 1985 through 1989. GEC-Marconi's GaAs annual shipments exceeded $10 million by 1991. The company's GaAs foundry has more than 20 active customers. GEC-Marconi has been very active in many of the European Community ESPRIT projects.

GEC-Marconi has MESFET, HEMT, and heterojunction bipolar transistor (HBT) processes. Its F40 process is used to produce millimeter-wave GaAs ICs. The F14 process is used for 0.7-micron gate-length devices, and the F20 process features 0.5-micron gates. About 400 employees are at the 40,000-square-foot facility, which includes the GaAs foundry operation. GaAs and other compound semiconductor products include MMICs, HEMTs, HBTs, low-noise and power MESFETs, LEDs, lasers, and digICs.

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Harris Microwave Semiconductor Inc.

Harris Microwave Semiconductor Inc. (HMS) was formed in 1980 to develop and manufacture GaAs FETs, MMICs, and digICs. Founded by former HP employees, HMS is a vertically integrated operation of the Harris Corporation Semiconductor Sector capable of growing crystals (GaAs boules or ingots) and producing its own wafers.

Almost any company can penetrate existing markets; the real test of competence is in the ability to create new commercial demands and to reduce costs faster than those of competing technologies.

The company introduced the world's first commercial digICs as standard products, but later changed its strategy and withdrew from this market. A 37,000-square-foot expansion that would have doubled its facilities was sold to Litton Industries in mid-1988. HMS participated in Phase 0 and Phase 1 of the DARPA MIMIC initiative.

HMS' foundry processes feature air-bridge interconnections and 1.0- to 0.5-micron MESFET ICs, with 0.25-micron gate lengths in development. Standard and custom products now include FETs and MMICs.

Hughes Microelectronic Circuits Division

Acquired in the mid-1980s by General Motors, Hughes Aircraft Company began GaAs R&D in the late 1960s. The company patented the ion-implanted channel FET device. Hughes MCD began operations in Torrance, California, in 1977. By mid-1985, Hughes had invested more than $20 million in GaAs ICs and planned another $40 million support. This resulted in tripled capacity by 1987, which included 44,300 square feet of GaAs clean room facilities.

Hughes MCD operates a full-service GaAs IC foundry that includes device and circuit design, CAD support, wafer fabrication including second-generation MBE, packaging, chip test, and evaluation. The foundry supports both internal and selected external customers.

Hughes received a Phase 1 MIMIC award in 1988, which was completed by mid-1991. Hughes Radar Systems Group received a $78.9 million MIMIC Phase 2 award in mid-1991 and is teamed with AT&T, General Electric, M/A-COM, and others. The team is developing at least 16 GaAs chip types for military radar, communications, and smart weapons applications. Other strategic alliances include a team effort with AT&T and McDonnell Douglas on a DARPA-sponsored project to develop GaAs-based HEMT SRAMs and logic circuits.

Another major effort at Hughes MCD, together with other groups within General Motors, is directed at developing electronics for automotive applications, including proximity detection (collision avoidance) and communication. These and other projects and programs have served to strengthen Hughes MCD, making it a formidable competitor in the GaAs foundry business.

ITT GaAs Technology Center (GTC)

ITT's GaAs Technology Center in Roanoke, Virginia, offers full-service foundry support to other ITT divisions and to the merchant GaAs IC marketplace, both military and commercial. The operation was a part of ITT's Electro-Optical Division until early 1983. ITT GTC became a key member of DARPA's MMIC Program, Phase 1. By 1992, GTC had designed and fabricated more than 225 types of GaAs MMICs, for applications from DC to 18 GHz.

ITT GTC has a 27,000-square-foot 3-inch GaAs wafer fabrication facility, plus a 12,000-square-foot area for design, packaging, and test. A 2,000-square-foot area for packaging was added in late 1987. Throughput capacity exceeds 100 wafer starts per week. Equipment includes SEMs and very high burn-in temperature capability. The ion-implanted GaAs E/D-MESFET process developed by ITT GTC supports complexities beyond 5,000 gates per chip in production.

ITT's GaAs MESFET products include MMICs such as single-chip transmit/receive (T/R)

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modules, and digICs, such as standard cell direct-coupled FET logic (DCFL) arrays. T/R modules developed by ITT have been demonstrated for C-band operation in extreme environments.

Litton Solid State Division

Litton Industries' Solid State Division (SSD) has an interesting history. The division, located in Santa Clara, California, was originally the Dexcel Division of Gould until July 1987, at which time it was acquired by Litton Industries. In mid-1988, Litton bought the amplifier operations of Harris Microwave Semiconductor Inc. of Milpitas, California. The addition (in February 1991) of Varian's Solid State Microwave Division, including the Varian GaAs/InP foundry, increased the Litton facilities to about 100,000 square feet of GaAs and InP IC capacity. The Varian foundry was the world's premier InP foundry at the time of the acquisition.

Litton Industries, an integrated worldwide company (conglomerate), develops, manufactures, and markets electronics-based systems, products, and components for key high-growth world markets. Its markets include information systems, industrial automation, instrumentation, and defense systems; and other electronic components and materials. The SSD foundry supports these activities.

The SSD foundry uses such process technologies as recessed-gate submicron GaAs MESFET, GaAs HEMT, InP MESFET, and InP HEMT IC structures; vapor-phase and molecular beam epitaxy, and proton isolation; and 0.25-micron e-beam photolithography. Foundry products include Gunn oscillators, discrete and integrated GaAs and InP chips, and subassemblies. All products in Varian's III-V semiconductor line have been continued. About 240 employees were active in the SSD operations in late 1991.

Litton is on the Hughes MIMIC Phase 2 team. SSD's most significant market recently has been smart munitions, including the SADARM and STAFF programs. Its present strategy is to increase the noncaptive share of its foundry business, which required about half of its wafer starts in late 1991, and to increase the commercial share from the present 10 percent up to 50 percent over the next few years.

M/A-COM Advanced Semiconductor Operations

M/A-COM Inc. of Chelmsford, Massachusetts, is a major producer of RF, microwave, and millimeter-wave semiconductors, components, and subsystems primarily for defense electronics systems and for commercial applications, including surveillance. Its Advaned Semiconductor Operations (ASO) unit was set up to supply GaAs wafers, semiconductors including ICs and discretes, and foundry services for both internal and external requirements. About 50 percent of the company's 1991 sales were for weapons- and defense-related applications.

In mid-1989, M/A-COM bought Adams Russell Inc., including the Adams Russell Semiconductor Center. Consolidation of the two operations was completed early in 1990. M/A-COM in 1990 acquired Light Control Systems Inc., a producer of fiber-optic cable assemblies, and sold the Active Assemblies Division in 1991.

M/A-COM was an early supplier of foundry services to the GaAs IC community. In 1990, ASO and AT&T formed a strategic alliance that began jointly offering GaAs foundry services and MMIC products. AT&T's Reading foundry performs MBE processing, in-process testing, and reliability validation services.

ASO's GaAs manufacturing and support areas total more than 183,000 square feet including 58,000 square feet of Class 10 clean rooms. The foundry services include design, CAD support, assembly, test, and packaging of MMICs produced on 0.8-, 0.5-, and 0.25-micron gate lengths. The 0.25-micron process incorporates e-beam lithography. The company produces its own 2-, 3-, and 44-inch semi-insulating GaAs wafers.

OPTOTEK Limited

OPTOTEK Limited is unique in that it is the only merchant foundry located within Canada. The 15-year-old company was founded to capitalize on world market opportunities in LEDs and associated electronics for military and commercial applications.

In 1981, OPTOTEK entered the microwave market with the development of GaAs MMICs. Today the company's 37,000-square-foot facilities in Kanata, Ontario, process GaAs,

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HgCdTe, and other optoelectronic and microwave semiconductors. Processing includes selective ion implantation, ion annealing, and thick film and thin film hybrid packaging. The MMIC foundry uses 0.5-micron GaAs MESFET technology.

Philips Microwave Limeil

N.V. Philips Gloenlampenfabrieken is a 101-year-old multinational company based in Eindhoven, Netherlands. Philips has had basic research capability since 1914. In 1970 it established Philips Microwave Limeil, a GaAs foundry and ASIC design center in Limeil-Brevannes Cedex, France.

In the mid-1980s Philips and Cray Research initiated joint activity in GaAs SRAMs for supercomputer applications. This effort resulted in a 1K emitter-coupled logic (ECL)-compatible design with 2ns cycle time and 200mW power dissipation. The work was accomplished at the Limeil facility.

Other strategic alliances include joint ventures with Matsushita, Signetics, and North American Philips Electronics Corporation. Philips owns 35 percent of Matsushita Electronics Corporation and 100 percent of N.A. Philips Trust, which owns Signetics.

Semiconductor technologies within Philips include GaAs, AlGaAs, and other III-V MESFET and HEMT processes. Production processes at the foundry include 0.7-micron DCFL GaAs E/D MESFET for ICs, the ERO7AD lower-power version for MMICs and digICs, and an HEMT process.

Raytheon Monolithic Microwave Center

Raytheon Company has been a leader in GaAs technology for many years. The company claims the following firsts in MMIC technology:

- First completely monolithic microwave ICs
- First GaAs MMIC T/R switch
- First GaAs MMIC phase shifter
- First MMIC traveling-wave amplifier

Monolithic Microwave Center (MMC), located at Andover, Massachusetts, resulted from Raytheon's $150 million Advanced Device Center initiative. By 1991, more than $17 million of advanced GaAs wafer equipment was operating within the MMC facility, which includes a full-service GaAs foundry. Five processes currently are running at MMC, as follows:

- MMC-01, 2-micron gate length, 7 GHz f_t for power applications
- MMC-02, 0.9-micron gate length, 15 GHz f_t
- MMC-03, 0.5-micron gate length, 18 GHz f_t for X-band applications
- MMC-04, 0.5-micron gate length, 27 GHz f_t
- MMC-05, 0.5-micron gate length, 18 GHz f_t for wide-band power applications

Processing to 0.25-micron gate lengths is also available at MMC. Foundry facilities include more than 17,000 square feet of clean rooms exceeding Class 100, 8,300 square feet of assembly and test areas, and 16,800 square feet of office space. The foundry can produce more than 25,000 wafers per year.

Raytheon MMC's strategic alliances include the joint venture of Raytheon and Texas Instruments, which is a prime contractor on Phase 2 of the DARPA MIMIC program.

Rockwell Microelectronics Technology Center

Rockwell Microelectronics Technology Center's (MTC's) parent company, Rockwell International, is a multi-industry corporation engaged in research, development, manufacture, and marketing of products for government and commercial markets. It was the prime contractor for the B1A and B1B bombers. Its principal space activity is the space shuttle program for NASA.

The MTC facility at Newbury Park, California, contains the first Department of Defense-sponsored GaAs IC foundry, developed at a cost of $16 million, and was an early producer of GaAs SRAMs and gate arrays. By 1989 the production schedule was 100 3-inch wafers per week with a planned capacity for 250 wafers per shift per week. The plant has LEC crystal production capacity that produces GaAs wafers.

MTC's 70,000-square-foot plant includes 12,200 square feet of controlled environment and 5,240 square feet of Class 10 clean rooms. It processes 0.5-micron GaAs MESFET

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ICs on 4-inch wafers and 1.4-micron HBT ICs on 3-inch wafers. MTC will announce HBT products before mid-1992.

Texas Instruments Inc.

A vertically integrated producer of electronic hardware and services, TI began its involvement in GaAs technology in 1960. The company has invested more than $150 million in its GaAs activities during the last 32 years.

TI's Central Research Laboratories (CRL) has performed extensive development of GaAs materials, devices, and ICs, demonstrating GaAs FETs operating at 10 GHz in 1975 and 100-GHz GaAs ICs in 1990. CRL demonstrated the smallest reported SRAM cells in a functional 1K GaAs SRAM in 1985. In 1987, TI reported performance and yield data on its single-chip X-band radar transceiver MMIC, which contains a four-bit phase shifter, three-stage LNA, and four-stage power amplifier.

TI's joint venture with Raytheon received a MIMIC Phase 2 award of $83.4 million in August 1991. This strategic alliance includes as team members Aerojet General, Cadence, Consilium, General Dynamics, HP, Hittite Microwave, Litton Airtron, Lockheed-Sanders, and Teledyne. The team is developing at least 14 GaAs ICs for EW, radar, and other applications.

TI's full-service GaAs MMIC foundry is located in Dallas. It has offered merchant services since 1986. Processes include 0.5- and 0.25-micron geometries, ion-implanted 3-inch wafers, four doping profiles, e-beam lithography, and 4-micron gold-plated transmission lines with air bridges. The production foundry at TI's Defense Systems Electronics Group has 9,000 square feet of clean rooms with a capacity exceeding 100 3-inch wafer starts per week. The single-shift baseline in 1991 was 10 lot starts per week.

TI's GaAs foundry team developed a GaAs RISC microprocessor and other GaAs VLSI digICs in conjunction with Control Data Corporation and others. This mid-1980s chip development required advancement of the state-of-the-art GaAs VLSI to include 200-MHz clock rate operation of the 32-bit processor.

Thomson Composants Microondes

Thomson-CSF, a French government-controlled, vertically integrated electronic equipment and systems company, has had GaAs semiconductor activity since 1968. Today, its GaAs Department, located in Orsay Cedex near Paris, has about 250 employees of the Thomson Composants Microondes subsidiary engaged in GaAs device development and production.

Thomson produces its own GaAs crystals, wafers, and discrete and IC semiconductors to meet 80 percent of its internal needs and to supply to its merchant customer base. The GaAs fab facility converted to 2-inch wafers in 1983, 3-inch wafers in 1986, and expanded with an additional 50-wafers-per-week line in 1988. The facility is about 130,000 square feet in size, including more than 20,000 square feet of clean rooms. Thomson's total GaAs sales including modules exceeded $60 million last year.

To remain competitive, GaAs foundries have a number of advantages over companies that produce commodity products.

Thomson is a stakeholder in ANADIGICS Inc.—it invested $6 million in that company during 1988 and 1989—and in Vitesse Semiconductor Corporation (Camarillo, California). It is the exclusive supplier of ANADIGICS products in Europe. Thomson's GaAs foundry has a technology agreement with Vitesse allowing alternate sourcing of all Vitesse ICs including the Fury Series of GaAs LSI/VLSI ASICs.

MESFET and HEMT production supported by Thomson's GaAs foundry include scaled submicron E/D for the Vitesse and other products, 0.7- and 0.5-micron D-mode, and 0.25-micron processes.

TriQuint Semiconductor Inc.

TriQuint Semiconductor Inc. offers the broadest range of services of all the GaAs IC foundries. It also designs, develops, produces, and markets families of analog, linear, microwave, and

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digital products for use in high-speed computers and interfaces, fiber-optic communications systems, analog and digital instrumentation, military systems, and other electronic equipment.

TriQuint evolved from research on GaAs ICs that started at Tektronix Laboratories in 1978. TriQuint's founders included leaders on the Tektronix research team. In 1984, the Beaverton, Oregon-based company was established as a majority subsidiary of Tektronix and was given the entrepreneurial freedom to implement a portfolio of long-term manufacturing contracts. In January 1991, TriQuint bought GigaBit Logic Inc., a Newbury Park, California-based offshoot of Rockwell with annual revenue of about $12 million. TriQuint bought Gazelle Microcircuits (Santa Clara, California) in May 1991. By mid-1991, TriQuint's annual sales revenue rate was nearly $35 million and the company had more than 1,200 customers worldwide.

TriQuint was the first GaAs foundry to manufacture microwave and digital ICs on 4-inch wafers. It announced RF/LSI foundry services in February 1988 with the introduction of the QED/A GaAs IC process. The company was the first commercial IC manufacturer to ship GaAs IC wafers and dice screened to U.S. DOD Class S requirements, supporting satellite systems and other spaceborne requirements.

TriQuint's strategic alliances include many ventures and joint efforts, some related to DARPA and other U.S. government programs, as follows:

- A joint program of TriQuint and McDonnell Douglas is devoted to evaluating coproduction of GaAs VLSI including 64K SRAMs and 256K NVRAMs.
- TriQuint has been a major foundry for Pacific Monolithics, Gazelle, Motorola, Pacific Semiconductor Pty. (Sydney, Australia), TRW, and other GaAs IC design houses and users.
- In May 1988, TriQuint announced the incorporation of its MMIC Library of foundry design models into HP's microwave CAE design system.
- In mid-1990, TriQuint and Pacific Semiconductor jointly acquired all patents formerly held by Gain Electronics Company, an early developer of SDHT (HEMT) technology.
- TriQuint booked a 1991 order with OnChip Systems Inc. for synthesized clock chips for PCs and workstations, expected to exceed 100,000 units of first-year production.

The company offers at least five foundry processes that support enhancement and depletion MESFET ICs including VLSI, based on 1.0- or 0.5-micron gate lengths. TriQuint also offers multiproject wafer support; Class S screening and evaluation; and full foundry support of MMIC and digIC design, development, production including packaging, test, and evaluation.

TRW Inc.

The TRW Electronics and Technology Division of TRW's Electronic System Group operates a GaAs foundry and pilot production line in Redondo Beach, California. The parent company entered GaAs semiconductor development in 1975 and has invested more than $25 million in startup costs of the pilot line facilities and operations. By 1988, the foundry was in production and was operating two shifts per day by early 1991.

Foundry processing includes MESFET, HEMT, and HBT IC structures, MBE epitaxy, e-beam lithography, and minimum geometries to 0.2 microns. TRW's GaAs activities employ about 240 persons. The highly automated, 2,850-square-foot sub-Class 10 wafer fab line requires fewer than 20 operators; single-shift capacity is more than 100 3-inch wafers per week. The company's exclusive distributor of its GaAs ICs is FEI Microwave of Santa Clara, California.

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The TRW Systems Group is a Phase 2 prime contractor on the MIMIC program and received a $65.7 million Phase 2 award in August 1991. TRW's team members include Alliant, COMSAT Labs, General Dynamics, Hercules, HP, Mentor Graphics, Texas Instruments, and Westinghouse.

Vitesse Semiconductor Corporation

Vitesse Semiconductor Corporation (Vitesse) is the offshoot of Vitesse Electronics Corporation, which was founded in July 1984 by Norton Company (VEC) with an initial investment of $30 million to design, develop, produce, and market GaAs digICs and minisupercomputers. In July 1984, Vitesse bought substantially all of VEC's assets relating to the design and manufacture of GaAs semiconductors. Vitesse announced its initial public offering of 3.2 million shares at $9 per share on December 11, 1991. A net loss of $1.5 million on $23.7 million revenue for the fiscal year ending September 30, 1991, was described in its preliminary prospectus (October 25, 1991).

A significant accomplishment of Vitesse's foundry is the introduction of VLSI (100,000 to 340,000 gates per chip) gate arrays priced competitively against silicon ECL. The Vitesse ASICs offer higher density and lower power at state-of-the-art ECL speeds. Anticipated cost reduction is sought by scaling to 0.6-micron gate lengths and using four-layer aluminum interconnects.

Dataquest Perspective

Dataquest believes that sufficient foundry capacity is in place within the companies in the preceding analysis to serve the presently defined system applications. However, many foundries to date have failed in their efforts to develop major new markets for their products. This is because of internally directed—and in some cases frequent—changes in company direction, a lack of focus and sufficient horsepower in strategic marketing, government interference, and other factors.

The GaAs IC industry situation is akin to the developing silicon market in the late 1960s, before the availability of cost-effective bit slices and RAMs, when companies such as GME, Transitron, and Philco-Ford entered and soon left the competitive lineup. Almost any company can penetrate existing markets; the real test of competence is in the ability to create new commercial demands and to reduce costs faster than those of competing technologies. Many of the GaAs foundries appear to be running out of time and, as a result, available capital.

Dataquest predicts a severely competitive future for U.S.-based GaAs foundries, with only the very strong surviving the next round of fallouts.

To remain competitive, GaAs foundries have a number of advantages over companies that produce commodity products. One of the most significant advantages is the ability to process small lots of products rapidly. This is exactly the expertise required to support just-in-time programs, now increasingly demanded in the world community of IC users. Dataquest believes that this know-how should be skillfully applied by GaAs foundry marketers and production managers to enhance market penetration.

In summary, Dataquest predicts a severely competitive future for U.S.-based GaAs foundries, with only the very strong surviving the next round of fallouts. Only those foundries with national interests at stake, such as GEC-Marconi and Thomson CSF, or with sufficient internal demand, such as AT&T, will be allowed the luxury of continuing massive R&D expenditure without the support of merchant market profitability.

By Gene Miles

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News and Views

Recent Developments in the GaAs IC Industry

The following items provide some insight into the nature of the rapidly changing markets for GaAs and related compound semiconductor ICs:

- A joint venture of Andrew Corporation (Orland Park, Illinois) and Moscow Metro (Moscow) recently reported that it is supplying a fiber-optic, wide-band telecommunications system that will cover metropolitan Moscow, to be operational by March 1992. A multiband AM/FM, cellular telephone, traffic control, and emergency communications system also will be installed by the joint venture.
- COMSAT has signed agreements with officials of Colombia and Guatemala, by which the company will provide international satellite communications services to businesses in those countries.
- M/A-COM Inc. and Sumitomo Electric Industries Ltd. are collaborating on developing and marketing high-volume commercial electronic systems for such applications as the intelligent vehicle highway system (IVHS).
- Companies involved in the European Community Prometheus project recently demonstrated infrared detection hardware on board a Jaguar (Jaguar is now owned by Ford Motor Company) and other vehicles for use in collision avoidance and other highway safety systems. A heads-up display for the vehicle operator was also used in the demonstrations.
- The manager of Motorola's IVHS Strategic Business Unit, John Barrett, is using a unique business card that may reveal his if not the company's sensitivity to the global positioning system and related position location hardware market. His card gives the precise location of his office: latitude 42 deg.8'54.024", longitude 87 deg.52'27.540".

Dataquest Perspective

As in other industries, GaAs IC markets are increasingly global in nature. Dataquest believes that failure to recognize this reality is alone sufficient to limit the life of a GaAs foundry.

By Gene Miles

In Future Issues

The following topics will be addressed in future issues of Gallium Arsenide Semiconductors Worldwide *Dataquest Perspective:*

- GaAs and related compound semiconductor market update
- GaAs IC shipments in 1991
- GaAs IC market forecast

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