Dataquest

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April 30, 1990

If you're missing DQ Monday . . .
You're missing a lot!

Dear Client:

Since 1987, clients of Dataquest's semiconductor services have counted on *The Dataquest Monday Report (DQ Monday)* for weekly electronic delivery of industry information and analysis. Delivered with the timeliness of the trade press, *DQ Monday* supplies an additional valuable element; analysis of industry events from the context of Dataquest's primary research and analyst expertise.

A Cross-Service Feature
The information collection and analysis methodology behind *DQ Monday* links Dataquest analysts worldwide and across the different services that constitute the Components Group. Through *DQ Monday* all components group clients benefit from the scope of this information, regardless of which semiconductor service(s) they subscribe to.

Here's what we've been covering
For your convenience, we have compiled an index of the titles of all the stories featured in *DQ Monday* in 1989. This index is also available on-line and can be sorted according to the categories listed.

Here's what you've been missing
For those clients who are not familiar with this feature of their service subscriptions, I am sending you a copy of a recent *DQ Monday* report to review.

For further information on how to establish your connection to this report, please contact Karen Foley, manager of On-Line Services, at (408) 437-8576, or Patricia Galligan, Editor, *DQ Monday*, at (408) 437-8642.

Sincerely,

Patricia Galligan

Patricia Galligan
Editor, *DQ Monday*
Semiconductor Industry Service

DQ Monday

Industry Events and Analyst Insights

March 26, 1990

DQ TAKE

The following items represent key industry events taking place during the week of March 19 - 23. Dataquest anlaysis of these events is generated through a weekly meeting of our worldwide staff of industry analysts.

PERKIN-ELMER ELECTRON BEAM UNIT SOLD TO ETEC Perkin-Elmer Corp. has sold its Electron Beam Technology Division (EBT) to ETEC. ETEC is a newly formed corporation founded by former and current employees of EBT with funding from IBM, Du Pont, Grumman, Micron Technology and Zitel Corp. Perkin-Elmer will also be an equity partner. Perkin-Elmer's EBT division has manufactured e-beam lithography systems for use in direct writing of semiconductor wafers and patterning semiconductor masks. Financial terms of the sale were not disclosed.

DQ TAKE At first glance, it may appear that ETEC is an example of the ability of U.S. companies to form consortia. In fact, this is not a consortium at all, but a venture capital deal. American e-beam technology will certainly get a boost from this deal, but Dataquest believes that strict business interests were the prime motives. Even though the motivations of all of the investors are not yet clear, the diversity of investors is interesting: they include both suppliers and customers of ETEC. A summary of each company's involvement follows:

IBM:

- Provides its own e-beam technology to ETEC
- Will transfer technology for EL-4 e-beam system to ETEC
- Looking to strengthen U.S. industry and improve balance of technology where IBM relies on local vendors
- May wish to establish an alternate supplier of its EL series

DuPont:

- Largest non-Japanese supplier of photomasks
- ETEC represents a strategic investment in maskmaking business
- As a large customer of e-beam machines, DuPont wants to assure domestic supply of state-of-the-art machines

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Grumman:

- Currently manufacturing EL-3 system for IBM, but not yet manufacturing EL-4
- Motives are unclear--investing in potential competitor to their IBM business

Micron Technology:

- Involvement may simply be an investment position Zitel
- Manufactures high speed memory subsystems, used in e-beam lithography systems
- Is an OEM supplier to ETEC, providing memory/control subsystem for their e-beam systems
- Dataquest believes that Zitel provides memory subsystems to Grumman/IBM for the EL e-beam series.

Dataquest Conclusions: It is clear that ETEC will emerge as a stronger entity than the EBT division of Perkin-Elmer. It will be stronger technically with the EL-4 technology and it should be stronger financially as Dataquest believes that the EBT division was starved for R&D funds. Finally, the U.S. e-beam lithography effort will benefit from the the domestic preservation of Perkin-Elmer's e-beam technology.

TI AND KOBE STEEL ANNOUNCE JOINT VENTURE Texas Instruments and Kobe Steel have announced an agreement to establish a joint-venture company to manufacture advanced semiconductors in Japan. The new joint-venture company, named KTI Semiconductor Ltd., will manufacture CMOS logic devices, including VLSI circuits and ASICs. Total investment in the initial wafer fab facility, to be located in the Kansai region of Japan, is estimated to be approximately $350 million, which includes property, plant and equipment. Kobe steel will own a majority interest in KTI and TI will hold a minority interest. Kobe steel will provide most of the equity capital required to start the new company, and TI will provide additional funding, along with the design and manufacturing technology necessary to build and operate the plant. Both companies will contribute personnel to the joint venture. All devices manufactured by KTI will be sold exclusively by TI for ten years using TI's name and logo. (For Dataquest's analysis of this deal, see this week's DQ Perspective.)

WESTERN DIGITAL INTRODUCES THREE PC CHIP SETS Western Digital (WD) has introduced three new systems chip sets. The WD7500 is a low cost logic chip set targeted at the low-end 286 market. The WD7600 is a high-performance chip set for 286/386SX-based systems. Finally, the WD7600LP is an ultra-low power chip set for 286 or 386SX-based notebook/laptop PCs. Each chip set is a three-device set including core logic and storage and data communication chips. The devices are manufactured using a 1.25 micron CMOS process technology.

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DQ TAKE This announcement from Western Digital highlights the company's new theme and corporate strategy. WD appears to have a good understanding of the market and has introduced a series of commodity AT bus products. The company also manufactures an MCA chip set and is willing to pursue EISA bus products if the market so dictates. WD has introduced a set of highly integrated products with advanced power-saving, high-performance features. Western Digital is one of the few companies that offers graphics, storage and logic chip sets, and can therefore offer a full system solution. The company has emerged from the lethargic times following its Faraday acquisition to become a streamlined, highly focused operation.

HITACHI INTRODUCES 4 MEGABIT PSRAM Hitachi has introduced the industry's first 4Mb pseudo static RAM (PSRAM). These are the highest density PSRAMs currently available on the market. This device is produced using the same 0.8 micron CMOS process Hitachi uses in producing its 1 Mb SRAMs and 4 Mb DRAMs. The device is configured as 512K x 8.

DQ TAKE Hitachi is currently the leading supplier of 1 Mb PSRAMs. These devices are used mainly in laptop personal computers and portable systems. PSRAMs compete with both SRAMs and DRAMs by providing benefits over each of these types of devices. The pricing of PSRAMs tracks closer to that of DRAMs. In maturity, Dataquest predicts a 20 percent to 30 percent price adder over DRAMs for PSRAMs. PSRAMs compete with SRAMs on the basis of price, while competing with DRAMs by requiring less support circuitry and providing a x8 organization which is desirable in some applications. In the future, it will be interesting to observe how wider word-length DRAMs impact the PSRAM markets. Current pricing for 1 Mb devices is as follows: SRAM = $40, PSRAM = $11 and DRAM = $6.50. Other suppliers of PSRAMs include Toshiba, NEC and Motorola. Dataquest predicts a $26.5 million market for 4 Mb PSRAMs in 1990, rising to $70 million in 1991.

IN THE NEWS...

VITESSE INTRODUCES GaAs FOR MPU-BASED SYSTEMS Vitesse has announced the availability of the PLR2KT, a GaAs gate array designed to optimize the performance of high-end MPU-based systems. The device features 2400 gates and TTL and CMOS compatible signal I/O. The chip is targeted at the high-end PC and workstation markets, for use in 33, 40 and 50 MHz systems. This GaAs gate array is designed to replace PLDs in these systems. However, PLDs are not often used for high-speed applications. Because of this, other gate array replacements for PLDs have not proven successful. NRE charges for the PLR2KT are $35,000, and unit pricing is $45 purchased in 1,000 piece quantities.

FUJITSU INTRODUCES 200,000 GATE BiCMOS GATE ARRAY Fujitsu has introduced a prototype CMOS/BiCMOS sea-of-gates gate array having 200,000 gates. The new chip is 4 times the density of any currently available BiCMOS gate array. The triple-metal device features configurable RAM and ROM, and ECL or TTL interface. Fujitsu claims that they will begin shipping this device late in 1990. Dataquest expects that the company is targeting the workstation market with this product.

EUROPE PLANS TO SECURE MICROS European self-sufficiency in microprocessors by 1995 is the aim of a $420 million proposal called 'EMI' (European Microprocessor Initiative) backed by Europe's largest electronic companies. As well as the top European semiconductor companies (Philips, Siemens and SGS-Thomson), some of the leading European equipment companies like Olivetti, Bull and Alcatel have joined the project. Two U.K. designed processors will form the basis of the EMI project. One is the Inmos transputer designed in Bristol and now owned by SGS-Thomson, and the other processor is the Acorn ARM, now owned by Olivetti. Development of a totaly new processor will be designed based on the transputer and ARM chips and will probably utilise a 64-bit architecture. This move may be prompted by fears about a possible discontinuity of supply by U.S. companies, and the fact that the Japanese TRON has not as yet been widely adopted. The proposal which has yet to be presented to the European Commission, for funding under the JESSI section of the ESPRIT program, may give rise to fears among American and Japanese companies of 'Fortress Europe' because chips from Intel and Motorola may be ignored in the future in favour of a possible 'Europrocessor'.

DQ NOTES

The following section contains research findings from Components Group services on key issues in the semiconductor industry. The acronym of the contributing service follows each item.

- The math coprocessor war is heating up. Intel has purchased full-page ads in a national trade publication for its 80X87 math coprocessors. In recent weeks, we have reported price cuts by IIT and Cyrix, two companies producing Intel compatible parts (See DQ Monday March 5, 1990). Intel is reportedly planning a major PR campaign targeting the compatibility issue. (SIS)

- IBM was expected to announce a new notebook PC this past week, but was apparently caught off guard by a preemptory announcement of a similar product by Sharp. The new IBM notebook is rumored to contain Western Digital's WD7600LP logic chip set (referred to earlier). Western Digital's chip set sales may be greatly impacted if IBM changes its strategy. (SAM)

- A Dataquest analyst who attended SEMICON/Europe reports that a majority of capital flowing into European semiconductor manufacturing facilities is coming from Japan and the United States. Japanese and U.S. firms are supplying semiconductor equipment and materials, while European firms appear to be supplying only "bricks and mortar." A notable exception to this rule is IBM, who is actively promoting European equipment and materials companies. (SEMS)

- Vitelic Corp. recently announced that it intends to make its recently acquired Elcap Electronics facility into a state-of-the-art semiconductor manufacturing facility in Hong Kong. This announcement is significant for a number of reasons:

    -The new facility will manufacture the first memories made in Hong Kong
    -It highlights Vitelic's confidence in the Hong Kong/China memory market
    The Hong Kong population represents a future source of labor for Vitelic, who will be training personnel in Hong Kong
    -It suggests Vitelic's interest in the markets of mainland China. (ASETS)

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DQ PERSPECTIVE

KOBE STEEL AND TEXAS INSTRUMENTS: FROM STEEL TO SEMIS

This week Kobe Steel and Texas Instruments (TI) announced the establishment of a joint venture in Japan to manufacture VLSI ICs and ASICs. Construction of the $350 million wafer fab in Hyogo Prefecture, Japan, is expected to commence early in 1991 and be completed within the year. Kobe Steel will provide the majority of the equity capital and will own a majority interest in the joint venture. TI will provide the technical assistance in the form of design and manufacturing technology required to build and operate the plant and will provide some additional funding. TI will have the option to increase its ownership in the joint venture, although no specific terms have been divulged. Both companies will contribute personnel to the venture, which is called KTI Semiconductor Ltd. The semiconductor output from KTI will be sold exclusively to TI, who will have worldwide sales and distribution rights.

SILICON: THE NEW "CORE MATERIAL"

During the past three yers, Kobe Steel, while strengthening its core businesses in steel and machinery, has been increasing its emphasis on other businesses, such electronics, advanced materials, biotechnology and services. In 1986, Kobe Steel began diversifying into computers and telecommunications in response to several years of declining steel prices and sales. The company's fiscal year 1988 sales amounted to $8.9 billion, and it employed 21,436 people. Based on this data, Kobe Steel was Japan's twentieth largest industrial firm in 1988. By the year 2000, Kobe Steel plans to have it's non-steel line account for 40 percent of its total sales. The company's mid- to long-range management plan features further diversification into electronics as a key element. The firm's diversification will incorporate overseas expansion and target opportunities in the high-technology area through acquisitions or alliances. Kobe's current semiconductor-related activities include marketing inspection equipment and providing testing services through its subsidiary Genesis Technology, a joint venture with Megatest of the U.S.

In recent years there has been an observable trend among Japanese steel and heavy industry companies toward diversification into the electronics industry, partly to offset the strengthening of the yen and weakening markets. Steel companies such as Kawasaki Steel Kobe Steel and, Nippon Kokan, which supply core materials for steel, have turned their attentions toward the core materials of the electronics market: silicon. In the mid-1980s, LSI Logic formed Nihon Semiconductor, a joint venture with Kawasaki Steel. Now Kawasaki Steel is gearing up to run its own wafer fab facilities, which should be operational next year, and will produce ASICs and general-purpose memory ICs.

TI'S GLOBAL STRATEGY

TI, which ranked as the sixth largest semiconductor company worldwide and the leading non-domestic supplier to the Japanese market in 1989, has ambitious capital spending plans for 1990. TI, the first U.S. company to operate and own a semiconductor company in Japan, has always pursued aggressive regional investment. Table 1 shows that only one of the company's planned submicron CMOS memory and advanced logic fabs is located in the United States.

Table 1

Texas Instruments' Submicron Memory and Advanced Logic Fabs

Location	Product Type	Status
Avezzano, Italy	4Mb DRAM	Under construction
Freising, West Germany	Advanced logic	Upgrading
Miho, Japan	4Mb DRAM	Upgrading
Hiji, Japan	4Mb DRAM	Upgrading
Dallas, Texas	4Mb DRAM, advanced logic	Upgrading
Taiwan	4Mb DRAM	Under construction

Source: Dataquest
March 1990

TI has embraced the globalization of manufacturing, and is pursuing its goals through innovative financing that is global in scope. Dataquest estimates that TI will spend approximately $1 billion on semiconductor property, plant and equipment this year -- more than any other company in the world, and a whopping 36 percent of total semiconductor revenue (represented in 1989 dollars). Of this amount $780 would be internally funded. The remainder of the funding would be generated through its customers, local governments and joint-venture partners.

TI AS JAPANESE SUPPLIER

TI ranks as the seventh largest ASIC supplier worldwide. The company garners slightly more than one-third of its ASIC revenues from the Japanese market. TI Japan wants to continue to increase its market penetration in Japan by addressing the consumer electronics segment of that market, where it is investing both in terms of local design centers, (it currently has 4), and through strategic partnerships with Japanese companies. Aside from the large dollar volume represented by the consumer market, the economies of scale associated with it and the impetus it provides to hone quality and cost performance, ensure that participation in this market segment coincides with TI's strategic program. For example, one area of next-generation consumer ICs that TI has targeted is through an agreement with Nippon Hoso Kyokai (NHK), Japan's public television broadcasting company, for its "hi-vision" advanced TV receiver technology, which TI will use to develop chip sets for the different HDTV markets. Currently the consumer portion of the Japanese semiconductor market, which is about one-third of the market, is softening and is not expected to resume growth until 1992.

DATAQUEST ANALYSIS

From TI's perspective, this venture is expected to aid its market penetration of the Japanese market while availing it of a more risk-averse approach to the financing of additional manufacturing capability through Japan's lower cost of capital. Kobe Steel contnues to pursue its diversification goals through this partnership. However, a broader issue relates to how Japanese companies are adopting a comprehensive strategy that ranges from the location of overseas fabs, regionally-based R&D, technology exchanges and alliances, and the procurement of foreign-made ICs in terms of its strategy to address the increasingly globalized nature of the semiconductor industry. Under the shadow of strained trade relations between Japan and the United States, Dataquest observes that Japan is responding to U.S. criticism of the inaccessibility of Japan's marketplace by directing its efforts towards opening its markets through alliances, thereby achieving increased market access on a partnership basis.

Patricia Galligan
Ione Ishii
George Burns

DQ MONDAY INDEX

DATE	TITLE	COMPANY	SUBJECT
January 9, 1989	INTEL MATSUSHITA DEAL RUMORED IN JAPAN	INTEL	ALLIANCE
	JAPANESE SEMICONDUCTOR INDUSTRY REMAINS STRONG		INDUSTRY
	JAPANESE STUDY SHOWS DECLINE IN US ELECTRONICS MARKET SHARE		END USE
	DATAQUEST LOOKS AT ATT	ATT	
	ANGLO JAPANESE VENTURE BEARS FRUIT	ANAMARTIC	MEMORY
	PLESSEY RESISTS TAKEOVER BID	PLESSEY	ACQUISITION
	ERSO DEVELOPS PS2 CLONE CHIP SET	ERSO	MICRO
	HIGHLIGHTS FROM PRELIMINARY 1988 SEMICONDUCTOR MARKET SHARES		MARKET SHARE
	IDT LOWERS EARNINGS ESTIMATE	IDT	FINANCIALS
	COMPREHENSIVE REPRODUCTIVE STUDY COMMISSIONED BY SIA	SIA	
	MICRON WARNS AGAINST COUNTERFEIT DRAMS	MICRON	MEMORY
January 16, 1989	ITALY CHOSEN AS SITE OF TI'S NEW DRAM FAB	TI	CAPITAL EXPENDITURE
	NATIONAL TURNS NAS INTO JOINT VENTURE	NATIONAL	ALLIANCE
	VITELIC RAISES $39 MILLION IN PRIVATE PLACEMENT	VITELIC	VENTURE CAPITAL
	GAZELLE ACCUSES AMD OF PATENT FRAUD	GAZELLE	LITIGATION
	GIGABIT AND SC HIGHTECH SIGN AGREEMENT	GIBABIT	ALLIANCE
	US ELECTRONICS COMPANIES WILL FORM HDTV PARTNERSHIP		HDTV
	ONGOING DIALOG BETWEEN AEA AND SIA	AEA	
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	FINANCIAL RESULTS, LSI LOGIC	LSI LOGIC	
	APPLIED MATERIALS EXPANDS ETCH PRODUCTS MARKETING IN EUROPE	APPLIED MATERIALS	
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	VLSI EUROPE	MOTOROLA	
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	FINANCIAL RESULTS, IDT	IDT	FINANCIALS
	FINANCIAL RESULTS, KLA	KLA	FINANCIALS
	FINANCIAL RESULTS, LSI LOGIC	LSI LOGIC	FINANCIALS
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	DECISION ON MONSANTO SALE STILL PENDING	MONSANTO	MERGERS AND ACQUISITIONS
	MOTOROLA SUES HITACHI OVER MICROCONTROLLER	MOTOROLA	LITIGATION
	FUJITSU TO OPEN US HYBRID IC DESIGN CENTER	FUJITSU	ANALOG
	HITACHI COMPLETES US WAFER FAB PLANT	HITACHI	WAFER FAB
	TOP 1989 ELECTRONICS PRODUCTS RANKED		END USE
	MEMORY DEMAND CONTINUES TO EXCEED SUPPLY		MEMORY
	PLESSEY TO BROADEN ITS HORIZONS?	PLESSEY	MEMORY
	SIA, AEA PROPOSE 4MB DRAM CONSORTIUM	SIA	MEMORY
	HAMPSHIRE INSTRUMENTS SELLS XRAY LITHOGRAPHY SYSTEMS TO BELL LABS	HAMPSHIRE INSTRUMENTS	
	MINICOMPUTER COMPANIES EXPERIENCE HARD TIMES		LAY OFFS

DATE	TITLE	COMPANY	SUBJECT
January 30, 1989	HANDS ACROSS THE WATER	NEC	MEMORY
	CMD LAUNCHES NEW DIVISION	CMD	REORGANIZATION
	APPLE WRITES DOWN 1MB DRAM INVENTORY	APPLE	MEMORY
	FINANCIAL RESULTS, CALIFORNIA MICRO DEVICES	CALIFORNIA MICRO DEVICES	FINANCIALS
	FINANICAL RESULTS, CYPRESS	CYPRESS	FINANCIALS
	FINANICAL RESULTS, LAM RESEARCH	LAM RESEARCH	FINANCIALS
	FINANICAL RESULTS, LINEAR TECHNOLOGY	LINEAR TECHNOLOGY	FINANCIALS
	FINANICAL RESULTS, MOTOROLA	MOTOROLA	FINANCIALS
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	LOGIC DEVICES AND ATT SIGN FOUNDRY AGREEMENT	LOGIC DEVICES	ALLIANCE
	SPECULATION ABOUT INTERSIL'S FUTURE	INTERSIL	
	EUROPEAN COMMISSION UPHOLDS DUMPING DUTIES	EC	TRADE
	"NEW" EUROPEAN GAAS PLANT		GAAS
February 6, 1989	ATT AND INTEL ANNOUNCE ISDN, LAN AGREEMENT	ATT	ALLIANCE
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	FINANCIAL RESULTS, WEITEK	WEITEK	FINANCIALS
	RUMORS RE RISC DEAL BETWEEN MIPS, NEC AND SIEMENS	MIPS	MICRO
	INTEL CUTS PRICE OF 386SX	INTEL	PRICING
	NEW CACHE CONTROLLERS FROM CHIPS AND TECHNOLOGIES	CHIPS AND TECHNOLOGIES	MEMORY
	INTERGRAPH ANNOUNCES CLIPPER PRICE CUT	INTERGRAPH	PRICING
	NATIONAL REORGANIZATION	NATIONAL	REORGANIZATION
	A NOVEL IDEA--U S COMPANY ANNOUNCES VLSI CONSUMER IC	ZILOG	
	FUJITSU PLANT RUMORS	FUJITSU	CAPITAL EXPENDITURE
February 13, 1989	DECISION REACHED ON NEC, INTEL LAWSUIT	NEC	LITIGATION
	MIPS' SEMICONDUCTOR PARTNER STRATEGY	MIPS	MICRO
	NEW NEC GATE ARARYS	NEC	ASIC
	16 BIT SINGLE-CHIP ADC FROM MOTOROLA	MOTOROLA	ANALOG
	AEA REPORTS ELECTRONICS INDUSTRY HEALTHY	AEA	END USE
February 20, 1989	US BOOK TO BILL TURNS POSITIVE		BOOK TO BILL
	BUSH OKS SALE OF MONSANTO ELECTRONICS MATERIALS CO	MONSANTO	MERGERS AND ACQUISITIONS
	DATAQUEST REPORTS PRELIMINARY ANALOG MARKET SHARE		ANALOG
	INTEL ENHANCES 80C51 CELL LIBRARY	INTEL	ASIC
	TI INTRODUCES HIGH SPEED CHIP DESIGNS AT ISSCC	TI	MEMORY
	INTEL FILES TRADE SECRET SUIT	INTEL	LITIGATION
	FLASH EEPROM ANNOUNCEMENTS AT ISSCC		MEMORY
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	SINGLE CRYSTAL SILICON SALES EXPECTED TO RISE IN JAPAN		MATERIALS
	TOSHIBA DOUBLES ASIC PRODUCTION	TOSHIBA	ASIC
	ACER TO ANNOUNCE DRAM DEAL WITH TI	ACER	ALLIANCE
	1992 UPDATE		
February 27, 1989	VLSI'S Q1 RESULTS AFFECTED BY NEW FAB	VLSI	FINANCIALS
	CHIPS AND TECHNOLOGIES ENTERS MASS STORAGE CONTROLLER BUSINESS	CHIPS AND TECHNOLOGIES	MICRO
	SAMSUNG AND QUADTREE SIGN SOFTWARE DEVELOPMENT AGREEMENT	SAMSUNG	ALLIANCE

DATE	TITLE	COMPANY	SUBJECT
	XICOR SIGNS ON JAPANESE DISTRIBUTOR	XICOR	DISTRIBUTION
	GATT DISPUTES US TRADE POLICY		TRADE
	CYPRESS SPARC CHIP BOOSTED TO 33MHZ	CYPRESS	MICRO
	NEW SOFTWARE PUSH FROM 88OPEN CONSORTIUM		MICRO
	FRENCH GOVERNMENT OKS THOMSON, AEROSPATIALE MERGER	THOMSON	MERGERS AND ACQUISITIONS
	PHILIPS ANNOUNCES CELLULAR RADIO CHIP SET	PHILIPS	
	MATSUSHITA TO INCREASE EUROPEAN INVESTMENT	MATSUSHITA	CAPITAL EXPENDITURE
	FUJITSU BUYS MOSTEK PLANT IN IRELAND	FUJITSU	MERGERS AND ACQUISITIONS
	SONY RUNNING FLAT OUT IN SRAM PRODUCTION	SONY	MEMORY
	JAPANESE SEMICONDUCTOR MARKET SHARE ANALYSIS SHOWS FOREIGN GAINS		MARKET SHARE
March 6, 1989	INTEL INTRODUCES 64 BIT MICROPROCESSOR	INTEL	MICRO
	SORRY, MEMOREX TELEX, HITACHI EDS TO BUY NAS	HITACHI	MERGERS AND ACQUISITIONS
	ALLIANCE TO LEASE ATT FAB		WAFER FAB
	ATT TO DEVELOP FUTURE UNIX FOR INTEL	ATT	SOFTWARE
	DATAQUEST LOOKS AT ASIC MARKET		ASIC
	SIA KEEPS THE PRESSURE ON	SIA	TRADE
	ATT AND ZENITH TARGET HDTV MARKET	ATT	HDTV
	BOSCH CONSIDERS SITE FOR AUTOMOTIVE PRODUCTS	BOSCH	
	OLIVETTI CHOOSES INTEL RISC CHIP	OLIVETTI	MICRO
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	AMD, INTEL ARBITRATION RULING ANNOUNCED	AMD	LITIGATION
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	APPLIED MATERIALS RECEIVES BIG ORDERS FROM SAMSUNG	APPLIED MATERIALS	EQUIPMENT
	WEITEK INTRODUCES 33MHZ VERSION OF MATH COPROCESSOR	WEITEK	MICRO
	INTEL ANNOUNCES 7.5 NS CMOS PLD	INTEL	ASIC
	AEA REPORTS OVERALL IMPROVEMENT IN US ELECTRONICS TRADE DEFICIT	AEA	END USE
	MICRON TECHNOLOGY TO BUY ZILOG?	MICRON TECHNOLOGY	MERGERS AND ACQUISITIONS
	EIAJ ESTIMATES 7 PERCENT ELECTRONICS EQUIPMENT GROWTH IN 1989	EIAJ	END USE
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	DATAQUEST NOTES RAPID GROWTH OF ASIAN FABS		WAFER FAB
	THOMSON, PHILIPS AND SONY IN US HDTV BID	THOMSON	HDTV
	EEC IS SET TO INCREASE DRAM IMPORT DUTY	EC	TRADE
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	FINANCIAL RESULTS, MICRON	MICRON	FINANCIALS
	NATIONAL AND MICRON ANNOUNCE FINANCIAL RESULTS	NATIONAL	FINANCIALS
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	FUJITSU TO JOINTLY DEVELOP SUN COMPATIBLE WORKSTATION CHIP SETS	FUJITSU	MICRO
	INTEL WINS EXCLUSION ORDER AGAINST HYUNDAI EPROMS	INTEL	TRADE
	MICROCHIP TECHNOLOGY GOES SOLO	MICROCHIP TECHNOLOGY	
	RAMTRON RECEIVES $19.5 MILLION EQUITY INVESTMENT	RAMTRON	
	MITEL AND IMP ANNOUNCE ISDN ALLIANCE	ISDN	ALLIANCE
	INTEL SELLS SUPERCOMPUTER TO BRITISH RESEARCH LAB	INTEL	
	COMMERCE SECRETARY TO KEEP PRESSURE ON JAPAN		TRADE
	RUMORS OF JESSI AND SEMATECH TALKS	JESSI	
March 27, 1989	SEMATECH CHIEF OPERATING OFFICER RESIGNS	SEMATECH	EMPLOYMENT

DATE	TITLE	COMPANY	SUBJECT
	NATIONAL SEMICONDUCTOR EXECUTIVE VP OF SEMICONDUCTORS RETIRES	NATIONAL	EMPLOYMENT
	AMD PATENT ON PROGRAMMABLE ARRAY LOGIC DEVICES UPHELD	AMD	LITIGATION
	SARNOFF'S OPTOELECTRONICS GROUP ADDRESES KEY SEMICONDUCTOR AREA	SARNOFF	OPTOELECTRONICS
	HDTV LEGISLATION INTRODUCED		HDTV
	EUROPE EXPECTED TO OPT FOR HOME GROWN HDTV STANDARD		HDTV
	JAPANESE WAFER FAB UPDATE		WAFER FAB
April 3, 1989	TOSHIBA INTRODUCES NEW CMOS PLDS	TOSHIBA	ASIC
	MOTOROLA TALKS ABOUT 68040	MOTOROLA	MICRO
	INTEL, IBM ANNOUNCE DVI TECHNOLOGY AGREEMENT	INTEL	ALLIANCE
	NATIONAL CLOSES DANBURY PLANT	NATIONAL	
	SEMATECH ACHIEVES FIRST SILICON	SEMATECH	
	AEA TARGETS SUPER 301 OFFENDERS	AEA	TRADE
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	INTEL INTRODUCES NEW FLASH MEMORY DEVICES	INTEL	MEMORY
	INMOS ACQUISITION ANNOUNCED	INMOS	MERGERS AND ACQUISITIONS
	EAST GERMANY LOOKS AT 4MBIT DRAM		MEMORY
April 10, 1989	MOTOROLA ANNOUNCES 50 MHZ VERSION OF 68030	MOTOROLA	MICRO
	FINANICAL RESULTS, ZYMOS	ZYMOS	FINANCIALS
	FINANICAL RESULTS, LOGIC DEVICES	LOGIC DEVICES	FINANCIALS
	LSI LOGIC AFFILIATES COMBINE	LSI LOGIC	MERGERS AND ACQUISITIONS
	VAN POPPELEN TO LEAVE NATIONAL	NATIONAL	EMPLOYMENT
	FLAT PANEL VGA CONTROLLERS FROM CHIPS AND TECHNOLOGIES, CIRRUS LOGIC	CHIPS AND TECHNOLOGIES	MICRO
	RAMTRON AND SEIKO EPSON SIGN FERROELECTRIC DEAL	RAMTRON	ALLIANCE
	VLSI AND HITACHI INTRODUCE JOINT SRAM PRODUCT	VLSI	MEMORY
	TOSHIBA DEBUTS 4MB DRAM BASED MEMORY MODULE	TOSHIBA	MEMORY
	TI INTRODUCES EP DEVICES	TI	ASIC
	SILICON SYSTEMS IN MERGER NEGOTIATIONS	SILICON SYSTEMS	MERGERS AND ACQUISITIONS
	HUELS CONSOLIDATES MONSANTO DYNAMIT	HUELS	MERGERS AND ACQUISITIONS
	NEC INTRODUCES NEW GATE ARRAY PRODUCTS	NEC	ASIC
	SONY PLANT IN THAILAND	SONY	CAPITAL EXPENDITURE
	JAPANESE ELECTRONIC CASH REGISTER MAKERS INCREASE PRODUCTION		END USE
	SEMICONDUCTOR MANUFACTURING EQUIPMENT SALES INCREASE IN JAPAN		EQUIPMENT
April 17, 1989	US BOOKINGS AND BILLINGS HIT ALL TIME HIGH!		BOOK TO BILL
	INTEL INTRODUCES THE I486	INTEL	MICRO
	IXYS ACQUIRES ABB POWER SEMICONDUCTOR GROUP	IXYS	MERGERS AND ACQUISITIONS
	WILF CORRIGAN TAKES MEDICAL LEAVE OF ABSENCE FROM LSI	LSI	EMPLOYMENT
	IBM AND SAMSUNG SIGN PATENT AGREEMENT	IBM	ALLIANCE
	SILICON SYSTEMS TO BE ACQUIRED BY TDK	SILICON SYSTEMS	MERGERS AND ACQUISITIONS
	INTEL SIGNS DARPA AGREEMENT	INTEL	ALLIANCE
	NEW LASER PRINTER FAMILY USES NATIONAL MICROPROCESSOR	NATIONAL	END USE
	HP TO ACQUIRE APOLLO COMPUTER	HP	MERGERS AND ACQUISITIONS
	FINANCIAL RESULTS, ALTERA	ALTERA	FINANCIALS
	FINANICAL RESULTS, DALLAS SEMICONDUCTOR	DALLAS SEMICONDUCTOR	FINANICALS
	FINANCIAL RESULTS, INTEL	INTEL	FINANICALS
	FINANCIAL RESULTS, VLSI	VLSI	FINANICALS
	FINANCIAL RESULTS, XICOR	XICOR	FINANICALS

DATE	TITLE	COMPANY	SUBJECT
	HITACHI ANNOUNCES ULTRAHIGH SPEED BICMOS MPU	HITACHI	MICRO
	SANYO BEGINS RESEARCH CENTER CONSTRUCTION	SANYO	CAPITAL EXPENDITURE
April 24, 1989	MOTOROLA INTRODUCES INDUSTRY'S FIRST 32 BIT MICROCONTROLLER	MOTOROLA	MICRO
	START UP OFFERS PLUG COMPATIBLE VERSION OF 80287	INTEGRATED INFO TECHNOLOGY	MICRO
	US LAB MAKES COMMERCIAL BROADCAST OF ADVANCED TV SIGNAL		
	FINANCIAL RESULTS, CYPRESS	CYPRESS	FINANCIALS
	FINANCIAL RESULTS, CHIPS AND TECHNOLOGIES		
	FINANCIAL RESULTS, IDT	IDT	FINANCIALS
	FINANCIAL RESULTS, LSI LOGIC	LSI LOGIC	FINANCIALS
	FINANCIAL RESULTS, LINEAR TECHNOLOGY	LINEAR TECHNOLOGY	FINANCIALS
	FINANCIAL RESULTS, SILICON GENERAL	SILICON GENERAL	FINANCIALS
	FINANCIAL RESULTS, TI	TI	FINANCIALS
	FINANCIAL RESULTS, WESTERN DIGITAL	WESTERN DIGITAL	FINANCIALS
	EC RULING ON GEC, SIEMENS JOINT BID FOR PLESSEY	EC	MERGERS AND ACQUISITIONS
	PHILIPS IN CORPORATE REORGANIZATION	PHILIPS	
	FUJITSU CHOOSES UK FOR EUROPEAN FAB	FUJITSU	CAPITAL EXPENDITURE
	SGS THOMSON PLEDGES INVESTMENT IN INMOS	SGS-THOMSON	MERGERS AND ACQUISITIONS
May 1, 1989	LSI PURCHASES LAND FOR NEW HQ	LSI	CAPITAL EXPENDITURES
	ZYMOS POSTS Q1 PROFIT	ZYMOS	FINANCIALS
	EXCESS CAPACITY AT FAB 6 PROMPTS INTEL STAFF REDUCTION	INTEL	EMPLOYMENT
	AMD ANNOUNCES "GAL LIKE" PRODUCT	AMD	ASIC
	A CASE OF OVERCAPACITY?, DQ LOOKS AT PC CHIP SET MARKET		MICRO
	SONY SETS UP HDTV CENTER IN SAN JOSE	SONY	HDTV
	SANYO AND CANADIAN COMPANY TO DEVELOP 4MB DRAM	SANYO	ALLIANCE
	HITACHI SETS UP US LABS	HITACHI	CAPITAL EXPENDITURE
	MITI RELEASES FLASH REPORT FOR FEBRUARY	MITI	
	TAIWANESE CONGLOMERATE ENTERS ELECTRONICS BUSINESS	FORMOSA PLASTICS	END USE
	HUALON DIVERSIFIES MEMORY LINE	HUALON	MEMORY
	PHILIPS COMPONENTS REORGANIZATION	PHILIPS	
	DEC CHOOSES OLIVETTI AS EUROPEAN SUPPLIER	DEC	END USE
May 8, 1989	NATIONAL REORGANIZATION UPDATE	NATIONAL	REORGANIZATION
	SANYO TO REACH COMPLETION OF CHIP DEAL WITH MOTOROLA	SANYO	ALLIANCE
	SEQUOIA COMPLETES MICROCHIP PURCHASE	SEQUOIA	MERGERS AND ACQUISITIONS
	NATIONAL COMPLETES SALE OF NAS	NATIONAL	MERGERS AND ACQUISITIONS
	APPLIED MATERIALS PROPOSES INDUSTRY STANDARD BASED ON PRECISION	APPLIED MATERIALS	
	UTMC OFFERS FOUNDRY SERVICE	UTMC	
	EIAJ MAY NULLIFY SEMICONDUCTOR TRADE ARRANGEMENT	EIAJ	TRADE
	EC LOOKS AT $4 BILLION INVESTMENT IN JESSI	EC	
	PHILIPS CHALLENGES UK SUBSIDIES OF JAPANESE FIRMS	PHILIPS	
	NEC TO INCREASE MICROCOMPONENT PRODUCTION	NEC	MICRO
	TI JAPAN AND VICTOR JAPAN DEVELOP DSP DEVICE	TI JAPAN	DSP
	KOREAN COMPANY TO BUILD GAAS PLANT	HANIL GROUP	CAPITAL EXPENDITURE
	MOTOROLA ESTABLISHES VLSI DESIGN CENTER IN TAIWAN	MOTOROLA	
	WALSIN LIHWAN EXPENDS IC PRODUCTION	WALSIN LIHWAN	

DATE	TITLE	COMPANY	SUBJECT
May 15, 1989	US SEMICONDUCTOR ORDERS SLOW IN APRIL		BOOK TO BILL
	TI AND ACER TO FUND JOINT DRAM VENTURE	TI	ALLIANCE
	MENTOR GRAPHICS AND LSI LOGIC MERGE DESIGN TOOLS	LSI	
	MITI UNVEILS 11 POINT TRADE PROGRAM	MITI	TRADE
	Q1 ELECTRONICS ORDERS UP OVER LAST YEAR		END USE
	INDUSTRY PERIODICAL SHOWS DECLINE IN ELECTRONICS BUSINESS		END USE
	IBM SNUBBED BY JESSI	IBM	
	FINANCIAL RESULTS, CALIFORNIA MICRO DEVICES	CALIF MICRO DEVICES	FINANCIALS
	FINANCIAL RESULTS, IMP	IMP	FINANCIALS
	FINANCIAL RESULTS, LOGIC DEVICES	LOGIC DEVICES	FINANCIALS
	FINANCIAL RESULTS, SILICONIX	SILICONIX	FINANCIALS
	LOW POWER PLL CHIP FROM FUJITSU	FUJITSU	ANALOG
	NEC INTRODUCES IMPROVED DEFINITION TV		HDTV
May 22, 1989	TI DESCRIBES 1 MILLION TRANSISTOR BICMOS GATE ARRAY	TI	ASIC
	SIEMENS AND TOSHIBA TO ALTERNATE SOURCE CMOS GATE ARRAYS	SIEMENS	ALLIANCE
	AMD AND LATTICE EXPAND CROSS LICENSING DEAL	AMD	ALLIANCE
	FORMER NATIONAL VP JOINS IXYS		PERSONNEL
	NATIONAL APPOINTS TECHNOLOGY HEADS	NATIONAL	REORGANIZATION
	GENE HILL JOINS LSI LOGIC	LSI LOGIC	PERSONNEL
	DATAQUEST REPORTS ON SUB 1.5 MICRON PRODUCTS		
	SIA PUSHES FOR DRAM CONSORTIUM	SIA	
	"SILICON EXCHANGE" PROPOSED FOR EUROPE		
	RUMORS OF HITACHI'S EURO FAB	HITACHI	CAPITAL EXPENDITURE
	DQ VISITS HSINCHU SCIENCE PARK		
	DATAQUEST PUBLISHES PRELIMINARY MARKET SHARE FIGURES FOR ROW		MARKET SHARE
May 29, 1989	ATT AND TI INTRODUCE NEW DSP PRODUCTS	ATT	DSP
	SEMATECH AWARDS JOINT DEVELOPMENT CONTRACTS	SEMATECH	
	MOTOROLA, THOMSON CSF AGREEMENT ON MILITARY VERSION OF 88000	MOTOROLA	ALLIANCE
	WESTERN DIGITAL SIGNS LAN AGREEMENT WITH IBM	WESTERN DIGITAL	ALLIANCE
	TECHNOLOGY BREAKTHROUGH ANNOUNCEMENTS		
	DATAQUEST FORECASTS CBIC GROWTH		ASIC
	EXAR REPORTS YEAR END FINANCIAL RESULTS	EXAR	FINANCIALS
	JAPAN PLACED ON SUPER 301 LIST, BUT NOT FOR SEMICONDUCTOS		TRADE
	EC AND JAPAN SET FOR AGREEMENT ON CHIP DUMPING	EC	TRADE
	PLESSEY'S GAAS CHIP PRODUCTION TO STAY	PLESSEY	GAAS
	SONY TO BUILD PLANT IN HOLLAND	SONY	CAPITAL EXPENDITURE
	MEMC HEULS' MONSANTO FACTORY TO CLOSE	HEULS	LAYOFFS
June 5, 1989	MOTOROLA AND SCHLUMBERGER TO DEVELOP SEMICONDUCTOR TEST EQUIPMENT	MOTOROLA	EQUIPMENT
	MOTOROLA SECOND SOURCES TOSHIBA BICMOS LOGIC PRODUCTS	MOTOROLA	ALLIANCE
	AMD CHALLENGES BROOKTREE PATENTS	AMD	LITIGATION
	EPROM PRODUCT ANNOUNCEMENTS FROM INTEL	INTEL	MEMORY
	THE EMERGING RISC BASED CAMPS		MICRO
	VLSI QUALIFIES SAN ANTONIO FAB	VLSI	WAFER FAB
	ATMEL TO BUY HONEYWELL SEMICONDUCTOR DIVISION	ATMEL	MERGERS AND ACQUISITIONS
	NIKON HITS ALL TIME HIGH IN STEPPER SALES	NIKON	EQUIPMENT
	OKI ELECTRIC JOINS DEVELOPMENT OF TRON BASED 32 BIT MPU	OKI	MICRO

DATE	TITLE	COMPANY	SUBJECT
	TAIWAN ADVISOR PREDICTS VLSI OUTPUT TO DOUBLE BY 1991	OKI	MICRO
	MINIFABS FAVORED BY SOME TAIWANESE IC DESIGN HOUSES		WAFER FAB
	INTEL TO ANNOUNCE EUROFAB	INTEL	CAPITAL EXPENDITURE
	DATAQUEST EUROPEAN SEMICONDUCTOR CONFERENCE		
	DQ PERSPECTIVE, PSE TO TRADE FUTURES CONTRACTS IN DRAMS?		MEMORY
June 12, 1989	NATIONAL AND SEEQ LIMIT DEVELOPMENT AGREEMENT	NATIONAL	ALLIANCE
	FUJITSU MICROELECTRONICS APPOINTS 3 NEW VPS	FUJITSU	PERSONNEL
	BIT UNVEILS ECL SPARC CHIP SET	BIT	MICRO
	NEC EXPANDS IN ROSEVILLE	NEC	CAPITAL EXPENDITURE
	HITACHI EXPANDS LAWSUIT AGAINST MOTOROLA	HITACHI	LITIGATION
	ICT HAS SMALL IPO	ICT	PUBLIC OFFERING
	ALCAN AND RAMTRON SIGN DEVELOPMENT AGREEMENT	ALCAN	ALLIANCE
	GRAPHICS CHIP SET ANNOUNCEMENT BY WESTERN DIGITAL IMAGING	WESTERN DIGITAL	MICRO
	OUTLOOK FOR EQUIPMENT MARKETS		EQUIPMENT
	DATAQUEST FORECASTS ISDN SEMICONDUCTORS		ISDN
	TAIWAN'S SIP LOOKING FOR MORE IC PRODUCERS		
	EIAJ RECOMMENDS HDTV TASK FORCE IN SIA MEETING	EIAJ	HDTV
	JAPANESE COMPANIES FORM "GIANT ELECTRONICS PROJECT"		
	DQ PERSPECTIVE, WSTS DATA SHOW DECLINE IN Q1 SHIPMENTS		FORECAST
June 19, 1989	US BOOK TO BILL DOWN IN MAY		BOOK TO BILL
	EUROPEAN BOOK TO BILL DIPS BELOW UNITY		BOOK TO BILL
	OKI FAB FOR OREGON	OKI	CAPITAL EXPENDITURE
	VARIAN AND TOKYO ELECTRON FORM US JOINT MANUFACTURING VENTURE	VARIAN	ALLIANCE
	TOKYO OHKA KOGYO ANNOUNCES PURCHASE OF OREGON SITE	TOKYO OHKA KOGYO	CAPITAL EXPENDITURE
	ZILOG EMPLOYEE BUY OUT	ZILOG	MERGERS AND ACQUISITIONS
	ATT TO SWITCH PC SUPPLIERS?	ATT	
	EUROPEAN SEMICONDUCTOR CONFERENCE INPUT, SOVIET JOINT VENTURES		JOINT VENTURES
	SEMICONDUCTOR MANAGEMENT BUY OUT AT PLESSEY?		MERGERS AND ACQUISITIONS
	KOREA'S SEMICONDUCTOR INDUSTRY SETS ITS SIGHTS ON THE 1990S		KOREA
	DQ PERSPECTIVE, WAFER FAB TRENDS IN JAPAN		WAFER FAB
June 26, 1989	NATIONAL FINANCIAL RESULTS FOR FISCAL 1989	NATIONAL	FINANCIALS
	LOWERED EXPECTATIONS FROM VARIAN AND BURR-BROWN	VARIAN	FINANCIALS
	IBM ANNOUNCES INDUSTRY'S FIRST I486 COMPUTER PLATFORM	IBM	END USE
	SEATTLE SILICON AND GIGABIT TO DEVELOP DESIGN AUTOMATION TOOLS FOR GAAS ASICS	SEATTLE SILICON	ALLIANCE
	SEMATECH IN TALKS WITH JESSI	SEMATECH	
	SIEMENS TO MAKE SINGAPORE ITS LARGEST IC FACILITY	SIEMENS	CAPITAL EXPENDITURE
	CRISIS IN THE WORLD'S FUTURE LARGEST MARKET: CHINA		CHINA
	IC INVENTORY INDEX TO BE INTRODUCED		
	HITACHI BOOSTS SRAM PRODUCTION IN THE US	HITACHI	MEMORY
	NMB BUILDS 4MB DRAM FAB	NMB	CAPITAL EXPENDITURE
	DQ PERSPECTIVE, US MEMORIES		MEMORY
July 3, 1989	CMD FILES $80 MILLION SUIT	CALIFORNIA MICRO DEVICES	LITIGATION
	OPPORTUNITIES FOR HIGH TECH BUSINESS IN INDIA		INDIA
	DRAM SUPPLY WILD CARD?		MEMORY
	INTEL'S EUROFAB SITE STILL UNCERTAIN	INTEL	CAPITAL EXPENDITURE

DATE	TITLE	COMPANY	SUBJECT
	EUROPE INVESTS IN FUTURE		RESEARCH AND DEVELOPMENT
	ITALY GETS $86 MILLION CHIP PLANT	SGS THOMSON	CAPITAL EXPENDITURE
	MATRA IS LOOKING FOR A PARTNER	MATRA	
	DQ PUBLISHES FINAL MARKET SHARE ESTIMATES FOR EUROPEAN SEMICONDUCTOR MARKET		MARKET SHARE
	TOSHIBA AND FUJITSU BOOST DRAM PRODUCTION	TOSHIBA	MEMORY
	NTT FORGES AHEAD WITH IMPLEMENTATION OF ISDN	NTT	ISDN
	DQ PERSPECTIVE, DRAM PRODUCTION		MEMORY
July 10, 1989	INTEL AND NATIONAL ACQUIRE DATACOM BUSINESSES	INTEL	MERGERS AND ACQUISITIONS
	US LEASING COMPANY SIGNS DEAL WITH JAPANESE VENTURE CAPITAL COMPANY	CAPITAL ASSOCIATES	ALLIANCE
	HARRIS ACQUIRES GE'S MICROELECTRONICS CENTER		MERGERS AND ACQUISITIONS
	GOULD AMI ANNOUNCES 1MB ROM	GOULD AMI	MEMORY
	ALTERA EXPANDS FACILITIES	ALTERA	
	DATAQUEST OBSERVES SHARP DROP IN WORLDWIDE DRAM PRICES		PRICING
	JAPANESE INDUSTRY UPDATE		
	FUJITSU INVESTS IN SILICON VALLEY COMPUTER START UP	FUJITSU	
	HITACHI AND TOSHIBA PICK UP 4MB DRAM PACE	HITACHI	MEMORY
	MOTOROLA JAPAN BUILDS SUBMICRON PROCESS FAB	MOTOROLA	CAPITAL EXPENDITURE
	IBM STEPS UP PRODUCTION OF 4MB DRAMs	IBM	MEMORY
	JAPAN DROPS EXPORT CONTROLS ON EC MEMORIES		
	CAPITAL SPENDING IN ASIA TO SURPASS EUROPE		CAPITAL EXPENDITURE
	DQ PERSPECTIVE, VENTURE CAPITAL IN JAPAN		
July 17, 1989	US BOOKINGS HIT PLATEAU IN JUNE		BOOK TO BILL
	EUROPEAN BOOK TO BILL UP SHARPLY		BOOK TO BILL
	SHARING GOOD TIMES AT IDT	IDT	
	EISA CHIP SET FROM INTEL	INTEL	MICROS
	INTEL'S LAN STRATEGY EMERGES	INTEL	
	UNISYS CHOOSES MOTOROLA'S 88000 FOR NEW PRODUCT	MOTOROLA	END USE
	MOVE TO OPEN EQUIPMENT ARCHITECTURE?		EQUIPMENT
	GATT RECOMMENDATIONS IMPLEMENTED BY JAPAN		TRADE
	MANAGEMENT BUY OUT FORMS NEW COMPANY		MERGERS AND ACQUISITIONS
	PERSONAL COMPUTER SHIPMENTS FORECAST GROWTH		END USE
	HITACHI STRENGTHENS MPU BUSINESS	HITACHI	MICRO
	SHI ANNOUNCED SR BASED MICROLITHOGRAPHIC SYSTEM	SHI	EQUIPMENT
	NIPPON STEEL ENTERS SEMICONDUCTOR EQUIPMENT BUSINESS	NIPPON STEEL	ALLIANCE
	ATT OPENS TEST LAB IN HONG KONG	ATT	
	DQ PERSPECTIVE, ASIAN ELECTRONICS		
July 24, 1989	FINANCIAL RESULTS, AMD	AMD	FINANCIALS
	FINANCIAL RESULTS, ALTERA	ALTERA	FINANCIALS
	FINANCIAL RESULTS, BURR BROWN	BURR BROWN	FINANCIALS
	FINANCIAL RESULTS, CIRRUS LOGIC	CIRRUS LOGIC	FINANCIALS
	FINANCIAL RESULTS, CYPRESS	CYPRESS	FINANCIALS
	FINANCIAL RESULTS, INTEL	INTEL	FINANCIALS
	FINANCIAL RESULTS, IDT	IDT	FINANCIALS
	FINANCIAL RESULTS, MOTOROLA	MOTOROLA	FINANCIALS
	FINANCIAL RESULTS, LSI LOGIC	LSI LOGIC	FINANCIALS

DATE	TITLE	COMPANY	SUBJECT
	SEMICONDUCTOR EQUIPMENT MANUFACTURERS REPORT STRONG GAINS		FINANCIALS
	HOYA CORPORATION MAKES A BID FOR MICRO MASK	HOYA	MERGERS AND ACQUISITIONS
	TI JOINS MESA	TI	
	SEMATECH ORDER BOLSTERS EATON'S THIN FILM OPERATIONS	SEMATECH	
	CAMBRIDGE INSTRUMENTS AND WILD LEITZ TO MERGE		MERGERS AND ACQUISITIONS
	FINALLY CONSENSUS ON PRICE MONITORING SCHEME FOR ASICS		TRADE
	COMPAQ AND IBM SIGN CROSS LICENSE AGREEMENT		ALLIANCE
	DQ PERSPECTIVE, SEMICONDUCTOR FORECAST		FORECAST
July 31, 1989	FINANCIAL RESULTS, ADAPTEC	ADAPTEC	FINANCIALS
	FINANCIAL RESULTS, CHIPS AND TECHNOLOGIES	CHIPS AND TECHNOLOGIES	FINANCIALS
	FINANCIAL RESULTS, LINEAR TECH	LINEAR TECH	FINANCIALS
	PLANT MANAGERS EXHIBIT WANING OPTIMISM		INDICATOR
	ADVANCED NETWORKING GROUP FORMED	AMD	LANS
	HITACHI PROVIDES NEW CUSTOMER SUPPORT CENTER	HITACHI	
	SIX POUNDER IS TRULY PORTABLE		
	VIDEO DACS ON THE FAST TRACK		ANALOG
	SIMTEK AND PLESSEY TO SHARE MEMORY TECHNOLOGY	SIMTEK	ALLIANCE
	GOLDSTAR TO ACQUIRE 1MB DRAM TECHNOLOGY FROM HITACHI		ALLIANCE
	CONTROVERSY ERUPTS OVER EC, JAPAN PRICING ARRANGEMENT		TRADE
	FUJITSU JOINS 4MB DRAM RACE		MEMORY
	HITACHI AND TI COOPERATE IN 64K SRAM SUPPLY	HITACHI	ALLIANCE
	CYPRESS CEO OPPOSED TO US MEMORIES	CYPRESS	
	DQ PERSPECTIVE, TRADE		TRADE
August 7, 1989	FINANCIAL RESULTS, KLA	KLA	FINANCIALS
	FINANCIAL RESULTS, MAXIM	MAXIM	FINANCIALS
	FINANCIAL RESULTS, WEITEK	WEITEK	FINANCIALS
	FINANCIAL RESULTS, WESTERN DIGITAL	WESTERN DIGITAL	FINANCIALS
	XILINX UNVEILS HIGH DENSITY FPGA	XILINX	ASIC
	UNITRODE TO SELL PASSIVE COMPONENTS DIVISION	UNITRODE	MERGERS AND ACQUISITIONS
	NATIONAL AND HITACHI EXPAND FACT AGREEMENT	NATIONAL	ALLIANCE
	CHANGE OF VENUE FOR HITACHI SUIT AGAINST MOTOROLA	HITACHI	LITIGATION
	AMD ANNOUNCES FOUR DAY SHUTDOWN	AMD	
	MAJOR REORGANIZATION AT VARIAN	VARIAN	REORGANIZATION
	SARATOGA SEMICONDUCTOR AND INTEL SIGN BICMOS DEAL	SARATOGA SEMICONDUCTOR	ALLIANCE
	DAEWOO ZYMOS TECHNOLOGY, LTD	ZYMOS	ALLIANCE
	MOTOROLA HALTS NEGOTIATION FOR TIANJIN SEMICONDUCTOR FACILITY	MOTOROLA	CHINA
	SEMICONDUCTOR EQUIPMENT COMPANIES RUSH TO SOUTH KOREA		EQUIPMENT
	JAPANESE SEMICONDUCTOR EQUIPMENT MANUFACTURERS COME ON STRONG		EQUIPMENT
	DQ PERSPECTIVE, SEMATECH	SEMATECH	
August 14, 1989	FINANCIAL RESULTS, LOGIC DEVICES	LOGIC DEVICES	FINANCIALS
	FINANCIAL RESULTS, VLSI	VLSI	FINANCIALS
	FINANCIAL RESULTS, ZYMOS	ZYMOS	FINANCIALS
	DOMESTIC ELECTRONICS EMPLOYMENT SHOWS SMALL INCREASE IN JUNE		EMPLOYMENT
	EMERGING MEMORY MARKET OF FLASH		MEMORY
	CYPRESS INTRODUCES MAX	CYPRESS	ASIC

DATE	TITLE	COMPANY	SUBJECT
	GOULD AMI OFFERS COMPILABLE RAM ON GATE ARRAYS	GOULD AMI	ASIC
	HP AND SAMSUNG IN RISC DEAL	HP	ALLIANCE
	OPPOSITES ATTRACT?	INTEL	MERGERS AND ACQUISITIONS
	EUROPEAN BOOK TO BILL GOES UP FOR JULY		BOOK TO BILL
	INTEL NEARS DECISION ON EUROPEAN FAB SITE	INTEL	CAPITAL EXPENDITURE
	PHILIPS AND SUN IN 'RISC' ALLIANCE	PHILIPS	ALLIANCE
	US MARKET BOOK TO BILL		BOOK TO BILL
	IT'S 10:00 PM, DO YOU KNOW WHERE YOUR REJECTS ARE?	WESTERN DIGITAL	LITIGATION
	DQ PERSPECTIVE, BOOK TO BILL		BOOK TO BILL
August 21, 1989	WILL 1989 SEE APPLIED HALF WAY TOWARD ITS 1993 GOAL OF $1 BILLION?	APPLIED MATERIAL	FINANCIALS
	SONY ACQUIRES MATERIALS RESEARCH CORP	SONY	MERGERS AND ACQUISITIONS
	SARATOGA SEMICONDUCTOR REORGANIZES	SARATOGA	REORGANIZATION
	INTEL EXPECTS Q3 TO BE DOWN	INTEL	FINANCIALS
	HP, SIEMENS AND ATT AGREE ON FDDI IC	FDDI	ALLIANCE
	ATT AND PARADIGM IN SRAM ALLIANCE	ATT	ALLIANCE
	SHIN ETSU EXPANDS WAFER PRODUCTION IN EUROPE	SHIN-ETSU	CAPITAL EXPENDITURE
	DRAM PLANS FOR EUROPE		TRADE
	PLESSEY, THE SAGA CONTINUES	PLESSEY	
	JAPAN DEFENDS THEIR "SCREWDRIVER" PLANTS		TRADE
	ASIA POSITIONS FOR FUTURE SEMICONDUCTOR GROWTH		ASIA
	TAIWANESE ALLIANCE TO DEVELOP ADVANCED ICS		ALLIANCE
	DQ PERSPECTIVE, SEMATECH	SEMATECH	
August 28, 1989	TI INTRODUCES 386 PC CHIP SET	TI	MICRO
	CHIPS AND TECHNOLOGIES AUGMENTS ITS MASS STORAGE OPERATION	CHIPS AND TECHNOLOGIES	MICRO
	SALES OF ELECTRONICS PRODUCTS AND SERVICES INCREASE		END USE
	RECORD RESULTS FROM LAM RESEARCH	LAM RESEARCH	FINANCIALS
	SEMICON WEST MOVES TO NEW LOCATION		
	KOREAN FIRM TO LOCATE FAB IN EUROPE?		CAPITAL EXPENDITURE
	CONCERN OVER EUROPEAN COMMUNITY CHIP RULES		TRADE
	MITSUBISHI TO BUILD FAB IN EUROPE	MITSUBISHI	CAPITAL EXPENDITURE
	KEEP AN EYE ON SOLBOURNE	SOLBOURNE	END USE
	ERRATA "HP,SIEMENS AND ATT AGREE ON FDDI CHIP"		ALLIANCE
	DQ PERSPECTIVE, JAPANESE ELECTRONICS INDUSTRY REVISITED		
September 5, 1989	BUSINESS FAILURES DROP SHARPLY		INDICATOR
	APPLIED MATERIAL'S STRATEGY TO SUCCEED IN JAPAN	APPLIED MATERIALS	
	LAM AND DU PONT TEAM UP TO PROVIDE SYSTEM SOLUTION	LAM	ALLIANCE
	TWO NATIONAL ASSETS COMBINE TO FORM SETEC	SEMATECH	ALLIANCE
	JOINT VENTURE ESTABLISHES NEW TEST EQUIPMENT COMPANY	SCHLUMBERGER	ALLIANCE
	KAWASAKI STEEL ENTERS 256K SRAM MARKET	KAWASAKI STEEL	MEMORY
	HITACHI STARTS INTEGRATED DRAM PRODUCTION IN WEST GERMANY	HITACHI	MEMORY
	NEC ADOPTS MIPS' RISC PROCESSOR FOR MPU AND EWS	NEC	END USE
	SIEMENS MARKETS 1MB DRAM IN JAPAN	SIEMENS	MEMORY
	SONY TO BE PLESSEY'S EASTERN CHIP PARTNER?	SONY	ALLIANCE
	OLIVETTI IN SMART CARD DEAL	OLIVETTI	SMARTCARD
	THREE NEW LOCAL FABS PLANNED IN TAIWAN		CAPITAL EXPENDITURE
	TI DOUBLES 1MB AND 4MB ASSEMBLY TEST CAPACITY IN SINGAPORE	TI	MEMORY

DATE	TITLE	COMPANY	SUBJECT
	DQ PERSPECTIVE, TI'S "TECHNOLOGY TRENDS '89 SEMINAR	TI	
September 11, 1989	MESA MERGES INTO SEMI STANDARDS PROGRAM	SEMI	EQUIPMENT
	APPLIED MATERIALS ENTERS METAL CVD MARKET	APPLIED MATERIALS	EQUIPMENT
	NATIONAL COMPUTE ENGINE GARNERS NEW DESIGN WINS	NATIONAL	MICRO
	NATIONAL TO OFFER PC FAX BOARDS UNDER LICENSE AGREEMENT	NATIONAL	ALLIANCE
	THROUGH THE GRAPEVINE	VARIOUS	VARIOUS
	SGS THOMSON INVESTMENT IN INMOS TO BE REVIEWED AT PRESS MEETING	SGS THOMSON	
	XICOR INTRODUCES LOW DENSITY, LOW POWER EEPROMS	XICOR	MEMORY
	INVESTORS SHYING AWAY FROM CHINA		
	MITSUBISHI "FAB" IN U.K.	MITSUBISHI	CAPITAL EXPENDITURE
	SGS THOMSON STILL ON THE ACQUISITION TRAIL	SGS THOMSON	MERGERS AND ACQUISITIONS
	DQ PERSPECTIVE, SEMICONDUCTOR FORECAST		FORECAST
September 18, 1989	NHK TRANSFERS MUSE TO TI JAPAN	NHK	ALLIANCE
	US BOOK TO BILL FALLS TO 0.94		BOOK TO BILL
	NATIONAL REPORTS Q1 LOSS	NATIONAL	FINANCIALS
	APPLIED MATERIALS ADDS RTP FROM PEAK TO ITS REPERTOIRE	APPLIED MATERIALS	EQUIPMENT
	GENUS JOINS SEMATECH'S EIP	GENUS	EQUIPMENT
	THROUGH THE GRAPEVINE	VARIOUS	PERSONNEL
	CONTINUED HIGH GROWTH FOR TECHNICAL WORKSTATION MARKET		END USE
	KOREAN GOVERNMENT ANNOUNCES $58 MILLION R AND D SUPPORT FOR SEMI EQUIPMENT		R AND D
	DAMING SEMICONDUCTOR REPORTS PROFITS IN SHENZHEN JOINT VENTURE	DAMING SEMICONDUCTOR	FINANCIALS
	EUROPEAN BOOK TO BILL DROPS TO 1.03		BOOK TO BILL
	IT'S ALL OVER BAR THE SHOUTING	PLESSEY	MERGERS AND ACQUISITIONS
	SIEMENS TAKES SLICE OF ES2	SIEMENS	MERGERS AND ACQUISITIONS
	MORE HEADACHES FOR AMSTRAD		END USE
	DQ PERSPECTIVE, TI AND HDTV	TI	HDTV
September 25, 1989	MOTOROLA AND DIGITAL ALLIANCE TO DELIVER FDDI CHIP SET	MOTOROLA	ALLIANCE
	LSI ADDRESSES MARKET NEED WITH NEW EMBEDDED ARRAYS	LSI	ASIC
	FINANCIAL RESULTS, CALIFORNIA MICRO DEVICES	CALIFORNIA MICRO DEVICES	FINANCIALS
	FINANCIAL RESULTS, MICRON	MICRON	FINANCIALS
	LSI LOGIC AND VARIAN DOWNGRADE EXPECTATIONS FOR QUARTER	LSI	FINANCIALS
	ORACLE JOINS SEMI, SEMATECH	SEMATECH	
	FAST 1MBIT DRAM FROM HITACHI IN BICMOS	HITACHI	MEMORY
	THROUGH THE GRAPEVINE	US MEMORY	INVESTMENT
	SIA URGES ANTITRUST REFORM	SIA	
	COLOR MONITORS DISPLAY SALES GROWTH AND DESIGN INNOVATION		END USE
	FUTURE OF ANALOG ICS IS MIXED		ANALOG
	YOUR DRAMS OR YOUR LIFE		MEMORY
	CONSTRUCTION BEGINS ON TI, ACER SEMICONDUCTOR PLANT	TI ACER	CAPITAL EXPENDITURE
	MATRA SELLS 50% OF CHIP SUBSIDIARY	MATRA	MERGERS AND ACQUISITIONS
	DQ PERSPECTIVE EUROPE 1992		TRADE
October 2, 1989	DIGITAL EQUIPMENT CORP. ANNOUNCES ADVANCES IN PACKAGING TECHNOLOGY	DIGITAL	PACKAGING
	HP AND OKI AGREE TO BUILD A PCB MANUFACTURING PLANT	HP	ALLIANCE
	PHILIPS LICENSES EEPROM TO CATALYST	PHILIPS	ALLIANCE
	HP AND AMD TO DELIVER NETWORK IC BASED ON TWISTED PAIR LAN STANDARD	HP	ALLIANCE

DATE	TITLE	COMPANY	SUBJECT
	LATTICE GOES PUBIC	LATTICE	IPO
	SARATOGA SEMICONDUCTOR TO SELL FAB	SARATOGA	
	RECENT FINANCIAL RESULTS CONTINUE LACKLUSTER TREND	XICOR	FINANCIALS
	ATEQ DOUBLES THROUGHPUT WITH NEW SCANNED LASER LITHOGRAPHY SYSTEM	ATEQ	EQUIPMENT
	CONGRESSIONAL HEARINGS TAKE PLACE ON US MEMORIES	US MEMORIES	
	BRIEFLY IN THE NEWS (INTEL,MICRON,CROSSCHECK)	VARIOUS	ALLIANCE
	NMB GOES PUBLIC	NMB	IPO
	FROM POTATOES TO CHIPS?	INTEL	CAPITAL EXPENDITURE
	SAMSUNG CORNING PLANS TO CONSTRUCT GAAS WAFER PLANT BY 1991	SAMSUNG	CAPITAL EXPENDITURE
	KEC EXPANDS ITS WAFER OUTPUT CAPACITY	KEC	CAPITAL EXPENDITURE
	DQ PERSPECTIVE, DRAM FORECAST		MEMORY
October 9, 1989	BUSY WEEK FOR INTEL	INTEL	CAPITAL EXPENDITURE
	BULL GRABS ZENITH BY THE HORNS		END USE
	BRIEFLY IN THE NEWS	VARIOUS	VARIOUS
	EQUIPMENT COMPANIES GO TO COURT		LITIGATION
	SPEC RELEASES FIRST BENCHMARK SUITE		SOFTWARE
	VITELIC AND OKI EXPAND RELATIONSHP	VITELIC	ALLIANCE
	PHILIPS INCREASES OWNERSHIP OF TSMC	PHILIPS	INVESTMENT
	EC CHIP RULES REVISITED		TRADE
	DQ PERSPECTIVE, US MEMORIES	US MEMORIES	MEMORY
October 16, 1989	US BOOK TO BILL DROPS TO 0.90		BOOK TO BILL
	FINANCIAL RESULTS, AMD	AMD	FINANCIALS
	FINANCIAL RESULTS, ALTERA	ALTERA	FINANCIALS
	FINANCIAL RESULTS, DALLAS SEMICONDUCTOR	DALLAS SEMICONDUCTOR	FINANCIALS
	SEEQ ALLIES WITH PHILIPS SIGNETICS	SEEQ	ALLIANCE
	MOSAIC ANNOUNCES FIRST FOUNDRY ARRANGEMENT	MOSAIC	FOUNDRY
	BRIEFLY IN THE NEWS	VARIOUS	VARIOUS
	EUROPEAN BOOK TO BILL DROPS TO 0.95	EUROPEAN	BOOK TO BILL
	IBM ENTERS THE LASER PRINTER MARKET		END USE
	CHIP SET DILEMMA, VOLUMES UP, REVENUES DOWN		MICRO
	US ELECTRONICS INDUSTRY TRADE FIGURES DO NOT INSPIRE OPTIMISM		TRADE
	NEWSLETTER HIGHLIGHTS ASIC TRENDS IN THE 1990S		ASIC
	DQ PERSPECTIVE, BOOK TO BILL REPORT		BOOK TO BILL
October 18, 1989	FINANCIAL RESULTS, ADAPTEC	ADAPTEC	FINANCIALS
	FINANICAL RESULTS, CALIFORNIA MICRO DEVICES	CALIFORNIA MICRO DEVICE	FINANCIALS
	FINANICAL RESULTS, CHIPS AND TECHNOLOGIES	CHIPS AND TECHNOLOGIES	FINANCIALS
	FINANCIAL RESULTS, CIRRUS LOGIC	CIRRUS LOGIC	FINANCIALS
	FINANCIAL RESULTS, CYPRESS	CYPRESS	FINANCIALS
	FINANCIAL RESULTS, IDT	IDT	FINANCIALS
	FINANCIAL RESULTS, INTEL	INTEL	FINANCIALS
	FINANCIAL RESULTS, LINEAR TECH	LINEAR TECH	FINANCIALS
	FINANCIAL RESULTS, SILICON GENERAL	SILICON GENERAL	FINANCIALS
	FINANCIAL RESULTS, TI	TI	FINANICALS
	FINANCIAL RESULTS, WEITEK	WEITEK	FINANICALS
	NATIONAL AND LINEAR SETTLE SUIT		LITIGATION
	NATIONAL ACQUIRES FERROELECTRIC START UP		MERGERS AND ACQUISITIONS

DATE	TITLE	COMPANY	SUBJECT
	NMB INVESTS IN NEW 4MBIT DRAM FAB		CAPITAL EXPENDITURE
	INTEL ALLIANCE WITH ALLIANT COMPUTERS	INTEL	ALLIANCE
	BULL AND NIXDORF IN 'RISC' DEAL WITH MIPS		ALLIANCE
	EXPERT SYSTEM CHIP IS MADE IN USA, FUNDED BY JAPAN		ALLIANCE
	CYPRESS, VITESSE AND WEITEK CONTRIBUTE TO NEW SOLBOURNE WORKSTATION		END USE
	ARE THERE DRAMS IN YOUR FUTURE?		MEMORY
	GOOD NEWS, DQ SURVEY SHOWS PICKUP IN COMPONENT ORDERS		PROCUREMENT
	DQ PERSPECTIVE, IN THE WAKE OF THE EARTHQUAKE		
October 30, 1989	FINANCIAL RESULTS, IMP		FINANCIALS
	FINANCIAL RESULTS, LAM	LAM	FINANCIALS
	FINANCIAL RESULTS, SEEQ	SEEQ	FINANCIALS
	FINANCIAL RESULTS, WESTERN DIGITAL	WESTERN DIGITAL	FINANCIALS
	FINANICAL RESULTS, SILICON VALLEY GROUP	SILICON VALLEY GROUP	FINANCIALS
	FINANCIAL RESULTS, VARIAN	VARIAN	FINANCIALS
	BUSINESS FAILURES DROP SHARPLY		INDICATOR
	80480 CHIP FIX	INTEL	MICRO
	INTEL ENTERS GENERAL PURPOSE PLD MARKET	INTEL	ASIC
	FAST PLD WILL SUPPORT LATEST CISC AND RISC MPUS	GAZELLE	ASIC
	SGS THOMSON EXPANDS RF AND MICROWAVE PORTFOLIO	SGS THOMSON	DISCRETE
	EUROPEAN DEFENSE INDUSTRY RESTRUCTURES		MILITARY
	DARPA AWARD AIMS AT HIGH DEFINITION DISPLAY WORKSTATIONS		MILITARY
	DQ PERSPECTIVE, US MEMORIES SITE SELECTION	US MEMORIES	MEMORY
November 6, 1989	FINANCIAL RESULTS, LSI LOGIC	LSI LOGIC	FINANCIALS
	FINANCIAL RESULTS, MAXIM	MAXIM	FINANCIALS
	FINANCIAL RESULTS, MOTOROLA	MOTOROLA	FINANCIALS
	NATIONAL ENTERS INTO MACINTOSH BOARD AGREEMENT	NATIONAL	ALLIANCE
	SEMATECH SIGNS EQUIPMENT IMPROVEMENT CONTRACT WITH LAM	SEMATECH	
	BRIEFLY IN THE NEWS......	VARIOUS	VARIOUS
	HITACHI DEVELOPS DIGITAL IC WITH NEURAL NETWORK	HITACHI	
	MITSUBISHI ANNOUNCES 3MB MEMORY CARD	MITSUBISHI	MEMORY
	TI JAPAN ENTERS AUTOMOTIVE PARTS MARKET	TI JAPAN	AUTOMOTIVE
	INMOS TO DEVELOP ASIC TRANSPUTER	INMOS	ASIC
	THE VIEW FROM DQ EUROPE		FORECAST
	DQ PERSPECTIVE, IBM AND MOTOROLA COLLABORATE ON XRAY LITHOGRAPHY		
November 13, 1989	BOOK TO BILL TURNS UP IN OCTOBER		BOOK TO BILL
	IBM LICENCES MICRON FOR 4MB DRAM	ALLIANCE	MEMORY
	MOTOROLA AND PHILIPS TO COOPERATE ON INTERACTIVE COMPACT DISC	MOTOROLA	ALLIANCE
	TI TO EXPAND OPERATIONS IN ITALY	TI	CAPITAL EXPENDITURE
	IIT AND INTEL ARGUE COMPATIBILITY		
	MOTOROLA ANNOUNCES DESIGN WIN AND NEW DRAM OFFERING	MOTOROLA	MEMORY
	CIRRUS OPENS JAPAN OPERATION	CIRRUS LOGIC	
	GOLDSTAR SIGNS AGREEMENTS WITH SUN AND ZYMOS	GOLDSTAR	ALLIANCE
	FUJITSU TO SECOND SOURCE VITESSE GAAS GATE ARRAYS	FUJITSU	ALLIANCE
	GAZELLE INTRODUCES GAAS SERIAL DATA LINK CHIPS	GAZELLE	
	SAY IT ISN'T SO, GEORGE!	SEMATECH	
	DQ PERSEPCTIVE, BOOK TO BILL REPORT		BOOK TO BILL

DATE	TITLE	COMPANY	SUBJECT
November 20, 1989	FINANCIAL RESULTS, LATTICE	LATTICE	FINANCIALS
	FINANCIAL RESULTS, LOGIC DEVICES	LOGIC DEVICES	FINANCIALS
	FINANCIAL RESULTS, UNITRODE CORP	UNITRODE	FINANCIALS
	FINANCIAL RESULTS, ZYMOS	ZYMOS	FINANCIALS
	BRIEFLY IN THE NEWS......	VARIOUS	VARIOUS
	MOTOROLA PROPOSES CSIC DESIGN METHODOLOGY	MOTOROLA	MICRO
	DATAQUEST PROVIDES SEMICONDUCTOR MARKET SHARE BY APPLICATION		END USE
	OKI OFFERS 4MB DRAMS IN VARIOUS PACKAGE TYPES	OKI	MEMORY
	SAMSUNG ANNOUNCES MASS PRODUCTION OF 4MB DRAMS IN EARLY 1990	SAMSUNG	MEMORY
	NEW GATE ARRAY SERIES FROM TOSHIBA	TOSHIBA	ASIC
	DATAQUEST SLASHES GATE ARRAY DESIGN START FORECAST		ASIC
	WEITEK AND TOSHIBA AGREE THAT FAST PROCESSORS NEED FAST PROCESSES	WEITEK	ALLIANCE
	GOULD AMI AND CRYSTAL GET TOGETHER	GOULD AMI	ALLIANCE
	FOUR-INCH WAFERS IMPROVE GAAS VLSI COSTS		GAAS
	TRADE GROUPS CALL FOR MORE EFFECTIVE ANTIDUMPING LAWS		TRADE
	JAPANESE TRADE MISSION TO TOUR US		TRADE
	SEMATECH ADDS TO CENTERS OF EXCELLENCE	SEMATECH	
	TI BEGINS COMPONENT PRODUCTION AT JINCHUN PLANT	TI	
	DQ PERSPECTIVE, ADMINISTRATION LOOKS CLOSELY AT FUNDING OF US TECHNOLOGY		
November 27, 1989	A SCHIZOPHRENIC DAY FOR TI STOCK	TI	
	CONSOLIDATION AT KLA	KLA	
	SEMI ADDS ITS SUPPORT TO NACS REPORT	SEMI	
	DQ PERSPECTIVE, TI AWARDED IC PATENT IN JAPAN		
December 4, 1989	US MEMORIES SITE SELECTION SHORT LIST MAY BE SHORTER	US MEMORIES	
	APPLIED MATERIALS BOASTS RECORD REVENUES FOR 1989	APPLIED MATERIALS	FINANCIALS
	POSSIBLE SALE OF PERKIN-ELMER SEMICONDUCTOR EQUIPMENT	PERKIN-ELMER	EQUIPMENT
	SPEC TO DEVELOP GAAS SPARC SPEC	SPEC	MICRO
	FEWER SEMICONDUCTOR JOBS IN SILICON VALLEY		EMPLOYMENT
	AEA PROJECTS INCREASE IN US ELECTRONICS TRADE		TRADE
	GROWING COMPETITION OVER 4MB DRAM PRICING		MEMORY
	HITACHI LAUNCES PROCUREMENT PROGRAM	HITACHI	TRADE
	MATSUSHITA SURVEYS TEXAS FOR PRODUCTION SITE	MATSUSHITA	END USE
	MHS LAUNCH FAST SRAMS	MHS	MEMORY
	ALCATEL EXERCISES OPTION TO BUY MITEC	ALCATEL	MERGERS AND ACQUISITIONS
	SOUTH KOREAN ELECTRONICS COMPANIES SLAPPED WITH EC DUTIES		TRADE
	DQ PERSPECTIVE, SIA SYMPOSIUM ON COMPETITIVENESS OF THE US ELECTRONICS INDUSTRY		
December 11, 1989	US MEMORIES SAYS SITE SELECTION NOT A "DONE DEAL"	US MEMORIES	
	INTEL, NEC LITIGATION LOOSE ENDS TIED UP	INTEL	LITIGATION
	AT&T MICROELECTRONICS AND XILINX INK AGREEMENT	AT&T	ALLIANCE
	STANDARD PLATFORM FROM RAPRO AN INDUSTRY FIRST		EQUIPMENT
	AGREEMENT BETWEEN SEMATECH, TSTI, CORD AND ACADEMIA FOCUSES ON MANUFACTURING	SEMATECH	ALLIANCE
	DOD DIRECTED TO COMMERCIALIZE PROCUREMENT		MILITARY
	INSIGHTS INTO LASER PRINTERS		END USE
	SAMSUNG SIGNS ON FOR INTERGRAPH CLIPPER	SAMSUNG	ALLIANCE
	CHIP ON BOARD BREAKTHROUGH FROM SHARP AND DEXTER	SHARP	ALLIANCE

DATE	TITLE	COMPANY	SUBJECT
	TOSHIBA LICENSES IR'S MOSFET TECHNOLOGY	TOSHIBA	ALLIANCE
	BURR-BROWN REDUCES HEADCOUNT	BURR-BROWN	LAYOFFS
	NIKON'S STEPPER SHIPMENTS SLOW DOWN		EQUIPMENT
	NKK LEAPFROGS TO 4MB DRAM MARKET	NKK	MEMORY
	SANYO BECOMES SOLE AGENT FOR MICRON IN JAPAN	SANYO	DISTRIBUTION
December 18, 1989	FINANCIAL RESULTS	INT'L CMOS TECHNOLOGY	FINANCIALS
	FINANCIAL RESULTS	MICRON TECHNOLOGY	FINANCIALS
	FINANCIAL RESULTS	NATIONAL SEMICONDUCTOR	FINANCIALS
	DESC IMPOSES SHIPPING HOLD ON UNITRODE--AGAIN	UNITRODE	
	TOSHIBA AND ICS PLAN EXTENSIVE ALLIANCE	TOSHIBA	ALLIANCE
	PLUS LOGIC AND RICOH SIGN AGREEMENT	PLUS LOGIC	ALLIANCE
	U.S. BOOK TO BILL REMAINS AT 0.93		
	1990 A CHALLENGING YEAR FOR SEMICONDUCTOR EQUIPMENT MAKERS		EQUIPMENT
	SEMATECH AWARDS CONTRACT TO SVG	SEMATECH	ALLIANCE
	DUPONT ACQUIRES EXPENDED PRESENCE IN PHOTOMASK INDUSTRY	DUPONT	MERGERS AND ACQUISITIONS
	NOVELLUS PRODUCT CATERS TO EIGHT-INCH WAFER MARKET	NOVELLUS	EQUIPMENT
	HITACHI INTRODUCES 34NS 1 MB SRAM	HITACHI	MEMORY
	PLETHORA OF PRODUCTS FROM MOTOROL'S MICRO GROUP	MOTOROLA	MICRO
	HARRIS FOCUSES ON JAPANESE MARKET	HARRIS	ALLIANCE
	MITSUBISHI ANNOUNCES FAST 4MB EPROM	MITSUBISHI	MEMORY
	TAIWAN EXPECTS FOUNDRY SUPPLY TO EXCEED DEMAND IN 1990		FOUNDRY
	DQ PERSPECTIVE, U.S. SEMICONDUCTOR INDUSTRY		
December 25, 1989	SEMATECH ANNOUNCES CONTRACTS WITH ORNL, KLA AND ORASIS	SEMATECH	
	TEXAS INSTRUMENTS AND TOPPAN TEAM UP IN PHOTOMASKS	TEXAS INSTRUMENTS	ALLIANCE
	US MEMORIES FINALIZES AGREEMENT WITH IBM	US MEMORIES	
	UNITRODE ACQUIRES ADDACON	UNITRODE	MERGERS AND ACQUISITIONS
	TOSHIBA OFFERS BRIGHTER VISIBLE-LIGHT EMITTING LASER DIODE	TOSHIBA	DISCRETES
	TOSHIBA TO INVEST IN INTEGRATED ASIC PRODUCTION IN THE US	TOSHIBA	CAPITAL EXPENDITURE
	MAJOR JAPANESE SEMICONDUCTOR COMPAIES INCREASE CAPITAL SPENDING		CAPITAL EXPENDITURE
	HITACHI REDUCES SIZE AND POWER CONSUMPTION OF 4MB DRAMS	HITACHI	MEMORY
	HMC TO BUILD $259 MILLION FAB IN MALAYSIA	HMC	CAPITAL EXPENDITURE
	US TRADE TIES TO TAIWAN AND SOUTH KOREA IMPORVE		TRADE

Semiconductor Equipment and Materials Service Newsletters 1990

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1990 SEMS Newsletters and Bulletins

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Capital Spending	Intel's Capital Spending To Remain Steady in 1990	January
Industry Issues	Japanese Consortia	January
Other Newsletters	Preliminary 1989 Worldwide Semiconductor Market Share Estimates: NEC And Toshiba Neck And Neck	January
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Other Newsletters	A Preview Of The 1990s	
Other Newsletters	First Quarter 1990 Worldwide Semiconductor Industry Outlook: Stabilization Is Around The Corner	February
Etch/Clean	Wet Processing Equipment Trends In Japan	February
Industry and Technology Trends	Will Sematech Spur Growth of the U.S. ECR Equipment Market?	February
Worldwide Fabs	The Fab Database Series—A Comparison of Worldwide Fabs, Capacities, and Wafer Sizes	February
Worldwide Fabs	Over There: Hitachi Goes Overseas	February
Capital Spending	Texas Instruments' Capital Spending: Innovative and Global	February
Manufacturing Productivity	Production Axiom: Semiconductor Companies Must Double Revenue Every Five Years Just To Stay Even	February
Worldwide Fabs	The Fab Database Series: Fab Boom in North America—48 New Fabs Going Into Production in 1990 and 1991	February
Etch/Clean	Reprocessing: A Technology On The CUSP	February
Worldwide Fabs	Sony Establishes Fab Roots In The U.S.	March

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Deposition	Deposition And Cluster Tool Equipment Trends In Japan	March
Diffusion/Implant	Ion Implant Equipment Trends In Japan	March
Industry Issues	Japanese DRAM Company Update	March
Worldwide Fabs	The Fab Database Series: Shifting To 200MM Wafers - The Turning Point Has Come	March
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Other Newsletters	A New Decade—Where Does Opportunity Lie?	April
Other Newsletters	Worldwide Semiconductor Industry Outlook, Second Quarter 1990: Out Of The Trough	April
Other Newsletters	Economic Outlook: In Like A Lamb, Out Like A Lion	April
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Worldwide Fabs	Vitelic To Manufacture Memory Chips In Hong Kong	April
Deposition	Applied Materials Enters The PVD Equipment Market	May
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R&D	Japanese And U.S. Semiconductor Company R&D Expenditures: Approximately Equal	May

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Other Newsletters	Capital Equipment Spending: Some 1990 Recession Protection	May
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Other Newsletters	Second Quarter 1990 Worldwide Semiconductor Industry Outlook: The Corner Is Turned Amid Mixed Signals	June
Other Newsletters	Dataquest's 1990 Electronics Industry Market Shares	June
Worldwide Fabs	Taiwan's Drive For Wafer Fabrication	June
Capital Spending	Taiwan And Korea: The Twin Pillars Of Capital Spending In Asia Pacific	June
Semiconductor Materials	GaAs Materials Revisited: The Shakeout Takes Its Toll	June
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Equipment Business Index	Operating Income and R&D Expenditures of US Semiconductor Equipment Companies	June
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Lithography	New Track Players And Technologies At SEMICON\West	July

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Deposition	1990 Epi Equipment Forecast Revised Downward	July
Industry and Technology Trends	IBM Adopts Islands of Cluster Automation In 16Mb DRAM Process	August
Semiconductor Materials	Shortage Of Silicon Ripples Through Global Market	August
Semiconductor Materials	Semiconductor Gas Shortage Attributable To Saddam Hussein	August
Deposition	Cluster Tool Equipment Market May Surpass $2.2 Billion By 1994	August
Equipment Database	US Wafer Fab Equipment Market Continues Its Downward Spiral	August
Forecast	Soft Business Conditions Prevail In The Wafer Fab Equipment Market	August
Capital Spending	Japanese Capital Spending Surges Into Offshore Fabs	August
Equipment Database	Equipment Technology Ownership In The 1990s: Japanese Equipment Companies Take The Lead	August
R & D	Turning R&D Into Productive Manufacturing Knowledge-A Tour Through Pilot Lines In Japan	August
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Deposition	US Companies Dominate The CVD Equipment Market	August
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Equipment Business Index	Quick Look At — Applied Materials	September
Etch/Clean	Japan Based Companies Gain Dry Etch Market Share	September
Semiconductor Manufacturing	Liquid Replacements: Point, Counterpoint	September
Industry and Technology Trends	Taiwan: The Benefits Of An Industrial Policy	September
Lithography	The Ayes Have It: I-Line Lithography In the 1990s	September
Etch/Clean	US Companies Dominate The Dry Etch Market, But Face New Challenges In the 1990s	September
Other Newsletters	Technology Stocks Fall To Bargain Basement Levels--So What?	September
Other Newsletters	Dataquest's Outlook for 1990 And 1991: Slowing But Positive Growth	September

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Semiconductor Factory Automation	New Engineering Analysis System At Harris Increases Yield and Time to Market	October
Semiconductor Materials	Energy Impact On Semiconductor Materials	October
Equipment Business Index	A Quick Look At -- Novellus	October
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Semiconductor Materials	Merchants View Epi Wafers As An Opportunity	October
Equipment Business Index	A Quick Look At -- Lam Research	October
Worldwide Fabs	A Modular Approach to Fab Flexibility	October
Lithography	Lithography Strategies: Pushing The Limits Optical Lithography	October
Process Control	New Products, New Entity in CD/Wafer Inspection	October
Other Newsletters	Quarterly Economic Outlook: Persian Gulf Crisis Adds To An Already Lackluster Economy	October
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Industry Issues	Technology Trends and Fab Costs: An Overview	November

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Equipment Business Index	A Quick Look At -- FSI International	November
Trade Shows	SEMICON/Japan 1990: A Strong Display of Submicron 8-Inch Process Technology	November
Other Newsletters	Dataquest Conference Looks To Decade of Opportunities	November
R & D	Motorola's New Advanced Technology Center	December
Industry Issues	DRAM Product Life Cycles - A View From The Industry	December
Lithography	Lithography Strategies: Pushing The Limits X-Ray Lithography	December
Lithography	Lithography Strategies: Pushing The Limits E-Beam Lithography	December
Equipment Business Index	A Quick Look At -- Intel	December
Semiconductor Materials	Japanese 200mm Market Poised To Grow	December
Deposition	The Thermal CVD Market Heats Up As Lam Research Unveils Its Integrity System	December
Process Control	CD SEM Equipment--Smaller Geometries Lead To Larger Market	December
Equipment Business Index	A Quick Look At -- KLA	December

Business Conditions

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Research Newsletter

BANKING POLICY CASTS SHADOW OVER CAPITAL SPENDING

As semiconductor equipment and material companies plan for 1991, they should take into consideration the potential downside impact of monetary policy on semiconductor capital spending. Japan and the United States, which together will account for approximately 70 percent of semiconductor capital spending in 1991, both are experiencing tighter money growth, albeit for different reasons.

Money supply growth (M3) in the United States during 1990 was an anemic 1.0 percent through August, down from an average 3.0 percent in 1989. In Japan, the decline in money growth is even more pronounced; money supply growth (M2 plus certificates of deposit) averaged 3.3 percent for the second quarter of 1990, down from an average of 9.9 percent in 1989 and a whopping 11.2 percent in 1988.

OUTLOOK IN THE UNITED STATES

Perhaps the single most important issue impacting the Federal Reserve's monetary stance is the looming budget deficit. There are indications that the Federal Reserve is loosening the monetary reins in response to the congressional budget agreement. Congress is targeting a $500 billion reduction over five years. In fiscal year 1991, the budget calls for the deficit to be reduced by $40 billion (really $34 billion when accounting for the expenditures on the Middle East troop deployment).

US semiconductor manufacturers are currently evaluating their investment plans for 1991. The looming budget deficit is forecast to grow to $250 billion this year—conceivably $300 billion if the economy sinks into a recession. Dataquest believes that the success of the budget agreement is the single most important factor impacting capital investment decisions for 1991.

Yet the underlying assumptions built into the budget (see Table 1) are expected to make semiconductor manufacturers uneasy. Of the $500 billion in savings over five years, $70 billion is forecast to accrue as the federal government's debt service declines because of lower rates paid on treasury notes. But in today's economic environment, it is difficult to believe the government's 4.2 percent forecast on 90-day treasury bill rates in 1995.

The oil price assumptions appear to discount the gravity of the Persian Gulf crisis. The average price for 1990 is estimated to be $21 a barrel. This price will increase to $24 a barrel in 1991 and then fall back to $21 a barrel in 1992.

In the wake of the budget agreement, the Federal Reserve appears to have changed monetary policy. The discount rate paid by member banks is trending lower. Yet the Federal Reserve's loosening of monetary policy may be short-lived if the assumptions built into the budget are overly optimistic. Indeed, the very real possibility exists that the deficit-reducing budget will turn into a deficit-increasing budget. If the agreement fails to lower the deficit, the Federal Reserve is expected to return quickly to a tighter monetary policy.

Compounding this problem is the risk that foreign investors will abandon US credit markets. The drop in exchange value is happening partly because foreigners no longer are buying

TABLE 1
Congressional Budget Assumptions

	1990	1991	1992	1993	1994	1995
Inflation (%)	5.2	4.6	3.4	3.2	3.0	2.8
Interest Rate (%) (90-Day Treasury)	7.7	7.2	5.7	4.9	4.4	4.2

Source: Dataquest (November 1990)

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US treasury bonds to the same extent as in previous years. This problem is daunting for the United States Treasury, which must finance a $250 billion to $300 billion deficit. A tight monetary policy resulting in higher interest rates would help attract more capital because interest rates will be more competitive with international rates.

The Federal Reserve faces some tough decisions next year. Alan Greenspan would like to bring domestic rates lower to stimulate the stalled economy. But without a credible trimming of the federal budget deficit, such an action would drive away foreign investors and aggravate inflation if the economy remains stalled. In such a climate, semiconductor capital spending programs are expected to experience pressure because of economic uncertainty and the high cost of funds.

OUTLOOK IN JAPAN

Japanese industry, including semiconductor manufacturing, has had three years of very strong capital spending growth. When compared with recent post-World War II periods, capital investment as a percentage of real GNP reached record levels: in 1989, investment accounted for 23.5 percent of real GNP.

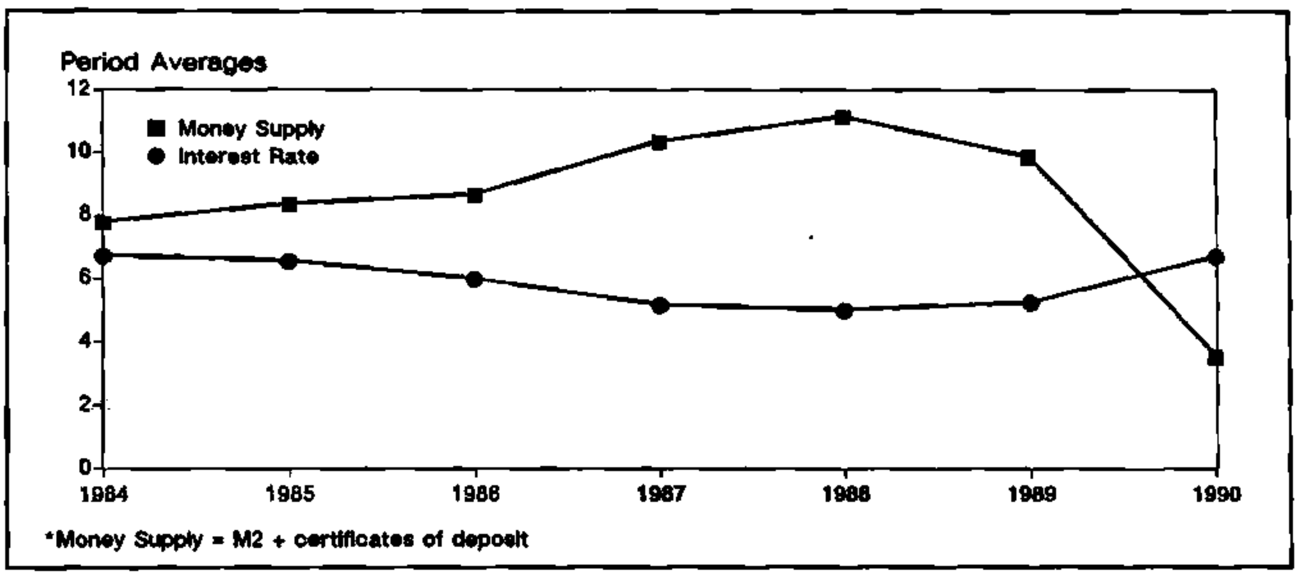
This growth in capital investment was fueled by a massive growth in Japan's money supply, which peaked in 1988 at just over 11 percent, and a decline in interest rates, which fell to 5 percent (see Figure 1). During that same period—1987 to 1989—capital spending in the semiconductor industry exploded, with yearly growth rates peaking in 1988 at 90 percent.

Three years of very strong growth in the money supply fueled capital spending and led to spiraling price appreciations in the domestic equity and real estate markets. Yasushi Mieno, the newly appointed governor of the Bank of Japan, has applied a brake to monetary policy in an effort to curtail inflation. With a tighter monetary policy and rising interest rates, the Japanese stock market has tumbled. The decline in the stock market, approximately 35 percent since the beginning of the year, has eroded the capital base of Japanese banks, limiting their ability to lend.

The liquidity crunch has broad implications. Capital investments that could be justified when interest rates were at 5 percent may be more difficult when rates are bumping 7 percent. Consequently, Japanese companies are expected to weigh each new investment more carefully.

Semiconductor manufacturers that are investing up to $300 million in each new front-end DRAM facility are certainly wrestling with return on capital issues. Profitability for such projects is being squeezed not only by a tighter monetary policy but also by low prices for DRAMs and what Dataquest suspects is a growing excess production capacity.

FIGURE 1
Tracking the Japanese Economy
Monetary Indexes (Period Averages)



Source: *Economic Eye*, Vol. II No. 3

Japanese semiconductor manufacturers are well known for investing throughout economic down cycles. During the 1986 downturn, Toshiba continued to invest in the 1Mb DRAM, giving it the leadership position. This lesson is readily recognized by Japanese DRAM manufacturers. Yet the risks associated with maintaining an aggressive level of capital investment are significantly higher today.

The investment required for 4Mb and 16Mb DRAM facilities is skyrocketing. If the current world recession is more severe than expected, or if the production currently being put in place results in serious excess capacity, these investments in leading-edge facilities could be catastrophic. Some of the smaller manufacturers may in fact be betting the company by pursuing their capital spending programs.

It is more likely that the Bank of Japan's tight monetary policy will act as a brake on Japanese industry. Capital spending also will be jeopardized by weakening export markets, which appear to be teetering on the edge of recession.

Even so, the five largest Japanese semiconductor companies are expected to forge ahead with their capital spending programs. They have strong balance sheets and will fund most of their own capital spending. In addition, they have a large captive requirement for DRAMs, which will insulate them from the demand and price vicissitudes of the merchant market.

It is the second-tier companies that will find it difficult to match the investment level sustained over the last three years. They rely much more heavily on the debt/equity markets and will find it more difficult to justify projects because of the cost of capital. Consequently, the strong growth in capital spending by Japanese semiconductor manufacturers during the last three years is not expected to be matched in 1991. (SEMMS will soon publish a newsletter with the capital spending forecast.)

DATAQUEST CONCLUSIONS

Dataquest believes that the current economic climate in both Japan and the United States suggests that the Federal Reserve and the Bank of Japan may pursue a tight monetary policy. In addition, if there is an increase in oil prices because of an outbreak of war in the Persian Gulf, inflationary pressures in both countries are expected to accelerate, further pressuring the central banks to tighten monetary policy. Such a policy, if adhered to over the next six months, is expected to dampen growth in semiconductor capital spending in 1991.

Mark FitzGerald

Dataquest

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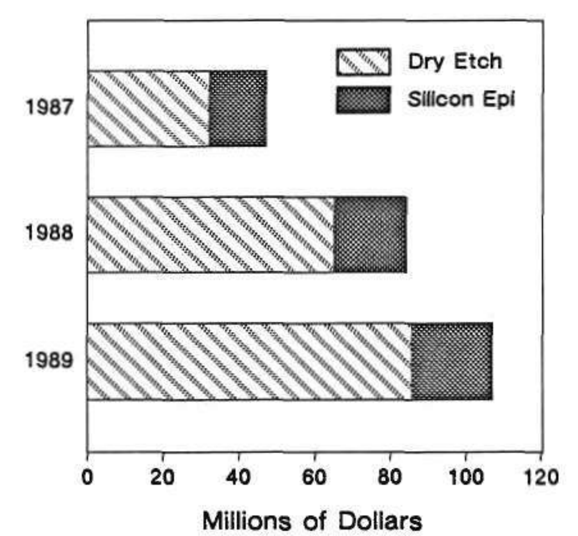
Research Bulletin

LAM RESEARCH EXITS SILICON EPI BUSINESS

Lam Research has announced plans to phase out the production of its Gemini silicon epitaxy systems, which include the Tetron system. The phaseout will result in an extraordinary charge to earnings in the fourth fiscal quarter. Gemini systems accounted for 19 percent of Lam's equipment sales (not including spares and service) in 1989 (see Figure 1).

Lam is the second-largest silicon epi equipment vendor in the world. Dataquest estimates that Lam's installed base of reactors is 235 worldwide. Only Applied Materials is larger, with over 1,000 reactors installed worldwide.

FIGURE 1
Lam Research Sales by Product Line



Note: Excludes spares and service.

Source: Dataquest (July 1990)

ANALYSIS

In the long term, Lam's decision will enable it to focus resources on its etch and new CVD products. Strategically, this decision appears to be sound because the silicon epi equipment market is very small relative to the dry etch and CVD markets (see Figure 2). In addition, both the CVD and dry etch markets are growing quickly, whereas the epi market is very cyclic and difficult to plan for from year to year.

Lam also was faced with the possibility that its current epi reactors did not target the growth segments of the epi market. In order to meet future requirements for low-particulate thin-film CMOS epi applications, Lam needed to invest heavily in R&D. Dataquest believes that Lam saw little opportunity to earn a return on this investment because of the size of the market and competitive factors.

In the short term, Lam's 1990 sales of new epi reactors declined considerably from 1989 levels. Faced with a loss in the operation of the Gemini Division, we believe that Lam management decided that it was better to cut the company's losses and take the write-down in fiscal 1990 rather than defer it for a year.

In addition, Dataquest anticipates that as Lam's introduction of the Integrity system—the new CVD reactor—moves closer, it is requiring more resources within the company. The Gemini Division closure should permit Lam to ramp up the production of the Integrity system without adding staff.

DATAQUEST CONCLUSIONS

Dataquest believes that the Gemini Division will be sold and that three companies are well-positioned to acquire its assets. ASM Epitaxy in

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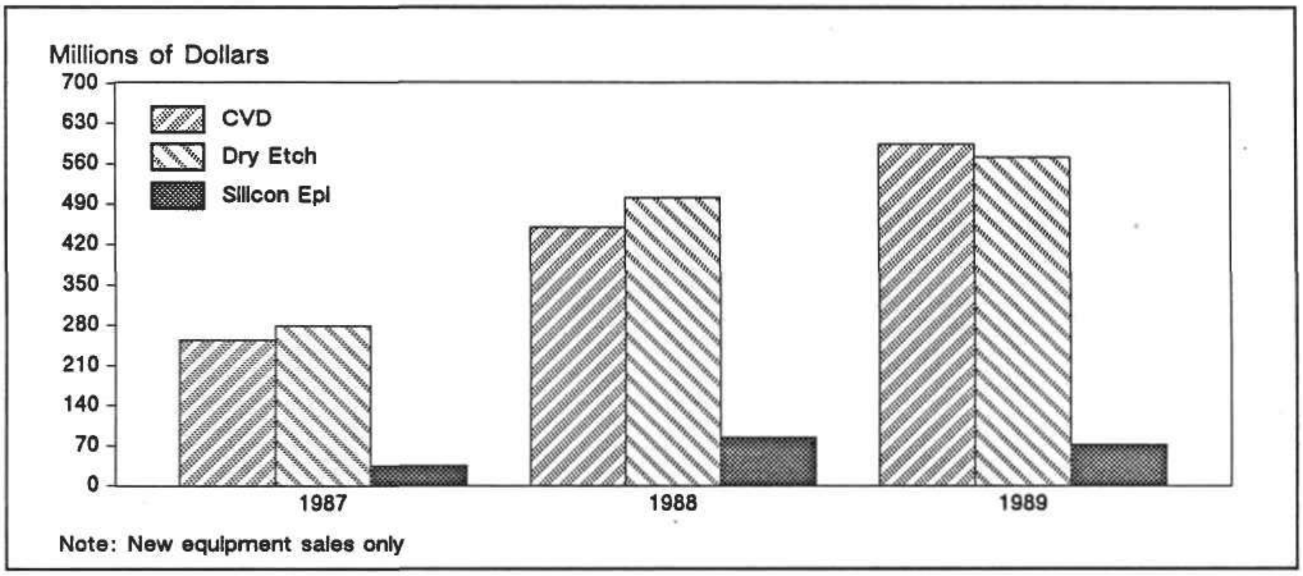
FIGURE 2
Worldwide Sales of Process Equipment by Technology



Source: Dataquest (July 1990)

Phoenix, Arizona, might pick up the Gemini product line in order to add a batch reactor line to its product offerings and increase its market share. Sitesa SA, a Europe-based company, may possibly be interested in the Gemini product because the installed base of reactors would offer it an opportunity to enter the US market. And finally, Concept System Designs, a San Jose, California, company that sells an upgrade kit for Gemini I systems, could use the product line to backward-integrate its product offering.

Dataquest does not believe that Lam's decision will have any material impact on the installed base of reactors. Lam intends to continue servicing the systems after the September closing of the Gemini Division. Moreover, if Lam sells the division, then it is likely that service contracts will be picked up by the new owner. Until the Gemini Division's fate is decided, Dataquest believes that Applied Materials, Lam's biggest competitor, will benefit most in the marketplace.

Mark FitzGerald

Capital Spending

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Research Newsletter

JAPANESE CAPITAL SPENDING SURGES INTO OFFSHORE FABS

Offshore capital spending by Japanese semiconductor manufacturers will double in 1990 and reach flood-tide levels in 1991. In 1989, Japanese offshore spending was over $400 million, and it should increase to $1 billion in 1990 to approximately $1.7 billion in 1991 (see Table 1). More and more of this surge of semiconductor capital will go into Europe because of the integration of the European Community (EC) countries into a unified market in 1992 and the recent upheavals in the political and economic landscape of Eastern Europe.

IMPORTANCE TO EQUIPMENT VENDORS

In 1990, Japanese companies should spend approximately 20 percent or $1 billion of their total semiconductor capital expenditures offshore. All Asia/Pacific semiconductor companies combined as well as all European semiconductor companies combined are likely to spend $1 billion offshore. Japanese offshore capital spending is a huge market in itself.

Because of the amount of offshore spending by Japanese semiconductor companies, US and European equipment vendors that rely on the their home region for their primary market will find themselves increasingly boxed in. For example, vendors that have relied on the United Stated as their home market already have felt squeezed as the US region declined in relative importance as a center of worldwide semiconductor production. In 1985, the US region as a whole represented 37 percent of the world's front-end equipment market. By 1989, the United States had declined in importance—representing only 29 percent of the total world market for front-end equipment.

TABLE 1
Actual and Forecast Offshore Japanese Capital Spending (Millions of Dollars)

	1989	1990	1991
Total Offshore	439	998	1,675
Percent in United States	93	62	54
Percent in Europe	7	38	46

Source: Dataquest (August 1990)

However, the relative decline of the United States as a production center is not the only dark cloud for US equipment vendors that rely on their home market as their primary base. Because of the growth of Japanese capital spending in the United States, less of this declining market will be available to those companies that cannot sell to Japanese semiconductor manufacturers.

One additional shadow darkens the US home market. Japanese equipment companies will use the presence of Japanese semiconductor companies as a protected perimeter from which they can set up overseas service capability. Once equipment companies have established these overseas service capabilities, they will be in a much better position to serve that regional market and therefore target more effectively the traditional market for US and European equipment vendors—the US and European semiconductor manufacturers.

PUSH TOWARD OFFSHORE DRAMs

A common pattern for many Japanese companies is to start by building an ASIC facility and then quickly announcing that they soon will be building a DRAM facility at the same location. This pattern was used by Fujitsu, for example, at its Gresham, Oregon, facility.

NEC was the first Japanese semiconductor company to set up fabrication facilities outside of Japan. NEC has fully operational DRAM fabs in Roseville, California, and Livingston, Scotland.

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TABLE 2
Existing and Planned Japanese Offshore Fabs to 1992

Company	Location	First Year of Operation
Fujitsu	Gresham, Oregon	1989
	Newton-Aycliffe, England	1990
Hitachi	Irving, Texas	1989
	Landshut, Germany	1992
Mitsubishi	Durham, North Carolina	1989
NEC	Roseville, California	1987
	Livingston, Scotland	1989
NMB	California	1992
Oki	Tualatin, Oregon	1990
Sony	San Antonio, Texas	1990
Toshiba	Portland, Oregon	1992

Source: Dataquest (August 1990)

The company reports that its Roseville facility's yields have been equal to and occasionally have surpassed the yields of its sister facility in Japan. NEC now is building an additional line for 4Mb DRAMs at its Roseville fab. Evidently, manufacturing overseas has been a good experience for NEC. Indeed, the company recently announced that 50 percent of its products sold in the United States will be produced there.

Japanese companies are building fabs offshore because they want to be close to their markets in order to avoid trade friction and trade barriers. Japanese fabs in the United States, for example, are not subject to foreign market value (FMV) pricing. This fact could be important if Japanese manufacturers believe that they could be forced into a price war with South Korean and other DRAM manufacturers in the future. It is noteworthy that six of the seven companies that have announced offshore fabs are DRAM manufacturers.

Japanese companies that currently have built or will be building fabs in the United States or Europe in 1990 or 1991 include Fujitsu, Hitachi, Mitsubishi, NEC, NMB, Oki, Sony, and Toshiba (see Table 2).

DATAQUEST CONCLUSIONS

Dataquest sees that Japanese semiconductor manufacturers are in the process of establishing substantial manufacturing presence in the United States and Europe. Indeed, due to the 1992 effect and the opening up of Eastern Europe, it is possible that Japanese companies will be spending more in Europe by 1992 and 1993 than in the United States. Beneficiaries of this offshore movement will be those vendors that already have established a relationship with Japanese manufacturers and that have worldwide support capability. Equipment vendors that have relied on home markets will find that not only are those markets boxed in by the expansion of Japanese semiconductor manufacturers, but that Japanese equipment vendors will be using their existing relationships with Japanese semiconductor manufacturers as safe havens from which to develop the service infrastructure to support equipment sales to non-Japanese semiconductor manufacturers. Increasingly in the semiconductor industry, the race will go not to the swift and the strong, but to the swift, the strong, and the global.

George Burns

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Research *Bulletin*

TAIWAN AND SOUTH KOREA: THE TWIN PILLARS OF ASIA/PACIFIC CAPITAL SPENDING

1990 CAPITAL SPENDING PLANS

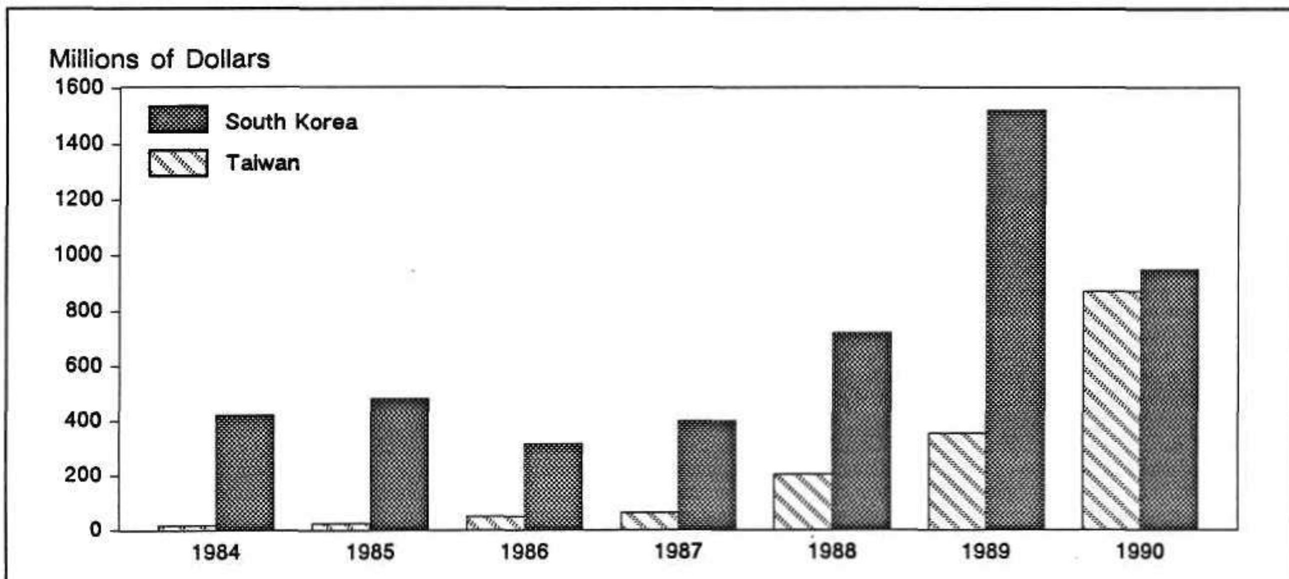
Taiwan and South Korea each will expend approximately $900 million in semiconductor capital spending in 1990. Each represents a market for capital equipment that is even larger than that of the largest semiconductor company in the world. Moreover, because capital spending leads to production, both Taiwan and South Korea are in the process of adding capacity equivalent to the largest semiconductor company in the world.

Capital spending in Taiwan and South Korea for the 1984 to 1990 period is shown in Figure 1. Spending in both countries accounts for 95 percent of all capital spending in the Asia/Pacific region.

Dataquest projects that spending in Taiwan will increase 146 percent in 1990; however, we believe that South Korean capital spending will decline by 38 percent in 1990. The large decline in capital spending in South Korea is due to the deceleration of spending by both Goldstar and Hyundai. The combined spending levels by these companies are slightly less than one-half of their 1989 levels.

Dataquest believes that Samsung also has cut back its spending plans for 1990, but much more moderately than Goldstar and Hyundai. We expect Samsung to cut its level of spending from $557 million in 1989 to $443 million in 1990. However, these three major South Korean semiconductor companies all plan to finish construction of

Figure 1
Semiconductor Capital Expenditure in South Korea and Taiwan



Source: Dataquest (June 1990)

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4Mb fabs in 1991. We therefore expect capital spending in South Korea to resume its upward trend in 1991.

Capital spending in Taiwan during 1990 will be four times its 1988 level. Spending in Taiwan is lead by TI/Acer, which is building a DRAM facility in Taiwan. The list of other companies building new fabs in Taiwan is very long and includes Holtek, Hualon, Macronix, MOSel, Taiwan Semiconductor Manufacturing Company (TSMC), United Microelectronics Corporation (UMC), Utic, Vitelic, and Winbond (see the SEMS research newsletter entitled "Taiwan's Drive for Wafer Fabrication" dated June 1990).

TSMC's newly completed fab is the world's first that is fully equipped with SMIF technology. As such, it will be watched closely by semiconductor manufacturers all over the world. TSMC also caught the semiconductor world's attention by announcing that it will manufacture 256K and 1Mb DRAMs this year and distribute them through Intel's distribution channels. That is not all the DRAM activity in Taiwan: Taiwan also is home to an emerging DRAM consortium, which currently is researching 4Mb and 16Mb DRAM technology.

Because of all of this activity, we expect capital spending in Taiwan to continue to grow at an aggressive rate for at least two years.

DATAQUEST CONCLUSIONS

Dataquest believes that the continuing emergence of South Korea and Taiwan as centers of semiconductor manufacturing has several major implications. The semiconductor industry is becoming more competitive. US semiconductor manufacturers engaged Japanese producers in major competitive battles during the 1980s. Japanese companies already have felt pressure from Korean companies in DRAM competition, and it is likely that, with all the DRAM effort in Taiwan, DRAM suppliers worldwide soon will feel Taiwan's heat.

Asia/Pacific is now a major market for semiconductor capital equipment, which creates a challenge as well as an opportunity: South Korean and Taiwanese semiconductor manufacturers have told Dataquest that after-sales support of wafer fab equipment from certain companies seems to be from a million miles away. Equipment and materials vendors must realize that South Korea and Taiwan are no longer marginal markets located in the hinterlands. Equipment and materials vendors will have to be able to service these areas if they hope to be competitive in the truly global arena of today's semiconductor industry.

A final observation—it is interesting to note that Taiwan is the location for the world's first fab that is fully equipped with SMIF technology. SMIF is a truly innovative approach to the clean room of the future and has the potential to revolutionize semiconductor manufacturing (see the SEMS research newsletter entitled "The Oasis Project" dated August 1988). Perhaps Asia/Pacific can be regarded as a "start-up" region because it is performing a service to the industry analogous to start-up companies: it is a focus of innovation for the industry because it is willing to try options that established companies and regions are not.

George Burns

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MOTOROLA'S CAPITAL SPENDING

Motorola is the largest U.S. merchant semiconductor manufacturer. It has plants worldwide, including locations in Europe, Japan, and Southeast Asia. Motorola manufactures DRAMs, ASICs, and MPUs, and thus is in the forefront of manufacturing technology. It is also one of the largest capital spenders in the world. To be an equipment vendor for Motorola, a company must have advanced process capability on a worldwide scale.

In 1989, more than $540 million (16 percent of the company's revenue) was allocated to semiconductor capital spending. We expect this figure to exceed $600 ~~b~~illion in 1990.

FAB FACILITIES

The focus of 1989's spending was on MOS 11, Motorola's new 4Mb DRAM facility in Oak Hill, Texas. MOS 11 is expected to be completed by the end of 1990 and go into production by mid-1991; estimated cost of the facility and equipment is $500 million. It and MOS 9 at East Kilbride, Scotland, will be the major fabrication centers for the company's 4Mb DRAMs. Oak Hill probably also will produce 16Mb DRAMs.

Although MOS 11 initially will run 4Mb DRAMs, it eventually will run other, more mature memory and microprocessor product lines. This combination is an example of a trend that Dataquest has long noted: Modern semiconductor manufacturers extend the life of a fab by planning a stream of products throughout the fab's lifetime. Typically, leading-edge products are built at the beginning of a fab's life, and more mature product lines as the fab ages.

FUTURE FACILITIES

Future sites for advanced DRAM production, other than MOS 11 and MOS 9, are now purely speculative. One possible future site is Japan: Motorola presently has two fabs in Fukushima, Japan, and a joint venture facility with Toshiba (Tohoku Semiconductor) at Sendai, Japan. There is room at the Sendai campus for a Motorola fab, and since the joint venture with Toshiba has been a source for Motorola's DRAM process, it is possible that Motorola's next major DRAM investment will be near this facility. Motorola already plans to begin construction of a new assembly facility in Sendai this year. Motorola expects the cost of this facility to be approximately $50 million. Completion is expected in the spring of 1991. The new plant will focus on assembly of both high-capacity memory devices and midrange and high-end microcontroller devices.

For equipment vendors, such investments in Japan underscore the importance of participation in the Japanese equipment market. In order to support a worldwide player like Motorola, equipment companies must be able to provide sales and service support anywhere in the world, including Japan.

In addition to MOS 11, Motorola's 1990 capital spending focus will include Bipolar 6 in Chandler, Arizona; Silicon Harbor in Hong Kong; and a new assembly facility in Sendai. Bipolar 6 is Motorola's new ASIC production and R&D facility. The company believes that Bipolar 6 is the first of its kind for an ASIC development facility, because it will be able to take devices from R&D to pilot to manufacturing, all within the same facility. It is specifically designed for small lots and for quick turns. Motorola estimates the cost of the new facility to be $325 million. Occupancy of the office and support portions of the building probably will be in August of this year, and initial wafer production is planned for the first quarter of 1991.

Motorola also expects to complete Silicon Harbor by the end of 1990. Silicon Harbor is a 300,000-square-foot facility that will house

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Motorola's Asia/Pacific headquarters, an advanced ASIC design center, and an assembly/test center.

DATAQUEST CONCLUSIONS

Motorola's future capital spending levels probably will continue to exceed $500 ~~b~~illion. It is possible that this spending level could fall back or

million

pause for one year when the company completes MOS 11. However, by 1992, Motorola will have to start building for the next generation of DRAMs. Major semiconductor companies have no choice but to keep spending in order to maintain their positions as broadbased advanced technology vendors.

George Burns

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Research *Newsletter*

TEXAS INSTRUMENTS' CAPITAL SPENDING: INNOVATIVE AND GLOBAL

Texas Instruments (TI) has one of the world's biggest semiconductor capital spending plans for 1990, and it will finance this plan in innovative ways. TI, a U.S. company, will spend a large portion of its capital spending funds outside of the United States. Texas Instruments is an example, par excellence, of a company that has embraced the globalization of manufacturing, and this newsletter examines how it has done that.

FINANCING FABS: SHARE THE BURDEN

Texas Instruments plans to double the number of its submicron CMOS memory and advanced logic fabs by 1991. To do this, it plans to spend about $780 million of its own money on semiconductor property, plant, and equipment (PPE) in 1990. This amount is not all that TI will spend on semiconductor PPE in 1990, however; TI is able to obtain funding from others such as its customers, local governments, and joint-venture partners. Counting others' money, Dataquest estimates that TI will spend approximately $1 billion on semiconductor PPE this year—more than any other company in the world.

For example, the company's new DRAM facility under construction in Avenzanno, Italy, at a reported cost of $250 million, is funded in part by its customers and in part by local European governments. Some of TI's DRAM customers (the exact list is highly proprietary) pay for their devices in advance with the understanding that these funds will be used for building DRAM capacity. Local governments in Europe have financed a large fraction of the Avenzanno facility in order to bolster the local economy.

The TI/ACER joint venture in Taiwan is another example of TI's innovation in financing expensive state-of-the-art facilities. This fab will cost $250 million also and will produce 4Mb DRAMs. Under the joint-venture agreement with ACER, ACER will provide most of the funding for the facility and TI will provide the technology. Output from the fab will be sold exclusively to TI, and TI, in turn, will guarantee up to 50 percent of the output to ACER.

CAPITAL SPENDING: A GLOBAL SCOPE

Although TI is a U.S.-based company, a large fraction of its production and capital spending takes place outside of the United States. Table 1 lists the locations and status of the company's submicron CMOS memory and advanced logic fabs. Only one of the six locations is in the United States.

In order to maintain its competitive position in memory and advanced logic, TI has had to aggressively expand its company-funded capital spending in recent years. Its spending level rose 65 percent in 1989 over 1988, increasing from $388 million to $641 million (see Table 2 and Figure 1). TI plans to increase its company-funded capital spending a further 22 percent in 1990, to $780 million. As TI has increased its company-funded spending, its ratio of capital spending to revenue has increased and now exceeds the U.S. semiconductor industry average (see Figure 1).

VIRTUAL INTEGRATION: A NEW ALTERNATIVE?

The cost of advanced semiconductor manufacturing has become truly staggering—and it will become more so in the future. Companies need to be large and need to have help to carry this

SEMS Newsletters Capital Spending

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burden; most of today's leading DRAM manufacturers are part of large vertically integrated electronics companies that have had the help of government policies designed to nurture advanced semiconductor manufacturing. TI's innovative financing is global in scope and integrates the contributions of customers, governments, and joint-venture partners. Perhaps it is an alternative to the models that have been so successful for European, Japanese, and South Korean manufacturers, as well as an alternative to the recently demised unsuccessful U.S. model: U.S. Memories.

George Burns

TABLE 1
Texas Instruments' Submicron CMOS Memory and Advanced Logic Fabs

Location	Product Type	Status
Avenzanno, Italy	4Mb DRAM	Under construction
Frising, West Germany	Advanced logic	Upgrading
Miho, Japan	4Mb DRAM	Upgrading
Hiji, Japan	4Mb DRAM	Upgrading
Dallas, Texas	4Mb DRAM, advanced logic	Upgrading
Taiwan	4Mb DRAM	Under construction

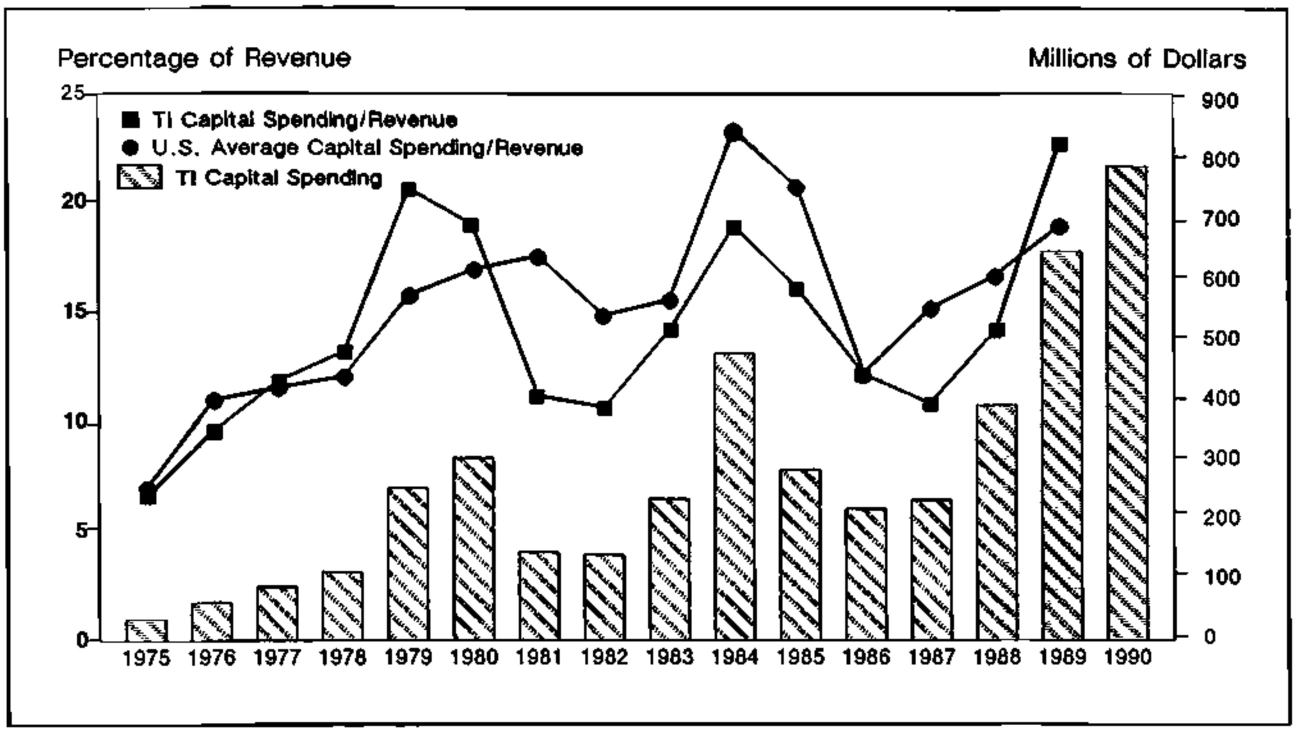
Source: Dataquest
February 1990

TABLE 2
Texas Instruments' Worldwide Capital Spending (Millions of Dollars)

Year	Expenditure	Year	Expenditure
1975	35	1983	232
1976	62	1984	472
1977	88	1985	281
1978	122	1986	217
1979	251	1987	231
1980	300	1988	388
1981	145	1989	641
1982	140	1990	780

Source: Dataquest
February 1990

FIGURE 1
Texas Instruments' Worldwide Semiconductor Capital Spending



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Source: Dataquest
February 1990

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Research *Bulletin*

INTEL'S CAPITAL SPENDING TO REMAIN STEADY IN 1990

SUMMARY

Intel semiconductor capital spending is expected to increase 17 percent in 1990. Dataquest estimates that Intel will spend $425 million on semiconductor investments (see Table 1) and $76 million on capital investments for its systems business in 1990.

Intel's ratio of capital spending to revenue generally has exceeded the U.S. industry's average since 1975. In 1989, however, the U.S. industry's ratio of capital spending to revenue exceeded Intel's (see Figure 1).

One of Intel's top priorities in its capital spending is its new submicron R&D facility, D2, in Santa Clara, California. Intel plans to study and develop three phases of technology simultaneously at D2; the phases are current process technology, the next generation of process technology, and beyond next-generation technology. Intel has spent $100 million for facilities and the first phase of equipment for D2 and believes that D2 is crucial to its goal of becoming one of the world leaders in semiconductor manufacturing technology.

Intel also plans to invest more than $400 million over 10 years to construct a facility on a 55-acre site in Leixlip, County Kildare, near Dublin in Ireland. This facility will be constructed in three phases. Phase 1 will be a computer systems plant, which Intel expects to operational by the end of 1990. Phase 2 will be a semiconductor fab; the company has not yet announced when construction of this new fab will begin. Dataquest believes that construction will begin by early 1991. Phase 3 will include an assembly and test facility.

Intel is continuing to equip Fab 9.1 in Albuquerque, New Mexico, in the United States, and has begun moving equipment into Fab 9.2, which also is located in Albuquerque. Dataquest believes that Intel's microprocessor fabs in Albuquerque and in Jerusalem, Israel, are operating at near-capacity levels and that Fab 9.2 is likely to come on-line in 1990.

TABLE 1
Estimated Intel Semiconductor Capital Spending (Millions of Dollars and Percentage of Revenue)

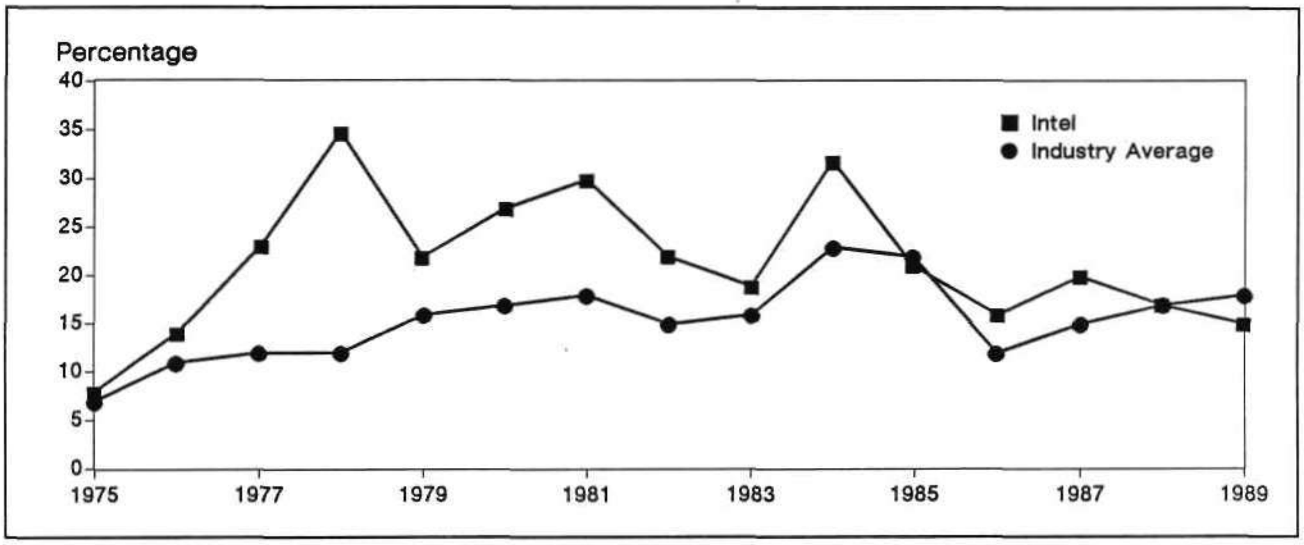
	1975	1976	1977	1978	1979	1980	1981	1982
Capital Spending	$11	$32	$46	$104	$97	$156	$157	$138
Capital Spending as a Percentage of Revenue	8%	14%	23%	35%	22%	27%	30%	22%
	1983	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Capital Spending	$146	$388	$214	$155	$302	$405	$363	$425
Capital Spending as a Percentage of Revenue	19%	32%	21%	16%	20%	17%	17%	15%

Source: Dataquest
January 1990

SEMS Newsletters 1990-2

0006269

FIGURE 1
Semiconductor Capital Spending as a Percentage of Semiconductor Revenue



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Source: Dataquest
January 1990

DATAQUEST CONCLUSIONS

Dataquest believes that Intel will maintain its current level of capital spending through 1990. However, capacity pressures at its microprocessor facilities, adding advanced equipment at D2, and building its fab in Ireland, in addition to test and assembly expenditure and normal equipment upgrades, all are likely to push Intel well into the $500 million range for semiconductor spending in 1991 and 1992.

George Burns

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Research Newsletter

AMD'S NEW SUBMICRON DEVELOPMENT CENTER

Advanced Micro Devices (AMD) began processing silicon wafers at its new Submicron Development Center (SDC) in the fall of 1990. The SDC is important because it represents AMD's manufacturing future for the next decade. It is also representative of the new thrust by US semiconductor manufacturers to make semiconductor development more efficient and compatible with manufacturing processes.

The SDC is one of the most advanced R&D lines in the world. It is a very innovative facility that has inspired innovative changes in the organization of clean room personnel. The SDC was designed and built with the collaboration of Dr. Ohmi of Tohoku University in Japan; thus, it represents a degree of cooperation between the Japanese and US industries that has been all too rare.

AN ALTERNATIVE VISION OF DEVELOPMENT AND PRODUCTION

The AMD approach to development at SDC is a very different approach than is the rule in Japan. (See the August 1990 SEMMS newsletter, entitled "Turning R&D into Productive Manufacturing Knowledge—A Tour through Pilot Lines in Japan.")

Rather than develop a process on a separate development line and then transfer the process to a production line, as many Japanese manufacturers do, the SDC approach is to combine both development and production onto one line. Of the 3,000-wafer-start capacity per week for which the SDC was designed, only 2,400 will be product wafers. The other 600 will be R&D wafers. The SDC is thus both an R&D facility and a production line.

AMD admits that having both production and development on the same line will add a level of complexity to both development and production, but the company emphasizes that it will also add a level of synergy that has been lacking between development and production. Manufacturing and process engineers will work in the same facility as development engineers, and they will use the same equipment. AMD believes that the close proximity of the production and development engineers will facilitate the exchange of ideas and concerns between people working in the two different areas.

Manufacturability, therefore, will be an integral part of all stages of the developmental cycle. This means a shorter development cycle, a faster time to market for new products, fewer defects once products reach production, and much higher quality.

The relationship between process engineers and development engineers is not the only thing that is different at SDC. In order to enhance flexibility, AMD has eliminated its operators. What were once operators are now wafer fab and manufacturing technicians with much more responsibility than the old-style operators. In addition to moving wafers, these new responsibilities include statistical process control, routine maintenance and troubleshooting, scheduling for their own work areas, interfacing with the CIM system, and some engineering analysis. In keeping with these expanded responsibilities, AMD now is sending a significant number of its SDC personnel to college full time to earn an Associate's Degree.

THE FACILITY

Table 1 lists features of the SDC in terms of the equipment used and the facility itself.

Special care was taken during the construction of the SDC, which was built using the "clean-build" technique. Gowned workers in a full clean room environment do the final stages of construction and equipment hookup. This technique was used at Sematech and at Intel's new developmental fab, D2. Dataquest believes that it probably will be used in the construction of all future advanced facilities.

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TABLE 1

Major Highlights of the SDC

The Facility	The Equipment
35,000 square feet of clean room	Photolithography operation integrates tracks and steppers as a process unit
Capacity of 3,000 6-inch wafer starts per week, or 2,000 8-inch wafer starts per week	Robotics applied to transport load/unload at diffusion and clean processes
Start-up investment of $155 million	Vapor-phase cleaning for improved surface conditioning
Parts-per-billion impurities for process gases and chemicals	Vertical furnaces driving 2-3 times improvement in process uniformity
Automatic ultraclean FSI chemical delivery system	Extensive use of load-locked cluster tools for process consolidation and cleanliness

Source: Advanced Micro Devices

The facility was designed to be able to process wafers down to 0.25 micron by the end of the decade. Air cleanliness will be Class 0.1 (i.e., only one 0.1-micron-size particle per cubic foot of clean room air). Cleanliness standards for gas, DI water, and chemical delivery systems are equally stringent. For gases, there is ultraclean, electropolished process piping, and impurities are measured in parts per billion. Chemical delivery systems have just as rigorous standards: an automatic FSI ultraclean bulk chemical delivery system and electropolished piping, with impurities also measured in parts per billion.

The SDC is a paperless fab with CIM process documentation and inventory control. It has been "brought up" (into production) in a fully paperless mode. The building is completely computer controlled, including air handling, humidity control, air temperature and velocity, the DI water system loop, and the chemical distribution system.

In order to maintain the integrity of the SDC, special care also has been given to human clean room practices. Clean room personnel will have to change into special garments even before they go into the clean room garment change room. In effect, they have to wear special garments just to get into the garment change room. During breaks, the company will provide clean room personnel with non-particulate-generating snacks such as yogurt.

THE SDC AND DR. OHMI

Dr. Ohmi of Tohoku University is one of the industry's pioneers in developing clean room concepts and technology for ultraclean wafer processing. AMD has worked closely with Dr. Ohmi in building the SDC. One of his major contributions, according to an AMD spokesperson, was "just providing a global point of view of the fab." Specific characteristics of the SDC that can be attributed to Dr. Ohmi include the fact that all surfaces in the fab are static free and all surfaces are also non-outgassing. The technology to eliminate both sodium and hydrocarbons from incoming air was provided by Dr. Ohmi.

This project represents a level of cooperation between the Japanese industry and the US industry that would have been unthinkable ten years ago.

DATAQUEST CONCLUSIONS

In order to bring products and processes from development to production quickly and efficiently, AMD has designed a developmental facility that is world class and will set standards for years to come.

In order to ensure that manufacturing be truly integral to all stages of development, the SDC has been designed with a dual purpose: to be both a production line and a development line. However, Dataquest believes that this seeming duality of purpose is in reality subservient to a single goal: communication. The SDC facility and its personnel have been organized so that people, process, and equipment can communicate.

Communication—it is a simple goal but a goal that, if achieved, can have dramatic effects on a company's bottom line by increasing yields and decreasing both cycle time and time to market. In our opinion, that is the real challenge for which the SDC has been designed.

George Burns

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Research Newsletter

MOTOROLA'S NEW ADVANCED TECHNOLOGY CENTER

One of the traditional and enduring problems of product and process development has been the transfer of technology from an R&D environment to a full production environment. What works or what is acceptable in an R&D environment often does not work or is not acceptable in a full-production environment. Semiconductor companies have tried various strategies to make this transfer process as fast and effective as possible.

Motorola's solution is taking shape in Chandler, Arizona, where the company is building its new Advanced Technology Center (ATC). The ATC is a facility that represents a relatively new concept in the development of semiconductor processes in the semiconductor industry: the merging of R&D and production in one facility.

One of the chief goals of the ATC is that new processes and products be developed so that they can be manufactured efficiently. Specifically for the ATC, this means getting product to market quickly, reducing cycle time, reducing defect densities, and increasing yields. The layout of the facility and the organization of the developmental process have been designed to integrate manufacturing and development so that both may be optimized. This newsletter highlights the ATC's layout and organization.

THE ATC's LAYOUT

Construction of the ATC is under way and will be completed by the end of 1990. Motorola hopes to begin production in the new facility by the second half of 1991. BiCMOS technologies for a broad array of products ranging from fast SRAMs to ASICs will be developed in the ATC. However, most of the development work will be for noncommodity products such as ASICs.

A unique feature of the ATC is the organization of its physical space. It will be laid out into quadrants: two quadrants for pilot lines, one for a developmental line, and an empty area than can be used for either expansion or support. The first pilot line is designed to be expanded to full production. It will be on this line that Motorola will bring the next generation of technology (0.6 micron) into full production.

The second pilot line is for the follow-on-generation technology (0.45 micron). The developmental line is for the characterization of process equipment and for R&D to develop nonstandard flows. These nonstandard process flows will move to the pilot line only after previously agreed-upon processing goals have been reached. This agreement, or contract, is a key feature of the ATC's organization.

ORGANIZED FOR MANUFACTURING

Contracts are the means whereby the organization knows that a process is ready for the next step in development. These steps are the movement from the R&D line to one of the pilot lines or the movement from pilot to full production. Contracts are agreements between development, manufacturing, and marketing in which specific manufacturing parameters are agreed upon in advance. Examples of these manufacturing parameters include defect density, yields, and cycle time.

Another important part of the organization for manufacturing is the assignment of personnel. Manufacturing personnel, such as manufacturing, process, and device engineers, are assigned to work on both pilot and R&D lines. By this means, Motorola hopes that communications between between development and manufacturing will be continuous, and manufacturing will be considered at every step of the developmental process.

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DATAQUEST CONCLUSIONS

The transfer of new process technologies and products from an R&D environment to a production environment has been a perennial problem in the semiconductor industry. Traditionally, a wall has existed between manufacturing and development over which new processes were tossed back and forth until the new process was truly capable of volume production at acceptable yields and quality levels. Motorola's solution to this problem is to try to get rid of the wall.

At Motorola's ATC, the two functions take place in one facility and are merged in the pilot line. This merging is accomplished by designing the actual physical layout of the facility so that R&D, pilot production, and full production each have separate quadrants. Each function is separate yet contiguous. The combination of physical separateness and contiguity is mirrored in the organization of ATC's personnel. Production and R&D personnel are assigned to both pilot production and R&D lines. By the use of contracts, which are previously agreed-upon goals and standards of transferring a process from one phase to another, the goals of one organization (manufacturing) become a part of another organization (development). Manufacturability becomes an integral part of the developmental process.

Manufacturability directly impacts the bottom line through decreased cycle time, decreased defect densities, and increased yields. Manufacturability also directly impacts the customer with improved quality, decreased cycle time, and quicker time to market. If the ATC is successful, Motorola will be an even more formidable competitor, both in manufacturing and in the marketplace, than it is today.

George Burns

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the newsletters. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Research Newsletter

TURNING R&D INTO PRODUCTIVE MANUFACTURING KNOWLEDGE—A TOUR THROUGH PILOT LINES IN JAPAN

INTRODUCTION

During a recent trip to Japan, Dataquest was able to tour Japanese pilot lines. This newsletter provides observations from that trip as well as compares pilot lines and their functions and strategies in Japan and the United States.

WHAT IS A PILOT LINE?

Semiconductor companies have varied perceptions of what a pilot line is or should be. These perceptions are much more homogeneous in Japan than they are in the United States. All of the pilot lines in Japan are chartered to handle the transition from R&D to volume production, but only some of the pilot lines in the United States have a similar charter. Other US pilot lines may combine R&D and pilot functions, perform mostly R&D functions, or operate like low-volume fabs.

THE DIFFERENCES IN JAPANESE AND US PILOT LINES

Size

The most notable difference between Japanese pilot lines and US pilot lines is their size. Pilot lines in Japan are very large. Clean room sizes commonly range from 40,000 to 60,000 square feet. Most large Japanese companies have one main pilot line for each generation of process technology. We are beginning to see some large pilot lines being built in the United States, but this is a new trend. Most of the pilot lines in the United States are one-half the size of Japanese pilot lines, or smaller.

Volume

Clean rooms in Japanese pilot lines are not just big; they also have a wafer capacity that is larger than many US production lines. We toured a mature 1.2-micron pilot line producing 25,000 wafers out per month. We also toured an advanced 4Mb DRAM pilot line that currently produces 10,000 wafers out and a very advanced 16Mb DRAM pilot line that has a capacity for 8,000 wafers out. By comparison, the capacity of US pilot lines is very small. The average US capacity is less than 4,000 wafers per month.

Many pilot lines in Japan ramp up a process to production level or near-production level before the process is transferred to manufacturing locations. This strategy reduces the occurrence and cost of correcting the same error or processing problem at multiple production sites. This strategy also can greatly reduce the time required to achieve full capacity at the production sites. The fact is that time to market does affect a company's future market share at the product level. Time to market obviously is impacted by time to volume production. New products and processes must be ramped up quickly, and the delivery of a well-defined and manufacturable process can help make this happen.

DESIGNED FOR MANUFACTURING

For a given generation of process technology, it is quite common to find the same level of processing equipment and automation in Japanese pilot lines and production lines. The automation and computer-integrated manufacturing (CIM) systems are not in the pilot line just for the sake of getting debugged; they are there also to speed up the development of the manufacturing process itself. These pilot lines look like production lines

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and appear to operate like them as well—i.e., with emphasis on line balancing, high throughput, and fast turnaround time. This emphasis reduces the time for a test or experiment to be completed, and this time reduction allows engineering to move on to the next test or experiment in less time. Therefore, the total development time is reduced.

PROCESS TRANSFER

As a result of bringing pilot lines in Japan up to high levels of production before transferring the process, many Japanese companies have been able to transfer new products and processes out to the production lines by sending only documentation and not people. When bringing up a new production line with leading-edge processes, Japanese companies might send a process evaluation engineer to the new fab for up to six weeks. Companies are able to do this because the pilot line and the production line use identical tool sets. The process being transferred also is fairly mature and well defined; therefore, the process environments are close to identical. In the United States, on the other hand, process environments in pilot and production lines can be very different. US manufacturers typically are required to transfer people in order to transfer the process successfully.

PILOT LINE LIFE CYCLE

Once a pilot line in Japan successfully transfers its first product or process, it then will begin to work on other products or processes for that particular level of technology. For example, most of the current 1.2-micron pilot lines in existence initially were used for 256K DRAM development. The next products worked on by these pilot lines were 16K and 64K SRAMs and 256K EPROMs; now these lines are working on 1.2-micron MPUs and gate array processes. These 1.2-micron pilot lines are matched to 1.2-micron production lines. Pilot lines will stay in existence as long as new products and processes need to be developed for matched production lines.

TO BE MANUFACTURING DRIVEN

Japanese semiconductor companies appear to be driven by the manufacturing side of the operation. The manufacturing group typically will determine the next generation of fab technology to be used. Once this next generation of fab technology is fairly well defined, the manufacturing group regulates the process design, number of people, number of wafers, floor space, and specific number of wafers to be produced per month during ramp up. The company then designs the new processes according to the fab's capability. This procedure is quite different from the typical routine in most US companies. Although the United States appears to be changing for the better, still it is all too common for US companies to be driven by the marketing and R&D organizations rather than the manufacturing organization. What then emerges is the development of products that are difficult to manufacture in a cost-effective manner or products that may not be manufacturable at all.

DATAQUEST CONCLUSIONS

Dataquest believes that Japanese companies have proven that being manufacturing driven works and US companies have proven that being marketing and/or R&D driven does not yield the best results. Today, we see automated pilot lines in Japan that look like production lines and pilot lines in the United States that look like R&D labs. We see pilot lines in Japan that are dedicated to one generation of technology and a single pilot line in the United States trying to develop up to three generations of technology. Another difference is that Japanese companies send documentation to the production lines and US companies send people.

Dataquest knows that Sematech considers the transfer of technology from R&D to production to be a major weakness in the United States. Some US companies are responding to this challenge by trying to integrate the Japanese methods mentioned in this newsletter into their pilot line activities. Other US companies are developing innovative alternatives to these ideas. For example, some US companies now are building large pilot lines. However, most of those are not being run like production lines: They operate more like combined R&D and pilot lines at less than 4,000 wafers per month. They have a diverse mixture of equipment and are developing up to three generations of technology under the same roof at one time. The big question is whether or not processes can be adequately transferred from pilot lines to production lines without ramping up the pilot lines to production levels. To date, most US companies have not been successful at this. We will be watching with interest the current US efforts to close the gap between R&D and production lines.

Mark T. Reagan

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Research Newsletter

INTEL'S D2: INTEGRATING MANUFACTURING AND DEVELOPMENT

SUMMARY

Only 10 years ago, Intel was known as a world-class innovator and designer but not as a world-class manufacturer. Today, Intel considers itself to be a world-class manufacturer, attributing the success of this turnaround, partly, to the way the company has managed its developmental process.

The developmental process at Intel's new D2 developmental fab in Santa Clara, California, illustrates a new approach toward development within the U.S. semiconductor industry (and one that has worked well for some time in Japan). The theory is that development of a new process or product is no longer anterior to manufacturing; it is integrated with manufacturing's main goals from the very beginning of the developmental process. This integration of development's and manufacturing's goals results in consistent quality in a mass-production environment, much more rapid product introductions, quicker availability, and lower prices.

This newsletter examines D2's development procedures and highlights some of the more important aspects of the fab itself.

DEVELOPMENT IS PART OF THE MANUFACTURING PROCESS

Intel's Manufacturing Goals and D2

D2 has been designed to develop the manufacturing processes to support three different technologies simultaneously. These three technologies are present generation down to 0.8 micron, 0.5 to 0.6 micron, and 0.2 to 0.3 micron. (Intel's estimate of the limit of optical lithography is 0.35 micron.) Examples of manufacturing processes to support these technologies include increasing gate speed, reducing oxide thickness, increasing die size, or decreasing line geometries.

Most importantly, D2's charter is to develop the processes for these technologies in a manner that supports Intel's manufacturing goals. Intel says that its manufacturing goals can be summarized in three words: FAST, CHEAP, and GOOD. In other words, Intel wants to be able to make devices quickly (FAST), efficiently (CHEAP), and with high quality (GOOD).

To achieve these goals, D2 is organized into process development teams. A process development team can consist of from 6 to 24 individuals. Each team is responsible for the development of a new process, and this development may take as long as five years.

Intel's Development Process

Product and process development was originally thought of as an R&D function, and development teams were responsible for the successful functioning of a new process only in a nonproduction environment. For example, development teams were responsible for a product only up to the design phase of the process or, more recently, only up to first silicon. It was manufacturing's job to bring the new process up to speed in a manufacturing environment. As a result, it took a long time to bring the new product up to consistent quality levels in the manufacturing environment. Debugging was done on the job and in the factory. Consequently, both quality and availability suffered.

Now at D2, however, Intel's process development teams are responsible for the new product or process up to the first 100,000 devices in a full production environment. Manufacturing's goals of FAST, CHEAP, and GOOD also are the developmental team's goals. The results are consistent

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quality in a mass-production environment (GOOD), much more rapid product introductions, quicker availability (FAST), and lower prices (CHEAP).

As an example of how well the development teams have performed in meeting manufacturing's goals, consider cycle time, a measure of FAST. Cycle time in a development fab refers to the time that it takes to fabricate in silicon a complete test chip. Before D2 became operational, test chips for Intel's EPROMs and flash memory products and processes were fabricated in a production fab where the cycle time for developmental devices was 65 days. Now in D2, the cycle time for such devices has been reduced to 50 days. Intel's goal is to drive D2's cycle time down to 40 days by the end of 1990. Because a new process under development can involve hundreds of cycles of running test chips on silicon, cutting the test chip cycle time can result in much quicker introduction of products and processes.

In addition to decreasing the cycle time for test chips, Intel also works on FAST in the developmental process by the extensive use of simulation before constructing a test chip. Intel uses simulation to select for testing on a test chip only those process recipes that are the most likely to succeed. Through simulation, Intel evaluates the feasibility of 50 to 60 process recipes and then selects the 4 or 5 best to test in silicon. Before Intel adopted the extensive use of simulation, the choice of which recipes to test in silicon was based more often on an engineer's hunch about what seemed most promising.

THE FAB

Fab Features

Intel has designed D2 to be one of the most advanced fabs in the world. D2 is at the leading edge of fab technology—not only in the United States, but worldwide. Significant features of D2 are as follows:

- D2 is the first development fab in the United States to use Dr. Ohmi's submicron clean room concepts.
- Intel claims that air and water quality at D2 is equal to that of the most advanced research facilities in Japan.
- D2 is an order of magnitude cleaner than Class 1: 10 particles at 0.01 micron and 0.2 particles at 0.1 micron.

In addition to being much cleaner than the standard Class 1 clean room, Intel's D2 also uses process gases of the highest possible purities. These gases are 10 to 100 times cleaner than in Intel's production fabs.

The clean room is designed for maximum flexibility. A key feature of the designed-in flexibility is removable floor plugs that will eliminate the need for cutting holes in the floor for equipment utility lines in case the equipment layout changes.

D2 is a memory and embedded-control device development fab with 25,000 square feet of clean room. (Microprocessor development is done at D1 in Hillsboro, Oregon.) Intel's current plans are to produce a maximum of 500 to 700 product wafer starts per week at D2.

All the equipment at D2 is 8-inch compatible. Intel believes not only that 8-inch wafer processing soon will become commonplace, but also that the company will be processing 10-inch wafers by the year 2000 (see Table 1).

Leading-Edge Fab at a Reasonable Cost

A persistent industry fear is that costs for sub-half-micron fabs will exceed $500 million. From the evidence of D2, this does not appear to be likely. D2 is certainly state of the art; its implementation of Dr. Ohmi's submicron clean room concepts makes it one of the most advanced in the world. Yet the construction and facilitization cost of the facility is about $3,300 per square foot. Although D2 has advanced the state of fab technology, it has done so at a reasonable cost.

TABLE 1
Intel's Memory Technology: Today and Tomorrow

	1990	2000
Minimum Feature	1.0 micron	0.25 micron
Flash/EPROM Density	4Mb	256Mb
Cell Size	12 U^2	<1 U^2
Technology	CMOS	CMOS
Chip Size	0.9 CM^2	1.8 CM^2
Power Size	5.0 volts	3.0 volts
Wafer Size	6 inches	10 inches

Source: Intel

DATAQUEST CONCLUSIONS

D2 is significant not only for its state-of-the-art fab but also for its extensive use of simulation and the organization of its developmental process. Product and process development at Intel is integral with manufacturing's main goals, and developmental teams are responsible for creating a production-worthy device. The results of this integration have been consistent quality in a mass-production environment, much more rapid product introductions, quicker availability, and lower prices.

George Burns

Have you registered yet for our ninth annual SEMICON/West seminar?

Date: Wednesday, May 23
Time: 7:00 a.m.
Place: Hotel Sofitel, Redwood City, CA

To register or for more information, call (408) 437-8245.

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Research Newsletter

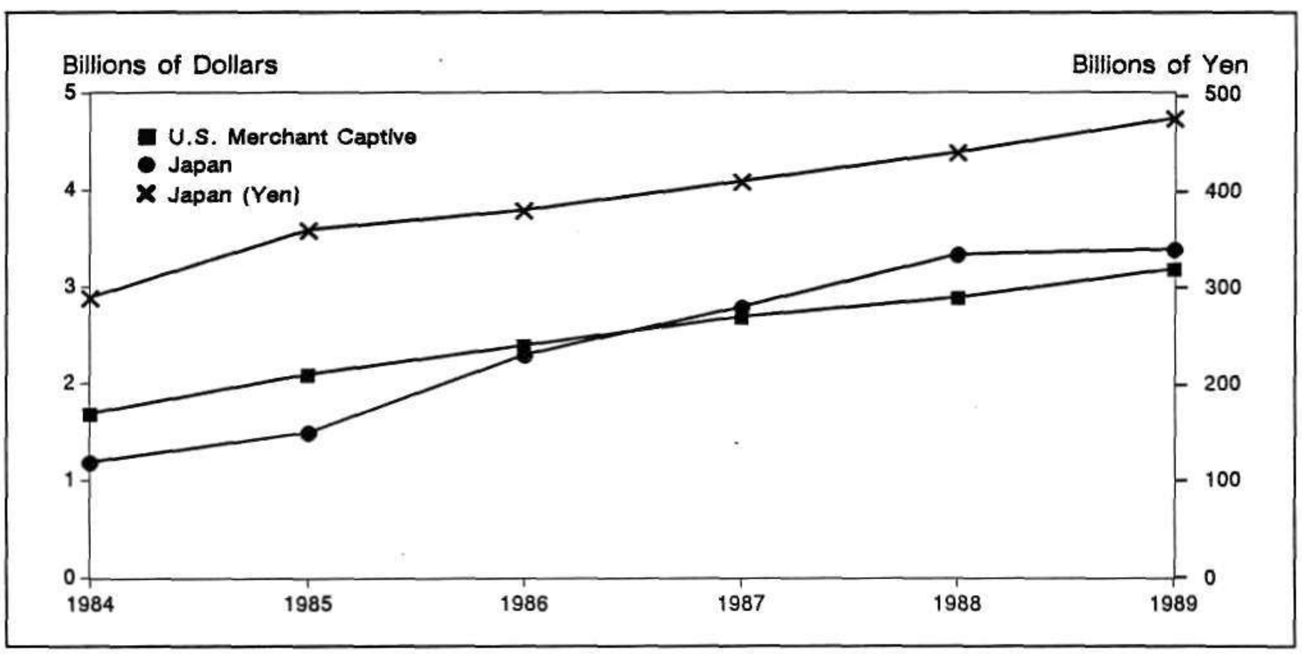
JAPANESE AND U.S. SEMICONDUCTOR COMPANY R&D EXPENDITURES: APPROXIMATELY EQUAL

LEVELS OF COMPANY R&D EXPENDITURE

Measured in actual dollars, Japanese companies' R&D expenditure is approximately 5.5 percent greater than the combined expenditure of U.S. merchants and captives. These estimates are of semiconductor company-funded R&D only and do not include the important contributions to R&D made by the U.S. and Japanese governments or by consortia. R&D spending by Japanese companies was $3.4 billion in 1989, and the amount spent by U.S. merchants and captives was $3.2 billion (1989 Japanese data is a preliminary estimate; see Figure 1).

The fact that Japanese company R&D expenditure exceeded that of U.S. companies is not surprising because Japanese company semiconductor revenue is greater than the combined revenue of U.S. merchants and captive semiconductor companies ($29 billion versus $24 billion). However, it

FIGURE 1
Semiconductor R&D Expenditure by Japanese and U.S. Companies



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Source: Dataquest
May 1990

SEMS Newsletters 1990 R&D

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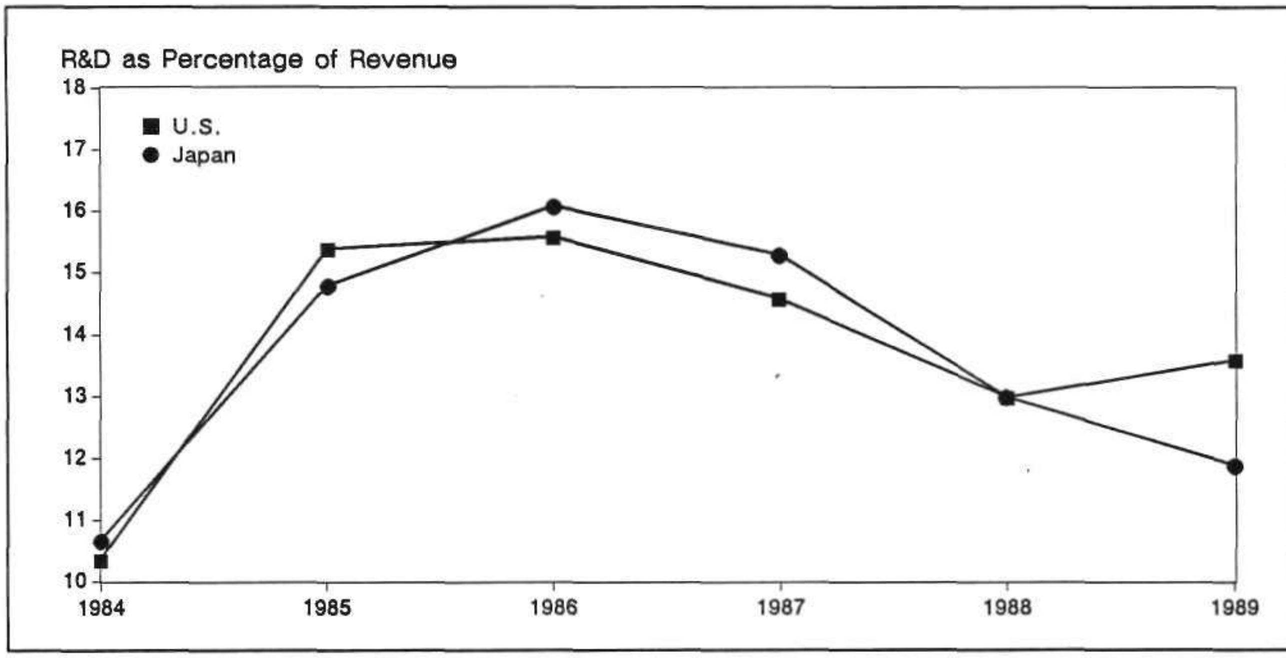
FIGURE 2
Semiconductor R&D Spending as a Percentage of Revenue Japanese and U.S. Companies



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Source: Dataquest
May 1990

is surprising that the ratio of R&D spending to semiconductor revenue, which is a measure of the level of R&D effort, is about the same between Japanese and U.S. companies. Indeed, as Figure 2 clarifies, the similarities in R&D spending as a percentage of revenue for Japanese and U.S. companies is remarkable.

There is one measure of R&D spending in which U.S. companies and Japanese companies do differ to some degree. The compound annual growth rate (CAGR) of Japanese companies, when measured in dollars, is greater than that of U.S. companies (23 percent versus 14 percent for 1984 to 1989). However, this fact is deceiving, because more than one-half of the large Japanese CAGR is due to the depreciation of the dollar during this period. Measured in local currencies (dollars for the United States, yen for Japan), the CAGR of U.S. companies' expenditure is greater. It totals 14 percent for U.S. merchants and captives and a more modest 11 percent for Japanese companies. The reason for this difference is that many U.S. companies believed that they were behind the Japanese in manufacturing during most of the 1980s and they therefore had to accelerate development efforts in order to remain competitive.

DATAQUEST CONCLUSIONS: R&D IS A BASIC INVESTMENT

Although the growth rate of R&D expenditure is greater for U.S. companies than for Japanese, what is striking is the similarity of R&D efforts as measured by expenditure as a percentage of revenue. A major reason for the similarity between Japanese and U.S. companies in R&D expenditure is that R&D is basic to the industry; it has to be made in order to stay in business. This fact is borne out by the observation that in both Japan and the United States, the expenditure level always rises—in both good and bad years.

Thus, in 1985 U.S. merchant and captive semiconductor manufacturers increased their R&D expenditure by 25 percent although their semiconductor revenue fell 16 percent. Likewise, Japanese manufacturers increased their R&D expenditure (measured in yen) in 1985 by 23 percent while their revenue (also measured in yen) fell 11 percent. Semiconductor R&D expenditure is like seed corn: unless it is spent, there will be no new products or processes.

George Burns

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Research Newsletter

A MODULAR APPROACH TO FAB FLEXIBILITY

INTRODUCTION

The cost to build a state-of-the-art fab today exceeds one quarter of a billion dollars, and a billion-dollar fab is likely to be built before the end of the current millennium. These are high costs!

One way to ease the burden of carrying these costs is to amortize them over a long period of time. However, to do this the fab must be designed and built to accommodate future changes in business, technology, and equipment. In other words, the fab must be designed to be flexible.

Key to fab flexibility is the concept of modularity. Modularity is important in designing the fab and its subsystems. Modularity has been used by equipment vendors for some time now. It not only allows speedy repair and maintenance of down equipment, it also allows the fab to continue to function because the "dirty" work of maintenance is done away from the clean room.

Designed modularity is integral to the architecture of the fab. It is becoming important for the different materials delivery systems, such as the under-the-floor utility piping to the process equipment.

WHAT IS FLEXIBILITY?

Flexibility is the ability to respond to changes in a manufacturing line caused by changes in technology, risk management, and major shifts in overall mission. Technological changes include the constant refinements in processes and equipment that are normal in semiconductor manufacturing. It also includes the migration of production from early product development to full-volume manufacturing. Risk management includes changes in facility and equipment maintenance, safety improvements, insurance cost reduction plans, and steps taken to limit lost production time or capacity. Mission shifts include changes in business strategy, product and process obsolescence, and resource balancing.

ACHIEVING FLEXIBILITY

Flexibility in a facility is determined by the following key features and design parameters:

- Accessibility to building systems
- Space for movement of people, materials, and equipment
- The ability to make changes to facility and process service systems

Accessibility is controlled by the horizontal and vertical space available in the structure and the way this space is allocated to the various building and manufacturing support systems. Increasing space makes a more flexible facility.

Not only horizontal space should be considered for good accessibility; vertical space is important, too. Vertical space is the space below or above the clean room. It often is the most serious limiter of flexibility, although it is one of the least expensive features to provide when building a new facility. By including a mechanical attic above the clean room for air handling and a basement below for utilities, the need for people to access support systems from the clean room is greatly reduced.

Horizontal space is primarily space for movement, as opposed to space for accessibility. Space for manufacturing equipment movement is a function of the horizontal dimensions of the area involved, the size and location of fixed structural elements, vertical clearances under support systems, turning radii in corridors, and the size and location of doorways. The effectiveness of the space-for-movement element of flexibility is measured by the level of manufacturing

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interruption or disturbance necessary to move manufacturing equipment.

Space/Cost Trade-Off

Increasing accessibility by increasing floor space increases the costs of building a facility. Thus, a trade-off exists between increasing accessibility and containing construction costs. Yet this choice has been one that the industry has been willing to make: capacity (measured in wafers per month) per square foot of clean room has fallen in both Japan and in the United States, from 0.8 wafer per square foot for fabs built in 1984 to 0.5 wafer per square foot for fabs built in 1990.

MODULAR APPROACHES TO FLEXIBILITY

To achieve flexibility in its manufacturing facilities, the industry is adopting the use of modular components whenever possible. The benefits of using a repeatable modular approach to the various architectural, electrical, and mechanical components of building a facility are many. They can include faster construction, more controlled costs, and a large reduction in the number of mistakes made.

An example of architectural modularity is separating the relatively static support areas of a facility from the more dynamic manufacturing clean room. Static support areas refer to such areas as garment rooms, chemical mix, and in-line test. Changes can be made in the manufacturing clean room without necessitating changes in the static support area, and conversely.

Because static support areas do not require a high-cost flexible environment, separating the dynamic from the static areas will result in minimizing the size and maximizing the density of the highest-cost and most flexible parts of a facility.

The ease with which changes can be made to the building and process support systems can be facilitated by segmenting the support systems into small elements. In designing beneath-the-floor utility piping, this segmentation can be achieved with valves (switching or damper), the redundance of service capacity and bypass routing built into systems, and the provisions made in systems to add or delete takeoffs without system shutdown.

Facility flexibility can be limited by building codes, safety requirements, and environmental regulations. However, because the basic strategy inherent in most of these regulatory requirements is the segregation of a facility and its systems into small elements, this approach can be turned into a flexibility advantage with good design. Isolation for safety also can be used in isolation for change.

Flexibility in the future layout of the equipment in the fab can be achieved by using the patterned design of systems, such as beneath-the-floor chemical and gas supply lines to process equipment. This allows the isolation of part of a system without interruption to the rest of the system. It also allows the inclusion of future takeoffs at regular intervals, thus permitting change without system interruption.

DATAQUEST CONCLUSIONS

Dataquest believes that fab costs will continue to increase. To contain these costs, manufacturers will build fabs that have long lifetimes. The specific changes these fabs will undergo may be debatable; that these changes will be many and large is not debatable. Therefore, these fabs will have to be designed for flexibility. Equipment will have to be moved and support systems expanded and upgraded without disrupting the entire fab.

A major strategy to achieve these ends will be the use of modular, expandable subsystems in the architectural, electrical, and mechanical components of the facility. To achieve this level of flexibility will take the best efforts not only of the facility designers but also of semiconductor industry equipment and materials vendors, because they will be supplying the delivery systems and equipment that will be expanded, upgraded, and moved.

(This newsletter was written by George Burns in conjunction with Bill Blackwell of Bechtel and Mike Lynch of IBM. For further information, please contact George Burns.)

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Research *Newsletter*

TAIWAN'S DRIVE FOR WAFER FABRICATION

SUMMARY

Taiwan's semiconductor industry will attempt unprecedented expansion during the next two years. The strategy prior to 1990 focused on integrated circuit (IC) design and relied on foundries for actual IC manufacturing. This approach provided flexibility and financial safeguards, which contributed to Taiwan's IC industry boom. Now Taiwanese design houses are choosing to increase the stakes by more than doubling the number of wafer fabrication facilities (fabs) on the island during the next two years. It is questionable whether or not companies with fabs can maintain traditional, small-scale dynamism and risk taking in an industry that requires long-term planning, focus, and discipline. This newsletter describes the current status of Taiwan's wafer fabrication capability, analyzes the plans for expansion from 1990 to 1992, and recommends strategies to enable long-term success of the industry.

FAB UPDATE

Taiwan's IC manufacturing began in the early 1980s, but the country had been involved in discrete production and chip assembly and testing since the early 1970s. The industry as a whole, excluding assembly and test, has grown fourfold since the early 1980s. Taiwan's total chip production, including foundry business but not assembly and test, reached approximately US$400 million in 1989. Dataquest currently believes that Taiwan's capacity is likely to reach US$2 billion by 1994 if its current expansion plans succeed. The current capability and capacity of Taiwan's semiconductor industry are described in Table 1.

TABLE 1
Taiwan's Current Wafer Facilities

Company[1]	Location	Cost (US$M)	Start Mfg.	Plant Type	Initial Products	Wafer Size/ Technology	Capacity Wafers/ Month
AMPI	Hsinchu	13.5	Q3/88	Fab	Discrete, consumer ICs	4"/1.2u	8,000
Hualon (Fab 1)	Hsinchu	200.0	Q3/88	Fab	ROMs, SRAMs, telecom ICs, consumer ICs	5"/1.2u	30,000
TSMC (ERSO)	Hsinchu	220.0	Q4/87	Fab	CMOS foundry	6"/1.0u	12,000
UMC (Fab 1)	Hsinchu	NA	1980	Fab	ROMs, SRAMs, consumer ICs	4"/1.2u	45,000
UMC (Fab 2)	Hsinchu	140.0	Q3/89	Fab	Memories, EPROMs, SRAMs	6"/1.5u	15,000
Winbond (Fab 1)	Hsinchu	50.0	Q4/88	Fab	SRAMs, ROMs, telecom ICs, consumer ICs	5"/1.0u	20,000

[1]Table does not include discrete companies in Taiwan.
NA = Not available

Source: Dataquest
June 1990

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FAB PLANS

Taiwanese semiconductor companies are implementing plans to build wafer fabrication facilities that could more than double the current semiconductor capacity of the island by 1992 (see Table 2). Despite the ease with which semiconductor companies are gaining support and securing financing, Taiwan's single-minded, public/private commitment to becoming "Silicon Island" is full of unexamined risks.

PROS AND CONS OF CURRENT FAB EXPANSION

Currently, six fabless semiconductor companies in Taiwan have achieved initial financing and broken ground to build a front-end wafer fabrication facility in Taiwan's Hsinchu Science-Based Industrial Park. Macronix International Company Ltd. recently leased the last available piece of land inside the park and will be the first to build a nine-story (three floors of which will be underground) facility in Hsinchu. In the past, Taiwan's six semiconductor design companies used Taiwan Semiconductor Manufacturing Company (TSMC) and United Microelectronics Corporation (UMC), as well as a few Japanese, South Korean, and U.S. foundry services, to manufacture their products. Not only are design houses building fabs, but companies with fabs are expanding capacity (see Tables 1 and 2).

Potential Benefits

Dataquest believes that there are some advantages to design companies that operate their own fabs rather than relying on foundries. These advantages are itemized as follows:

- In a market upturn, a design house with a fab generally can increase its profitability significantly by controlling its own products and output, whereas relying on a foundry requires more time to adjust product lines. In Taiwan's highly competitive semiconductor market, certain products such as video games can become very popular, and semiconductor companies will enter that market en masse. Latecomers are beaten as prices quickly drop.
- Most design houses claim that they can dramatically shorten their design-to-market time requirements from six to four weeks, which substantially enhances competitiveness in Asia/Pacific's dynamic equipment markets.
- In a market downturn, controlling one's fab enables quicker cutbacks in production, whereas foundries require more advanced notice on production quantity.
- Design houses add the important dimension of research and development (R&D) to their wafer business when operating a fab. However, relying on foundries for production is rarely conducive to full-time, leading-edge R&D.

TABLE 2
Taiwan's Wafer Fabs Planned in Hsinchu

Company[1]	Cost (US$M)	Start Mfg.	Plant Type	Initial Products	Wafer Size/ Technology	Capacity Wafers/ Month
TSMC (Fab 2)	150.0	Q2/90	Fab	CMOS foundry	6"/1-2u	15,000
Utic	15.4	Q3/90	Fab	Bipolar, discrete	5"/2-3u	8,000
Holtek	16.0	Q4/90	Fab	Consumer ICs, custom	5"/2.0u	10,000
Hualon (Fab 2)	120.0	Q2/91	Fab	256K, 1Mb DRAMs	6"/ NA	20,000
Macronix	100.0	1991	Fab	Telecom ICs, chip sets	6"/1.2u	20,000
MOSel	100.0	1991	Fab	SRAMs, ROMs	6"/0.8-1.0u	6,000
Vitelic	115.0	Q4/90	Fab	256K, 1Mb DRAM	6"/0.8-1.0u	10,000
Winbond (Fab 2)	40.0	1991	Fab	SRAMs, EPROMs	6"/1.0u	20,000
Acer-TI	250.0	1992	Fab	1Mb, 4Mb DRAMs	6"/0.8u	25,000

[1] Table does not include discrete companies in Taiwan.
NA = Not available

Source: Dataquest
June 1990

- When suppliers decide to discontinue a product that Taiwan might still demand, such as the 256K DRAM, a design house could supply these products to the dependent local users.
- Owning a fab in Taiwan increases a company's chances of going public and becoming highly profitable in the local stock exchange. The majority of experienced process engineers in Taiwan will probably continue to migrate to companies that provide attractive stock ownership options. If a local foundry, such as TSMC, cannot go public in Taiwan, then its ability to attract or retain scarce process engineers is severely impeded.

Risks to Consider

Despite the previously mentioned benefits that operating a wafer fab could add to a semiconductor company in Taiwan, Dataquest believes that the current expansion might become detrimental to the future of the fab industry and possibly to other vital technologies. A variety of conditions should be weighed before uniformly launching fab capacity expansion, particularly if there is little product differentiation. The following paragraphs highlight key factors that support a design-oriented rather than manufacturing-oriented strategy.

Market in Transition

While current expansion plans emphasize ROMs, SRAMs, EPROMs, and consumer ICs, Taiwan is facing the following two phenomena:

- The majority of Taiwan's low-end electronics equipment manufacturers that use these products will be located in China, Malaysia, Thailand, Indonesia, and the Philippines in order to cut huge production costs. Even small manufacturers have organized into groups such as Taiwan Computer Association (TCA) or Taiwan Electronic Appliance Manufacturers Association (TEAMA) to concentrate capital in order to establish Taiwanese manufacturing zones in Southeast Asia and, recently, Europe, where they plan to manufacture personal computers (PCs) and consumer electronics. Low-end PCs have become a commodity and can be produced more cheaply outside Taiwan.
- At the same time, semiconductor companies will be pressured to make 256K and 1Mb DRAMs, logic devices, microcomponents, ASICs, and chip sets in order to compete in these major markets internationally. Channels to new markets abroad will be extremely difficult for new companies to penetrate and to build credibility.

Dataquest expects high growth to occur in Taiwan's semiconductor market. Success depends on these semiconductor companies' ability to recognize the current domestic equipment trend and follow the demand while attempting to enter new international markets.

Need for High-End Systems Design

Current capital expenditure in semiconductor facilities, equipment, and R&D is being diverted from projects related to creating Taiwan's next generation of data processing and telecommunications equipment. In the face of skyrocketing production costs, Taiwanese systems companies must produce a cost-competitive generation of 386 and 486 PCs, workstations, laptops, notebook PCs, electronic diaries, laser printers, and fax machines to stay competitive in the world market. Now more than ever, Taiwan needs to build upon its strengths in systems and software design to develop its niche in these vital markets, products, and technologies. Continuing to use foundries rather than constructing their own fabs could save design houses equipment expenses of more than $500 million during the next year, at least $200 million annually thereafter, and immeasurable costs in training.

Engineering Challenges

More than 90 percent of Taiwanese engineers are trained in IC design, but very few have experience or training in process engineering. State-of-the-art wafer facilities are more often integrating work into architecture design and process design. Some of Taiwan's new start-ups argue that engineers making a transition from architecture to process design should have no problems. The difference between the industry trend and Taiwan's reality is that industry leaders are merging two well-established skills and Taiwanese design houses are attempting to make a transition from inexperience to an area of expertise.

To illustrate the magnitude of Taiwan's task, one need only compare the industries of South Korea and Taiwan. The impressive large-scale organization and discipline of South Korean companies' process engineers has catapulted its industry to technology parity with the United States and Japan in memory manufacturing. South Korea is the third-largest manufacturer of semiconductors in the world. Taiwan's achievements in custom chip design and entrepreneurial flexibility have led to impressive achievements in its PC and peripherals industries. The primary challenge that South Korea and Taiwan face is that both countries seek to change their images as exporters of niche products by attempting to achieve the silicon and systems balance of Japan.

As Taiwanese companies begin semiconductor manufacturing, engineering expertise should follow as quickly as anywhere. However, the task will require a significant amount of training hours, experience, and expenditure because of the industry's lopsided orientation toward design.

Fab Organizations Cannot Afford High-Risk Management

The electronics industry is dominated by small and medium-size companies. More than 2,500 personal computer companies in Taiwan account for the bulk of clone production. The risk-taking and cavalier financial schemes that characterize Taiwanese business practices have worked for many sectors of the economy, including the IBM PC clone business. Business plans either are nonexistent or concerned with very short-term profits for most businesses. The casino-like stock market today is a prime example of this obsession with short-term profit. The top four PC companies in Taiwan accounted for less than one-half of total PC production in 1989.

Until recently, the semiconductor industry, like the electronics industry, was made up of a variety of different design houses, research facilities, assembly and test plants, foundries, and a few wafer fabs. By suddenly focusing on wafer fabrication, Taiwan is taking its biggest risk so far in its electronics industry history. Unlike PC companies, however, wafer fabs do not die and resurrect very easily.

DATAQUEST CONCLUSIONS

The growth and flexibility of Taiwan's semiconductor industry has amazed the world up until now. Dataquest believes that the time and environment are appropriate for Taiwan's semiconductor design houses to enter manufacturing. The availability of capital, potentially huge stock returns, emerging markets in the region, an impressive pool of trainable engineers at home and abroad, and the increased regional competition currently make the country's fab expansion attractive and, in some cases, essential. A state-of-the-art fab industry will well serve Taiwan's future as a high-end systems producer.

On the other hand, many market, technology, and labor issues in Taiwan have yet to be resolved as semiconductor companies race ahead with massive amounts of capital expenditure in semiconductor hardware, determined to beat their neighbors in the Hsinchu Science-Based Industrial Park. The entire industry is undergoing transition and currently sits at crossroads. Industry and government leaders must carefully coordinate a coherent, far-sighted market strategy that seeks differentiation, regional expansion, and eventual international niche-market penetration. A dramatic change of course will be necessary to achieve all of these goals before uniform ramping begins in 1991.

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Mark T. Reagan
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Research Newsletter

THE FAB DATABASE SERIES: NEW START-UPS IN JAPAN—THE LAND OF DIVERSIFYING GIANTS

This newsletter looks at 11 start-ups in Japan that are entering the semiconductor industry. None of these companies are conventional start-ups; all are large, well-established companies that have decided to diversify into semiconductor manufacturing. This newsletter discusses who these companies are, why they are entering the semiconductor industry, and what their strategies are for entering it.

WHO ARE THEY?

All of these start-ups are well-established companies involved in heavy industries such as automobiles and steel. They are quite different from U.S. start-ups. They are bigger and more diversified, with lots of money that they are eager to invest. Unlike many fabless U.S. start-ups, these companies will do their own manufacturing. They are setting up device development centers now and are planning wholly owned or jointly owned fabs in the near future. Two of these companies already have announced capital outlay plans in excess of $700 million over the next 10 years. Table 1 lists these start-ups and the companies with which they are associated for technology sources and process knowledge, as well as a brief description of each start-up's activities.

WHY NOW?

The main reason for this mass diversification into the semiconductor industry is that Japan has targeted high-technology electronics as a strategic direction for the future. Of the 11 companies in Table 1, 5 are in the steel industry. These companies have experienced weakening business conditions because of declining steel prices and sales volumes. These softened business conditions have sharpened their focus on new opportunities in high

TABLE 1
Start-Ups in Japan

Start-Ups	Associated Companies	Details
Asahi Microsystems	Hitachi	To prepare for construction, 20 people sent to Hitachi to begin a feasibility study for building a fab in Miyazaki prefecture during early 1989; will most likely produce ASICs and logic chips
Honda	None	Captive high-volume GaAs production; plans to produce 10,000 units per month in the Tochigi plant by 1992; planning to mass-produce GaAs semiconductors such as engine control sensors by the mid-1990s
Isuzu	Fujitsu	Established an automotive electronic device development company; the joint venture will initially be staffed with Fujitsu engineers

(Continued)

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Table 1 (Continued)
Start-Ups in Japan

Start-Ups	Associated Companies	Details
Kawasaki Steel	LSI Logic and NTT	Plans to manufacture semiconductors on its own after a successful joint venture with LSI Logic called Nihon Semiconductor; established its own LSI Research Center during 1988; will spend $700 million on new manufacturing facilities over the next 10 years for the production of SRAMs and ASICs in the near future and DRAMs later on; also will use technology from NTT; is aiming for annual production of $1.5 billion by the year 2000
Kobe Steel	Texas Instruments	A joint venture called KTI Semiconductor Ltd; will construct a $350 million fab for production of VLSI logic and ASICs in Hyogo prefecture by 1992; a majority of the funding will come from Kobe Steel; process knowledge, fab technology, and most of the staff to come from TI, Japan
Nippon Steel	VLSI Technology	Will complete a $70 million VLSI pilot line for the production of ASICs in Kanagawa prefecture by the end of 1991; has started developing and marketing ASICs under its own brand name by teaming up with VLSI Technology; does not intend to enter the memory market or construct a semiconductor plant by itself
Nissan Motor	None	Has been working on custom ICs at its central research lab; has recently established the Electronics Technology Headquarters, which is staffed with 300 engineers; will initially package ICs; will start front-end operations five years from now
NKK Steel	None	Will spend $1.4 billion on fab construction over the next 10 years; first facility will be in Kanagawa prefecture and should be operational by 1992 at a cost of $171 million; will focus on 4Mb and 16Mb DRAM technology as well as ASICs; is actively looking for a partnership or acquisition
Sumitomo Metal Mining	None	Gave up manufacturing its own ASICs in 1988, but will construct an IC plant in Oita prefecture; will initially produce $3 million worth of devices with 40 employees; during the fifth year, plans to produce $18 million worth of devices with 200 employees
TDK	Silicon Systems	Recently purchased U.S company Silicon Systems, which has two fabs in California, one in Tustin and the other in Santa Cruz; TDK to build a fab in Ibaragi prefecture that will produce disk controller ICs and A/D D/A ICs; TDK believes that it needs a fab in Japan to help develop its semiconductor business; does not intend to compete directly with major chipmakers
Toyota Machine Works	Toshiba	Will start ASIC production at its Higashi-Kariya plant this year; chips will be used for controlling suspension, steering, transmission, door locks, and for use with lights; purchases base wafers from Toshiba

Source: Dataquest
May 1990

technology. Four other start-ups are automobile companies interested in developing better semiconductors for automotive applications. Some of these companies have been motivated by the expected 121 percent growth in semiconductor consumption by the transportation industry between 1989 and 1994; others are interested in developing proprietary chips for captive production.

WHAT ARE THEIR OPTIONS AND CHOICES?

Process knowledge is the key ingredient to entering semiconductor manufacturing—these start-ups cannot compete without it. They cannot develop their own process knowledge and hope to catch up to companies that already are well established in semiconductor manufacturing. So these companies face the following three choices to acquire the necessary process knowledge:

- Acquire companies that have the process knowledge
- Form manufacturing joint ventures
- Form strategic alliances

At first glance, acquiring companies that have the process knowledge appears to be the most favorable choice because all of these start-ups have substantial financial resources for acquisitions. However, the scenario for acquisitions by these Japanese start-ups has the following limitations:

- The Ministry of International Trade and Industry (MITI) says no to acquisitions within Japan (e.g., purchase of Oki by NKK Steel not allowed).
- Acquisition of major companies in the United States meets substantial resistance and politics because of trade issues (e.g., failed attempt by Fujitsu to acquire Fairchild).
- There is not much to buy in Europe (i.e., most of the smaller companies do not possess the technology that these start-ups need and companies such as Philips and Siemens are too large to be purchased).
- Acquisitions in the Asia/Pacific region are rare because of the cultural history between Japan and other countries in the Asia/Pacific region.

This scenario leaves partnerships in the form of manufacturing joint ventures and strategic alliances as the only real choices for these start-ups. They are finding partners that are well established in the industry and will create a synergistic environment. Trust is being built up by first working together on joint design, marketing, or research efforts—joint manufacturing, technology development centers, and technology transfer usually come later.

WHAT IS THEIR STRATEGY?

At present, most of these start-ups do not appear to have any intention of competing directly with the established semiconductor companies. Most will try to enter the market with differentiated products; for instance, 9 of the 11 start-ups will produce various types of ASICs.

Only two of these start-ups, Kawasaki Steel and NKK Steel, have announced their intention to compete with the big companies by producing DRAMs. Both of these companies have announced large capital outlays for new fabs over the next 10 years. Kawasaki Steel plans to spend $700 million, and NKK Steel plans to spend $1.4 billion during this time span. Along with DRAMs, both companies also will produce ASICs; Kawasaki Steel plans to produce SRAMs as well.

Assuming that Kawasaki and NKK are not able to purchase leading-edge DRAM technology, Dataquest anticipates that they will not achieve manufacturing parity with the marketplace before the ramp-up of the 64Mb DRAM. Most of the capital spending for these companies will occur during the second half of their 10-year plans, which is when they will be ready to begin volume production of DRAMs.

THE KAWASAKI STEEL MODEL

Kawasaki Steel's joint venture with LSI Logic is the most mature of the partnerships listed in Table 1. Kawasaki is expected to be the first start-up to achieve volume production levels on its own; therefore, Kawasaki might be considered the role model for the other start-ups to follow. Kawasaki's past and future milestones are listed as follows:

- 1985—Nihon Semiconductor joint venture established with LSI Logic.
- 1987—Nihon Semiconductor began phase 1 production.
- 1988—Kawasaki Steel established its own 0.8-micron pilot line.

- 1989—Kawasaki Steel announced its $700 million 10-year plan.
- 1991—Phase 1 of Kawasaki's production line will begin production.
- 1992—Nihon Semiconductor plans to begin phase 2 production.

Kawasaki will begin production in phase 1 of its own production line just six years after the birth of the joint venture. From the experience with Nihon Semiconductor, Kawasaki was able to set up a pilot line quickly and pursue development of its own technology. It is interesting to note that Kawasaki will continue its participation with LSI Logic at Nihon Semiconductor and pursue its own wafer fabrication at the same time.

DATAQUEST CONCLUSIONS

Dataquest believes that partnerships seem to be the best solution for these start-ups. Of these 11 start-ups, 6 have established partnerships, only one company has made an acquisition, and 4 start-ups have no major technology links at all. All six of the established partnerships involve Japanese or U.S. companies. Companies that operate outside of Japan should consider the possibilities of partnerships with companies such as these start-ups.

Equipment vendors that sell to companies involved in these joint ventures or to the Japanese market should keep a close eye on these partnerships as new sources of business in Japan. Semiconductor manufacturers also should watch these companies closely because there is a good chance that many of these start-ups will announce large capital spending plans similar to those by Kawasaki and NKK within five years. These new start-ups may bring more than just competition to the marketplace; they might add to the potential overcapacity problem that appears to be developing for the mid-1990s.

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Research Newsletter

KOBE STEEL AND TEXAS INSTRUMENTS: FROM STEEL TO SEMIS

SUMMARY

In March, Kobe Steel and Texas Instruments (TI) announced the establishment of a joint venture in Japan to manufacture VLSI ICs and ASICs. Construction of the $350 million wafer fab in Hyogo Prefecture, Japan, is expected to commence early in 1991 and be completed within the year. Kobe Steel will provide the majority of the equity capital and will own a majority interest in the joint venture. TI will provide the technical assistance in the form of design and manufacturing technology required to build and operate the plant and will provide some additional funding. TI will have the option to increase its ownership in the joint venture, although no specific terms have been divulged. Both companies will contribute personnel to the venture, which is called KTI Semiconductor Ltd. The semiconductor output from KTI will be sold exclusively to TI, which will have worldwide sales and distribution rights.

SILICON: THE NEW "CORE MATERIAL"

During the past three years, Kobe Steel, while strengthening its core businesses in steel and machinery, has been increasing its emphasis on other businesses such as electronics, advanced materials, biotechnology, and services. In 1986, Kobe Steel began diversifying into computers and telecommunications in response to several years of declining steel prices and sales. The company's fiscal year 1988 sales were $8.9 billion, and it employed 21,436 people. Based on these data, Kobe Steel was Japan's twentieth largest industrial firm in 1988. By the year 2000, Kobe Steel plans to have its non-steel line account for 40 percent of total sales. The company's mid- to long-range management plan features further diversification into electronics as a key element. The firm's diversification plans incorporate overseas expansion and target opportunities in the high-technology area through acquisitions or alliances. Kobe's current semiconductor-related activities include marketing inspection equipment and providing testing services through its subsidiary, Genesis Technology.

In recent years, there has been an observable trend among Japanese steel and heavy industry companies toward diversification into the electronics industry, partly to offset the strengthening yen and weakening markets. Steel companies such as Kawasaki Steel, Kobe Steel, and Nippon Kokan, which supply core materials for steel, have turned their attentions toward the core materials of the electronics market: ICs. In the mid-1980s, LSI Logic formed Nihon Semiconductor, a joint venture with Kawasaki Steel. Now Kawasaki Steel is gearing up to run its own wafer fab facilities, which should be operational next year and will produce ASICs and general-purpose memory ICs.

TI'S GLOBAL STRATEGY

TI, which ranked as the sixth largest semiconductor company worldwide and the leading nondomestic supplier to the Japanese market in 1989, has ambitious capital spending plans for 1990. TI, the first U.S. company to operate and own a semiconductor company in Japan, has always pursued aggressive regional investment. Table 1 shows that only one of the company's planned submicron CMOS memory and advanced logic fabs is located in the United States.

TI has embraced the globalization of manufacturing and is pursuing its goals through innovative financing that is global in scope. Dataquest estimates that TI will spend approximately $1 billion on semiconductor property, plant, and equipment this year—more than any other company in the world and a whopping 36 percent of total semiconductor revenue (represented in

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Table 1
Texas Instruments' Submicron Memory and Advanced Logic Fabs

Location	Product Type	Status
Avezzano, Italy	4Mb DRAM	Under construction
Freising, West Germany	Advanced logic	Upgrading
Miho, Japan	4Mb DRAM	Upgrading
Hiji, Japan	4Mb DRAM	Upgrading
Dallas, Texas	4Mb DRAM, advanced logic	Upgrading
Taiwan	4Mb DRAM	Under construction

Source: Dataquest
April 1990

1989 dollars). Of this amount, $780 million would be internally funded. The remainder of the funding would be generated through TI's customers, local governments, and joint-venture partners.

TI AS JAPANESE SUPPLIER

TI ranks as the seventh largest ASIC supplier worldwide. The company garners slightly more than one-third of its ASIC revenue from the Japanese market. TI Japan wants to continue to increase its market penetration in Japan by addressing the consumer electronics segment of that market, where it is investing both in terms of local design centers (it currently has four), and through strategic partnerships with Japanese companies. Aside from the large dollar volume represented by the consumer market, the economies of scale associated with it and the impetus it provides to hone quality and cost performance ensure that participation in this market segment coincides with TI's strategic program. For example, one area of next-generation consumer ICs that TI has targeted is through an agreement with Nippon Hoso Kyokai (NHK), Japan's public television broadcasting company, for its "hi-vision" advanced TV receiver technology, which TI will use to develop chip sets for the different HDTV markets. Currently, the consumer portion of the Japanese semiconductor market, which is about one-third of the market, is softening and is not expected to resume growth until 1992.

DATAQUEST ANALYSIS

From TI's perspective, this venture is expected to aid its market penetration of the Japanese market while availing it of a more risk-averse approach to the financing of additional manufacturing capability through Japan's lower cost of capital. Kobe Steel is forging ahead with its diversification goals through this partnership. However, a broader issue relates to how Japanese companies are adopting a comprehensive strategy that ranges from the location of overseas fabs, regionally based R&D, technology exchanges and alliances, and the procurement of foreign-made ICs in terms of its strategy to address the increasingly globalized nature of the semiconductor industry. Under the shadow of strained trade relations between Japan and the United States, Dataquest sees that Japan is responding to U.S. criticism of the inaccessibility of Japan's marketplace by directing its efforts toward opening its markets through alliances, thereby achieving increased market access on a partnership basis.

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Research Newsletter

VITELIC TO MANUFACTURE MEMORY CHIPS IN HONG KONG

SUMMARY

On March 23, 1990, Vitelic announced that it would use its February 1990 acquisition of Elcap Electronics Limited (Hong Kong) to manufacture high-speed 256K and 1Mb dynamic random-access memories (DRAMs), making Vitelic the first company to manufacture DRAMs in Hong Kong.

The announcement, made in Hong Kong, comes as a glimmer of hope for industry leaders there who have feared that the country may become a technology wasteland unless the government took a more active role in the industry's future in electronics. The Hong Kong government's laissez-faire policy has succeeded in creating one of the mercantile capitals of the world but has failed at developing domestic technology near the level of the other three tigers (South Korea, Taiwan, and Singapore).

Dataquest believes that Vitelic's strategy will provide the company with a significant lead in the region's rapidly growing memory market.

VITELIC'S MEMORY STRATEGY IN ASIA/PACIFIC

Officials from Vitelic said that the company will soon begin to invest US$10 million to upgrade the current 4-inch Class 10 fabrication line to produce 5-inch wafers with 0.8-micron geometries. The improved facility will be capable of producing high-speed 256K and 1Mb DRAMs and, in the future, fast 256K SRAMs. By the end of the year, the Class 10 line is likely to produce 2,000 5-inch wafers per month.

Vitelic also will maintain current production on Elcap's existing line of consumer and telecom products, which include telephone dialers, watch and clock chips, video game chips, and voice- and sound-generating devices. These products are manufactured on the facility's Class 100 line, which has the capacity of 7,000 4-inch wafers per month.

Vitelic is likely to benefit from Elcap's strong assembly and test capability at both the Tai Po Industrial Estate and in Shenzhen, China, where truckloads of ICs are assembled and tested daily. Officials in Vitelic confirmed rumors that Elcap and Great Wall Computers (China) have a joint-venture agreement in Shenzhen's Special Economic Zone (SEZ). Like all industries in Hong Kong, semiconductor manufacturing relationships with China are not only common but a necessity.

When Vitelic first made its plans to acquire Elcap Electronics Ltd., public, many people assumed that Vitelic was interested primarily in Elcap's large assembly and test capability. This second announcement regarding technology upgrades confirms that Vitelic is interested in Elcap for technology and manufacturing benefits.

The fact that Vitelic will use Elcap's assembly and test capability when its new fab comes on-line in late 1990 is one of the short-term benefits of the arrangement. Dataquest believes that this latest announcement—that advanced equipment capable of manufacturing 256K and 1Mb DRAMs will be installed at Elcap—signals confidence in Hong Kong's semiconductor market. We believe that recent strong growth in Hong Kong's personal computer, motherboard, and consumer electronics industry has prompted Vitelic's move toward such a significant investment. Furthermore, with large capacity coming on in Taiwan, Vitelic needs to mobilize and train its engineering personnel as soon as possible. Overall, Vitelic is likely to conduct R&D and mass production of 256K and 1Mb DRAMs in Taiwan while using Elcap for training, minor 256K DRAM production, and assembly and test during the next few years.

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A GREATER CHINA SEMICONDUCTOR STRATEGY

Large-scale trade and investment between the plethora of manufacturers in Hong Kong, Taiwan, and Southern China (Guangdong and Fujian Provinces) has inspired economists to coin the term "Greater China," a term that describes the current economic integration in the three countries. Because regional trade recently has grown among these countries, a mounting degree of economic interdependence necessitated a word to describe the region as a single economic system. Greater China's economy comprises the elements of technology in Taiwan, financing and service in Hong Kong, and inexpensive labor and manufacturing in China.

For the first time, the concept of Greater China applies to the semiconductor industry instead of commodities and consumer electronics. Dataquest notes that each of the elements described above will characterize Elcap in the following countries:

- Taiwan—Vitelic will be able to transfer technology and personnel to Elcap from its new state-of-the-art plant in Taiwan.
- China—Vitelic will utilize the labor-intensive assembly and test capability at Elcap's Shenzhen, China, plant while leveraging its relationship with Great Wall Computers, China's largest personal computer company.
- Hong Kong—Vitelic will benefit from Hong Kong's attractive tax structure, financial services, and regional trade and marketing leadership.

The Greater China phenomenon is illustrated in the increased difficulty experienced by multinationals when differentiating their sales to Hong Kong and China. An increasing number of companies no longer differentiate between the two countries in terms of sales revenue. Hong Kong/China now is a commonly used categorization of the sales that are made in Hong Kong but end up either in Hong Kong or China. One of the implications for future monitoring of sales into China of devices that are restricted by COCOM is that any crackdown on companies selling into Hong Kong would shatter the immediate attempt to transform Hong Kong into a manufacturing base in South China both for components and systems. Furthermore, restricting submicron manufacturing equipment in Hong Kong will hurt Hong Kong's IC industry more than China's. As the Vitelic move illustrates, Hong Kong has much more to offer than a bustling port for exporting mainland-assembled products.

DATAQUEST CONCLUSIONS

Dataquest believes that Vitelic's decision to acquire Elcap and significantly upgrade the technology level positions the company as Greater China's leading supplier of locally made, fully processed memory products. Not only is the company investing heavily in its Taiwan facilities, which are scheduled to ramp up production in the fourth quarter of 1990, but it is also spending to upgrade the capability of Elcap's wafer line. This announcement shows that Vitelic is serious about the memory market in the Asia/Pacific and that it is willing to make major expenditures in training and facilities at Elcap, which are likely to ensure the company's regional competitiveness well into 1997.

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Research Newsletter

THE FAB DATABASE SERIES: SHIFTING TO 200mm WAFERS—THE TURNING POINT HAS COME

INTRODUCTION

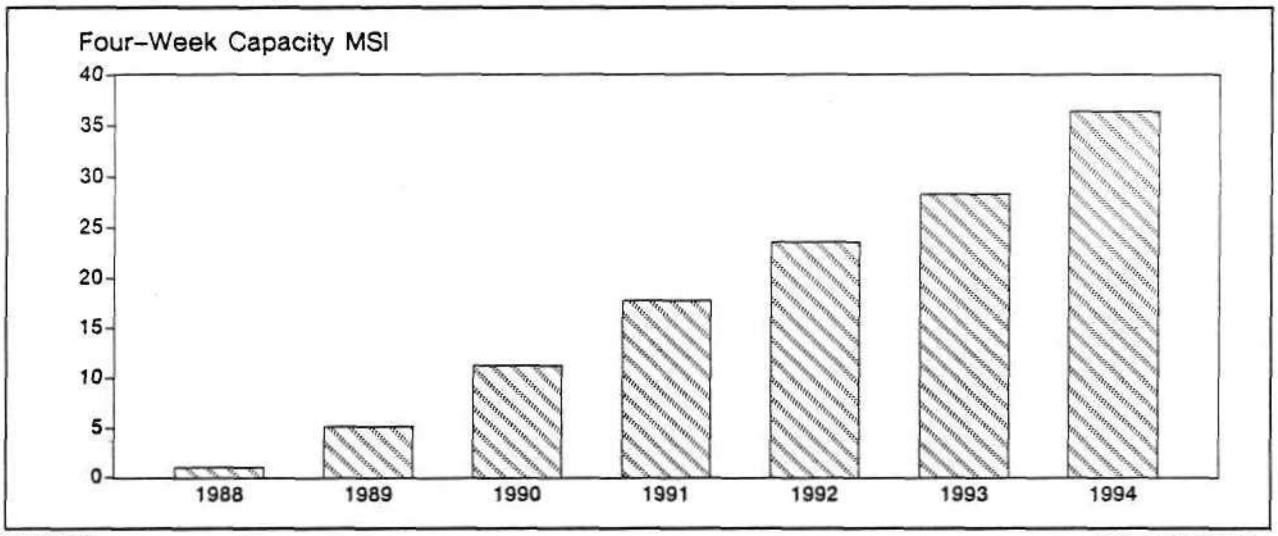
The acceptance of 200mm wafers into the production environment is now upon us. The capacity of the 200mm fab lines should total 11.3 million square inches (MSI) of silicon per month by the end of 1990 and grow to 36.5 MSI by the end of 1994 (see Figure 1).

This newsletter focuses on these 200mm fab lines and looks briefly at reasons why some companies are racing toward 200mm wafer usage, as well as the reasons that other companies are not.

200mm NOW, OR LATER?

Some companies believe that early entry into 200mm production is not more cost-effective than the well-understood 150mm technology. In many cases, these companies are correct—the development cost during the early stages of 200mm technology is very high, and companies with process problems on 150mm wafers will only magnify their problems on 200mm wafers. However, companies that can afford the development costs and have a well-defined process will reap sizable productivity

FIGURE 1
Running Total of 200mm Capacity per Year



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Source: Dataquest
March 1990

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rewards in the long term. Many of the companies that are reluctant to switch to 200mm wafers are taking a flexible approach to this issue by installing 150mm equipment that can be upgraded to 200mm in the future. Dataquest believes that, from now on, most of the new 150mm lines will be equipped with tools that can be upgraded to 200mm.

CHARACTERISTICS OF 200mm USERS

The companies that make early moves into 200mm wafer production are likely to be large companies that have the deep pockets and high-volume requirements necessary to support the switch. DRAM lines will likely be the first to use 200mm wafers because 200mm production is considered to be more applicable to high-volume production than to low-volume and niche production. However, 200mm wafers will be economically justified and should be used in the near future for ASIC, MPU, and EPROM production as well.

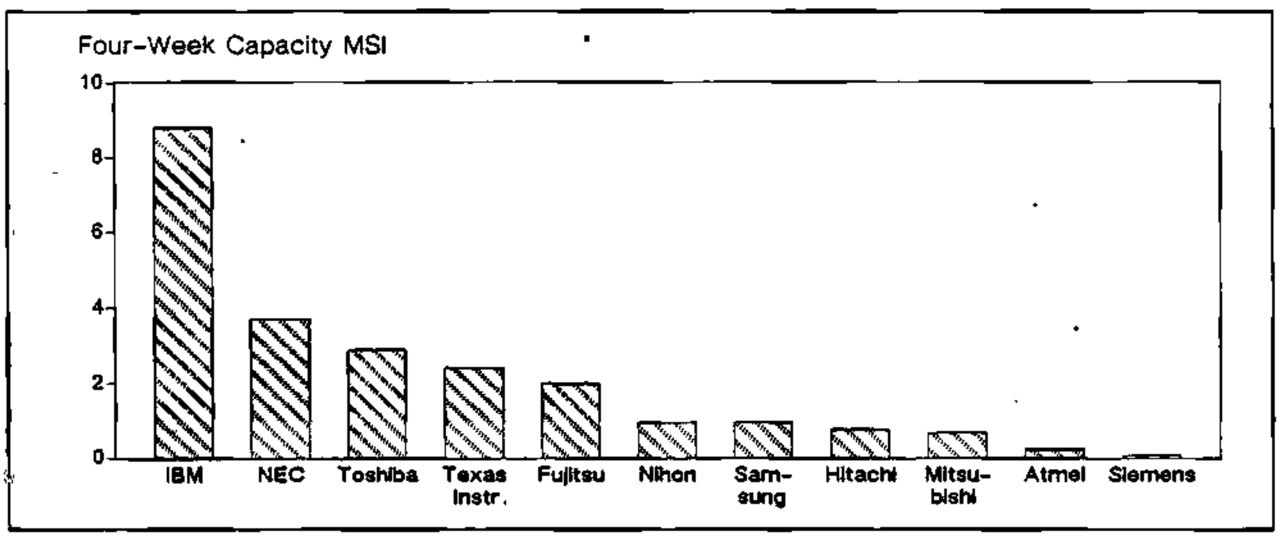
THE FIRST 200mm LINE

In December 1987, the first 200mm line in the world at the IBM, Burlington, Vermont, facility made the move from research and development to pilot production. Since then, we have seen the selective and somewhat reluctant acceptance of 200mm wafers by other companies while IBM has started upgrading a major portion of its capacity to 200mm wafers. Most of IBM's capacity will be on 200mm wafers by 1992, and perhaps some of the urgency at IBM is related to the fact that all of IBM's production was 125mm based before the switch to 200mm began. The switch from 125mm to 200mm gave IBM 2.5 times the silicon area per wafer and tripled IBM's usable die on the 1Mb DRAM process from 150 usable die per 125mm wafer to 450 usable die per 200mm wafer.

TURNING POINT

The turning point is here, and we are likely to see more 200mm activity at other major semiconductor manufacturers around the world. Additions to 200mm capacity will represent 33 percent of the new capacity that will be added from 1990 through 1992. Many companies in Japan, as well as companies such as Atmel, Samsung, Siemens, and Texas Instruments, now are getting involved with 200mm wafers and will have 200mm pilot or production activity by the end of 1992 (see Figure 2).

FIGURE 2
Total 200mm Capacity by Company by the End of 1992



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Source: Dataquest
March 1990

200mm HURDLES

While the availability of quality 200mm equipment has been a limiting factor, manufacturers have had many other issues to consider during this transition. Two years ago, the industry viewpoint indicated that the 200mm equipment was ready but the automation and process were not. Today, the industry cites the implementation of mechanical automation and the software that controls it as the major hurdles for 200mm implementation. Wafer-handling failures were cited as the most common source of poor mean time between failure (MTBF) performance on 200mm equipment.

PRIORITIES

Generally, Japanese equipment vendors took longer to offer 200mm equipment than U.S. equipment vendors. U.S. vendors were pushed by IBM to supply 200mm equipment, while the Japanese vendors were not pushed by their customers to do the same. The switch to 200mm wafers in Japan was delayed by the lack of Japanese 200mm equipment; however, this reason masked the true reason for the delay. The switch to 200mm was delayed in Japan because of the focus on automation and computer-integrated manufacturing (CIM). Japanese companies placed CIM and automation as higher priorities for many reasons. Some of the more notable reasons were as follows:

- Automation will be desirable for 200mm wafers because of the sheer weight of the wafer cassettes and diffusion boats.
- CIM may increase productivity, yields, and equipment uptime to such an extent that the benefits of CIM on 150mm wafers may outweigh the benefits of 200mm production without well-developed CIM capabilities.
- The move toward single-wafer processing is driving the development of single-wafer tracking systems.
- Companies are looking at manufacturing in terms of more than one chip type on each wafer, which also will drive the development of single-wafer tracking systems.

Although activity in automation may have delayed the initial introduction of 200mm wafers to the fabs in Japan, there is a good chance that the Japanese companies now boasting CIM and automation expertise will rapidly adopt 200mm technology during the next few years while most U.S. companies, except for IBM, may have difficulties.

DATAQUEST CONCLUSIONS

Although one U.S. company, IBM, has put the U.S. semiconductor industry into 200mm capacity leadership, Dataquest does not expect a long wait before most companies in Japan rapidly ramp up to 200mm lines and take the lead, as they did with 125mm and 150mm wafer capacity. The decision by Japanese companies to pursue CIM, automation, and process refinement before 200mm technology should prove to be a wise one. Success with 200mm capacity for companies in the United States may depend upon IBM's willingness to disseminate its 200mm knowledge through the equipment vendors and Sematech and may also depend on Sematech's ability to develop that information for its members. Another option for U.S. semiconductor companies will be to acquire CIM, automation, and process knowledge through technology exchange agreements and joint ventures with companies in Japan. Agreements such as this already have been established. Some examples include agreements between Toshiba and Motorola, Hitachi and VLSI Technology, and NMB and Intel.

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Research Newsletter

SONY ESTABLISHES FAB ROOTS IN THE UNITED STATES

It's a bird, it's a plane, it's...well, it's a little confusing. Based on a first reading, the February 20 press release issued by Advanced Micro Devices (AMD) regarding its newly announced agreement with Sony Corporation sounds by turns like a technology transfer, a foundry arrangement (with either AMD offering capacity to Sony or vice versa), or a basic sale of assets. Such confusion is certainly understandable. This latest development in AMD's five-year relationship with Sony is, in fact, all of these things.

As a further mingling of the fates of these two semiconductor producers, this latest agreement is definitely worth considering from the perspective of each of the alliance partners. This newsletter—a collaborative effort by analysts in Dataquest's Semiconductor Industry Service (SIS), Japanese Semiconductor Industry Service (JSIS), and Semiconductor Equipment and Materials Service (SEMS)—does just that.

THE AMD/SONY AGREEMENT

The Package: Fabs 11 and 12

The terms of the AMD/Sony agreement call for Sony to establish an advanced submicron integrated circuit manufacturing operation at AMD's San Antonio, Texas, wafer fab facilities. The San Antonio site consists of 50 acres of property with two buildings (fabs 11 and 12), one of which (fab 12) stands idle. The 650 AMD employees currently working in fabs 11 and 12 will report to Sony, and the facilities and staff will be managed by a newly established subsidiary called Sony Microelectronics Corporation.

AMD's fab 11 is a 5-inch wafer line that has been producing PLDs and PROMs based on a 1.5-micron bipolar process. Fab 12, which had been running Monolithic Memories Inc. (MMI) products, supported bipolar, CMOS, and even some BiCMOS processes at the 1.2-micron level. A Class 10 line running 6-inch wafers, the facility was mothballed in July 1989.

Although Sony will take over AMD's San Antonio fabs, fab 11's capacity will be utilized by AMD on a foundry basis. In addition, as Sony upgrades fab 12 for the volume production of CMOS SRAMs, AMD will place a four-man technology transfer team at the facility in order to, as AMD chairman and CEO Jerry Sanders puts it, "gain on-site, hands-on access to Sony's advanced submicron integrated circuit manufacturing technology."

Sony Expands Its Chip Manufacturing

Dataquest estimates that Sony's MOS memory production in 1989 grew 88 percent over the previous year—from $103 million to $194 million. Table 1 charts the rapid growth of Sony's semiconductor production as a whole during the past five years.

In its growing MOS memory business, Sony has been working especially hard to make its presence felt in both slow and fast segments of the SRAM market. Dataquest estimates that Sony ranked as the fourth largest worldwide supplier of slow SRAMs in 1988. In the 1Mb SRAM market, Sony stood second only to Hitachi, tying for the number two supplier slot along with Toshiba in 1988.

As far back as May of last year, Dataquest has been hearing reports that AMD would be interested in selling its San Antonio fabs to Sony. These reports were certainly in keeping with Sony's desire to increase its participation in the U.S. MOS memory market. Sony had announced

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TABLE 1
Sony Corporation Estimated Worldwide Semiconductor Revenue (Millions of Dollars)

	1985	1986	1987	1988	1989
Total Semiconductor	252	455	571	950	1,077
MOS Memory	12	38	56	103	194
MOS Micro	0	17	21	37	43
MOS Logic	47	58	67	95	95
Analog	96	166	217	386	388
Discrete	42	62	72	112	110
Optoelectronic	55	114	138	217	247

Source: Dataquest
March 1990

earlier that it would make a decision by the end of 1989 as to a U.S. fab location for the production of 1Mb SRAMs, and the company planned to begin construction on a submicron CMOS facility in the United States by the fall of 1990. The purchase of AMD's San Antonio fabs will give Sony a good running start at its proposed timetable.

AMD Gains Cash, Technology, and Concentration

The $55 million cash infusion that AMD gains from the sale of its San Antonio facilities to Sony should be very welcome. To put this price in perspective, one should remember that National Semiconductor purchased *all* of Fairchild's assets (except for one fab in Japan and one in West Germany) for approximately $120 million.

More important is the fact that the AMD/Sony relationship will allow AMD to continue to develop a CMOS process expertise during a time when the company has pared back costs to what Dataquest believes are now in the range of $260 million to $265 million per quarter. Having pulled out of the SRAM market itself, AMD not only will gain exposure to Sony's high-volume SRAM production techniques in advanced CMOS processes but will, according to a signed letter of intent, collaborate with Sony in developing CMOS process technology aimed at the 0.5-micron level.

AMD's agreement with Sony certainly complements the efforts that Jerry Sanders and company have been putting into CMOS capability. In the five years between 1984 and 1989, AMD invested more than $1 billion in research and development, most of it focused on CMOS technologies. According to Mr. Sanders, "Fourth quarter 1989 CMOS revenue reached a record 26 percent of total sales." In a recent strategic analysis newsletter on AMD, Dataquest vice president David Angel expressed his opinion that "by the end of 1990, approximately one-third of (AMD's) projected revenue will be derived from products manufactured in advanced CMOS technologies" (see SIS newsletter, "The New AMD Enters Its Third Decade"). With the sale of its San Antonio fabs, AMD now will concentrate its CMOS production capabilities in Austin, while a recently completed $100 million development center in Silicon Valley will target advanced products designed around a 0.35-micron capability.

ALL RHETORIC ASIDE... DATAQUEST CONCLUSIONS

There is a certain irony in hearing Jerry Sanders, one of the chip industry's best-known trade "cold warriors" describe his company's agreement with Sony as reflecting "a growing spirit of cooperation between the U.S. Semiconductor Industry Association (SIA) and the Electronic Industries Association of Japan (EIAJ)." Ironic or not, Mr. Sanders is right. Dataquest believes that whatever gyrations the governments of Japan and the United States will continue to go through over the issues of trade, U.S. and Japanese companies are making their own accommodations based on that most enlightened of human incentives—self-interest. In the case of the AMD/Sony agreement, both sides certainly seem to have advanced their respective agendas quite nicely through the arrangement.

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Research Newsletter

THE FAB DATABASE SERIES: FAB BOOM IN NORTH AMERICA—48 NEW FABS GOING INTO PRODUCTION IN 1990 AND 1991

INTRODUCTION

This newsletter focuses on the 48 new fabs going into production in the United States during 1990 and 1991 (see Table 1). These new fabs will have a total capacity of 15.7 million square inches of silicon per month when fully operational or 28 percent of the total capacity in North America at the beginning of 1990. Their average capacity will be 350,000 square inches per month or the equivalent of 12,782 150mm wafers per month.

NOTEWORTHY POINTS

It is interesting to note that only 6 of these 48 fab lines (13 percent) will use 200mm wafers. However, these lines represent 29 percent of the new capacity, measured in square inches, coming on-line in the next two years.

Another interesting point is that *all* of the 200mm lines will be running submicron processes, but only 15 of the 33 150mm lines will be running submicron processes. Nevertheless, 59 percent of the new capacity will be submicron.

Approximately one-half of these new fabs will be built in already-existing plants (shells), as opposed to building a shell and installing a fab line in the same time period. Building the shell first and then putting in a fab line later when it is needed saves time. Putting a fab line in an existing shell takes 7 to 16 months; building both a new shell and a fab line takes 18 to 27 months.

DATAQUEST ANALYSIS

Dataquest forecasts that state-of-the-art capacity in North America will grow at a healthy rate over the next two years as new 200mm lines go into production. We believe that this new capacity not only will satisfy a growing demand for new devices, but it also will provide a strong market for the capital equipment industry.

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SEMS Newsletters 1990 Worldwide Fabs

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TABLE 1
North American Fab Database
Fab Activity Planned or Initiated to Begin Production During 1990 and 1991

Company	City	St	Fab Name	Products to be Produced	Process Technology	Status	Target Date Prod. Begins	Waf. Size	Clean Room (Square Feet)	Min. Line-width	Wafer Start Capacity (4 wks.)	Sq. In. Start Capacity (4 wks.)
** Production Begins 1990												
ALLIANCE S/C	LEE'S SUMMIT	MO	KANSAS	256K SRAM 1Mb DRAM	CMOS MOS	RERAMP FROM SHUTDOWN	04/01/90	5	45000	1.20	12750	242473
AMCC	SAN DIEGO	CA	N/A	ARRAYS CBIC	BIP	NEW CLEAN ROOM		6	15000	1.00	8000	219052
AMD	SUNNYVALE	CA	R&D CTR	N/A	N/A	NEW SHELL/CLEAN ROOM	08/01/90	6	35000	0.80	6800	186194
AMD	AUSTIN	TX	FAB 10	FULL VLF LITHO AREA	N/A	NEW CLEAN ROOM	12/01/90	6	0	0.80	10000	273815
AT&T	ORLANDO	FL	OR2	256K 1Mb SRAM	CMOS MITSUBISHI	NEW CLEAN ROOM	11/01/90	6	35000	0.80	22400	613345
DALLAS S/C	DALLAS	TX	FAB 2	SRAM CCD	CMOS	NEW SHELL/CLEAN ROOM	04/01/90	6	20000	1.00	12000	328577
HARRIS S/C	MOUNTAINTOP	PA	N/A	ASIC PWR ICs AUTOMOTIVE	BICMOS CMOS	NEW CLEAN ROOM	02/01/90	6	0	0.00	8500	232742
HP	CORVALLIS	OR	N/A	ASIC MPR DSP	N/A	NEW SHELL/CLEAN ROOM	11/01/90[1]	6	25000	0.00	15000	410722
IBM	HOPEWELL JUNCTION	NY	ASTC/MEM	MEM PROCESS VERIFICATION	CMOS	NEW SHELL/CLEAN ROOM	02/01/90	8	20000	0.80	10000	486205
IBM	HOPEWELL JUNCTION	NY	ASTC/LOG	LOG PROCESS VERIFICATION	BIP CMOS	NEW SHELL/CLEAN ROOM	02/01/90	8	20000	0.80	10000	486205
IBM	ESSEX JUNCTION	VT	BLDG 973	1Mb 4Mb DRAM	CMOS	NEW CLEAN ROOM	03/01/90	8	40000	0.80	20000	972409
IBM	ESSEX JUNCTION	VT	BLDG 973	4Mb DRAM	CMOS M2	NEW CLEAN ROOM	11/01/90	8	40000	0.80	20000	972409
IDT	SANTA CLARA	CA	FAB 3	PROCESS DEVELOP	BICMOS CMOS	NEW SHELL/CLEAN ROOM	03/01/90	6	0	0.50	18000	492866
INTL. MICROCIRC.	MILPITAS	CA	N/A	ARRAYS	CMOS	NEW SHELL/CLEAN ROOM		0	12000	1.50	0	0

(Continued)

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TABLE 1 (Continued)
North American Fab Database
Fab Activity Planned or Initiated to Begin Production During 1990 and 1991

Company	City	St	Fab Name	Products to be Produced	Process Technology	Status	Target Date Prod. Begins	Waf. Size	Clean Room (Square Feet)	Min. Line-width	Wafer Start Capacity (4 wks.)	Sq. In. Start Capacity (4 wks.)
LINEAR TECHNOLOGY	MILPITAS	CA	FAB 2	LIN	BIP CMOS	NEW CLEAN ROOM	10/01/90	5	7500	2.00	6400	121712
MAXIM INTEGRATED PROD.	SUNNYVALE	CA	N/A	OP AMPS A/D D/A	CMOS	RERAMP FROM SHUTDOWN	06/01/90	4	13500	3.00	4000	48695
MICRON TECHNOLOGY	BOISE	ID	FAB 3	SAMPLE 4Mb DRAM 16Mb DEV.	CMOS IBM	NEW CLEAN ROOM	04/01/90	6	0	0.80	20000	547629
MITSUBISHI	DURHAM	NC	N/A	1Mb DRAM ARRAYS MCU	CMOS	NEW CLEAN ROOM	06/01/90	6	0	1.00	8500	232742
MOTOROLA	SCHAUMBERG	IL	N/A	SMARTPOWER	BIP	NEW CLEAN ROOM	02/01/90	4	26000	5.00	10000	121737
NATIONAL S/C	ARLINGTON	TX	CMOS 2	N/A	CMOS	NEW CLEAN ROOM	02/01/90	6	25000	1.20	18000	492866
NATIONAL S/C	PUYALLUP	WA	N/A	1Mb SRAM ARRAYS PLD	BICMOS BIP ECL	NEW CLEAN ROOM	01/01/90	6	40000	0.80	12000	328577
NATL. SECURITY ADMIN.	FORT MEADE	MD	N/A	MIL STD	N/A	NEW SHELL/CLEAN ROOM	12/01/90	6	0	0.80	5000	136907
OKI	TUALATIN	OR	N/A	ARRAYS 256K SRAM 4Mb DRAM	CMOS	NEW SHELL/CLEAN ROOM	06/01/90	6	15000	1.00	16000	438103
PARADIGM TECH.	SAN JOSE	CA	N/A	256K 1Mb SRAM 4 TR.	CMOS M2 POLY 2	NEW CLEAN ROOM	03/01/90	5	8000	1.00	2500	47544
PERFORMANCE S/C	SUNNYVALE	CA	FAB 2	SRAM MPU ASIC	BICMOS CMOS	NEW CLEAN ROOM	11/01/90	6	0	0.80	7000	191670
RAMTRON	COLORADO SPRINGS	CO	N/A	FERRAM 4Mb DRAM DEV.	CMOS M2	NEW SHELL/CLEAN ROOM	12/01/90	6	0	1.00	2700	73930

(Continued)

TABLE 1 (Continued)
North American Fab Database
Fab Activity Planned or Initiated to Begin Production During 1990 and 1991

Company	City	St	Fab Name	Products to be Produced	Process Technology	Status	Target Date Prod. Begins	Waf. Size	Clean Room (Square Feet)	Min. Line-width	Wafer Start Capacity (4 wks.)	Sq. In. Start Capacity (4 wks.)
RAYTHEON	MOUNTAIN VIEW	CA	N/A	N/A	BIP ECL	NEW CLEAN ROOM		4	15000	1.00	6400	77911
ROHM	SUNNYVALE	CA	PILOT	LIN ARRAYS	BIP EPI	RERAMP FROM SHUTDOWN	04/01/90	4	18400	0.00	17000	206952
SIGNETICS	ALBUQUERQUE	NM	FAB 24	N/A	N/A	NEW CLEAN ROOM		6	27000	1.00	8000	219052
VLSI TECHNOLOGY	SAN ANTONIO	TX	MODULE B	ARRAYS CBIC SRAM MPU E2	CMOS M3	NEW CLEAN ROOM	06/01/90	6	10000	0.80	6400	175241
WESTERN DIGITAL	COSTA MESA	CA	DVLPMNT	CUSTOM	CMOS M2	NEW SHELL/CLEAN ROOM	09/01/90	6	12000	1.25	6400	175241
ZILOG	NAMPA	ID	MOD 3	N/A	N/A	NEW CLEAN ROOM		6	12000	1.00	8000	219052
** Subtotal **												
									536400		337750	9772576
** Production Begins 1991												
CYPRESS S/C TEXAS INC.	ROUNDROCK	TX	FAB 3	N/A	CMOS	NEW SHELL/CLEAN ROOM		6	0	0.70	8000	219052
DIGITAL EQUIPMENT	SAN JOSE	CA	N/A	N/A	N/A	NEW SHELL/CLEAN ROOM		6	10000	0.80	3200	87621
GENESIS MICROCHIP	MARKHAM, ONTARIO	CN	N/A	PLD ARRAYS CBIC CUSTOM	CMOS M2	NEW SHELL/CLEAN ROOM	11/01/91	6	20000	1.00	8000	219052
HARRIS S/C	MELBOURNE	FL	N/A	N/A	N/A	NEW SHELL/CLEAN ROOM	11/01/91	6	0	0.00	0	0
IDT	SALINAS	CA	FAB 4	SRAM LOG DSP FIFO	CMOS	NEW SHELL/CLEAN ROOM		6	24000	0.70	10800	295720
INTEL	RIO RANCHO	NM	FAB 9.3	586 MPU EPROM	CMOS	NEW CLEAN ROOM		6	25000	0.80	24000	657155
MOTOROLA	CHANDLER	AZ	BP-6	ECL 50K ARRAYS	ECL BIP BICMOS	NEW SHELL/CLEAN ROOM	05/01/91	6	25000	1.00	20000	547629

(Continued)

TABLE 1 (Continued)
North American Fab Database
Fab Activity Planned or Initiated to Begin Production During 1990 and 1991

Company	City	St	Fab Name	Products to be Produced	Process Technology	Status	Target Date Prod. Begins	Waf. Size	Clean Room (Square Feet)	Min. Line-width	Wafer Start Capacity (4 wks.)	Sq. In. Start Capacity (4 wks.)
MOTOROLA	OAK HILL	TX	MOS-11	4Mb DRAM MCU MPU RISC	CMOS TOSHIBA	NEW SHELL/CLEAN ROOM	05/01/91	6	35000	0.80	17000	465485
NEC	ROSEVILLE	CA	PHASE 2	4Mb DRAM	CMOS	NEW SHELL/CLEAN ROOM	08/01/91	8	70000	0.70	16000	777927
SAMSUNG S/C	N/A	CA	N/A	DRAM SRAM FIFO PLD	CMOS	NEW SHELL/CLEAN ROOM	02/01/91	6	45000	0.00	30000	821444
SGS-THOMSON	SCOTTSDALE	AZ	N/A	1Mb EPROM	CMOS	READY FOR EQUIPMENT	02/01/91	6	22000	1.00	12000	328577
SHARP MICROELECT.	CAMUS	WA	N/A	1Mb SRAM FIFO ROM DSP	N/A	NEW CLEAN ROOM	11/01/91	6	20000	1.00	9600	262862
SIGNETICS	OREM	UT	FAB 18	N/A	BIP	NEW CLEAN ROOM	11/01/91	6	20000	1.00	12000	328577
TI	DALLAS	TX	DMOS 5.1	4Mb DRAM	CMOS	NEW SHELL/CLEAN ROOM	06/01/91	8	25000	0.80	16000	777927
UNITED Si STRUCTURES	N/A	N/A	N/A	CBIC ARRAYS CUSTOM	N/A	NEW SHELL/CLEAN ROOM		0	0	0.00	0	0
VLSI TECHNOLOGY	SAN ANTONIO	TX	MODULE C	ARRAYS CBIC SRAM MPU E2	CMOS M3	NEW CLEAN ROOM	09/01/91	6	10000	0.80	6400	175241
** Subtotal **									351000		193000	5964269
*** Total ***									887400		530750	15736845

N/A = Not Available

Source: Dataquest
February 1990

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Research Newsletter

OVER THERE: HITACHI GOES OVERSEAS

INTRODUCTION

Until recently, most Japanese semiconductor manufacturers have not had fabrication facilities overseas. Now that situation is changing. Hitachi is a case in point. Hitachi currently has a fab in the United States, and, by the summer of 1992, it will be producing wafers at its new facility in Landshut, West Germany (see Table 1).

HITACHI'S FAB IN EUROPE

Hitachi will begin construction of its new fab in Landshut, West Germany, in June 1990. The clean room and support facilities will be built within the grounds of the existing assembly facility at Landshut. Construction of the clean room is expected to be completed by the summer of 1991 when installation of the wafer fab equipment will begin.

The first products from this new facility will be 1Mb SRAMs in the spring of 1992. Hitachi plans to produce 4Mb DRAMs at Landshut with 0.8-micron line geometries at a later date. The company also plans to eventually produce ASICs at this location.

Hitachi expects to spend between $208 million and $278 million (¥30 billion to ¥40 billion) on this new facility. The Landshut fab will employ 300 additional persons when fully operational. Dataquest estimates that volume production capacity of the Landshut fab will be 15,000 to 20,000 wafers per month.

HITACHI'S FAB IN TEXAS

Hitachi already has begun production at its new Irving, Texas, fab in the United States. As in Europe, Hitachi made the final decision to build its fab after the success of its assembly operations at that location. Construction of the Irving fab began back in 1985 when the clean room shell was completed. However, because of the 1985 downturn, plans were put on hold. In March 1988, Hitachi began to reactivate the Irving fab. Currently, this fab is in a ramp-up mode, operating at approximately 3,000 wafers per month and producing 256K SRAMs at 1.3-micron line geometries. The clean room reportedly is 40,000 square feet in size. Hitachi plans to begin producing 1Mb SRAMs in June 1990 and hopes to be producing 5,000 wafers per month by the end of 1990. Dataquest believes that it is likely that Hitachi will begin production of 4Mb DRAMs at Irving, although the company has not yet announced such plans.

TABLE 1
Hitachi's Overseas Fabs

Location	Products	Capacity (Wafers/Month)	Total Fab Cost ($M)	Production Date
Irving, Texas, United States	SRAMs/DRAMs	7,000	120-150	May 1989
Landshut, West Germany	SRAMs/DRAMs	15,000-20,000	208-278	Spring 1992

Source: Dataquest
February 1990

SEMS Newsletters Worldwide Fabs
0006366

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Dataquest estimates that by the end of 1990, Hitachi will have spent between $120 million and $150 million on the Irving fab. This expenditure is roughly proportional to the investment per wafer for the Landshut facility.

DATAQUEST CONCLUSIONS

Although the overseas commitment is large, Hitachi has ample resources to successfully operate overseas. The company's expenditure on its Landshut and Irving fabs will total between $300 million and $400 million, representing a sizable investment. Dataquest notes, however, that Hitachi's worldwide capital spending totaled more than $500 million in 1989. Therefore, Hitachi's total overseas investment for the two new DRAM facilities represents less than one year's capital budget.

Another point worth noting is that both the Landshut and Irving fabs were built after Hitachi had successfully operated assembly facilities at those locations. Manufacturing overseas is a cultural operation as much as it is a manufacturing operation. Investing first in an assembly operation gives the company and its new culture time to get used to each other, before making the expensive and people-sensitive investment in a fab. Dataquest considers this a strategy that other semiconductor manufacturers might also follow and a strategy that local governments should be aware of when they seek to attract advanced semiconductor manufacturing to their locales.

Kunio Achiwa
George Burns

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Research Newsletter

THE FAB DATABASE SERIES—A COMPARISON OF WORLDWIDE FABS, CAPACITIES, AND WAFER SIZES

This newsletter is the first in a series that will discuss various topics on semiconductor manufacturing from a worldwide perspective using the Semiconductor Equipment and Materials Service (SEMS) fab database. This particular newsletter will discuss the number of fabs by region, capacities of the fabs in each region, and distribution within each region of the number of fabs and capacities by wafer size.

The SEMS worldwide fab database contains information on 1,050 fab lines. These fab lines are either production-based, pilot-based, quick-turn, or research and development (R&D) lines that use semiconductor substrates for front-end wafer processing.

The following analysis includes the 763 production-based and pilot-based front-end fab lines that currently are in production using silicon wafers. Also included in this analysis are production-based and pilot-based front-end fab lines that are going into production during 1990. The 763 fabs do not include R&D fab lines, quick-turn ASIC fab lines, or fab lines that process compound semiconductor substrates such as gallium arsenide (GaAs).

DEFINITIONS

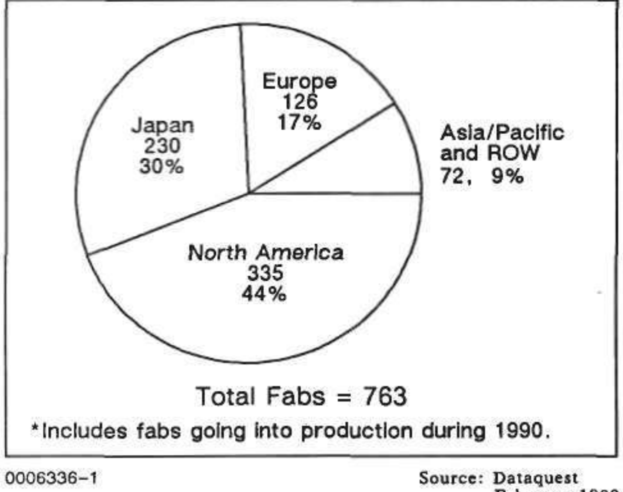
The definitions of a fab line and front-end wafer processing are as follows:

- A fab line is a processing line in a clean room that is equipped to do all front-end wafer processing. There can be many fab lines at one location.
- Front-end wafer processing is defined as all steps involved with semiconductor processing, beginning with the polished wafer and ending at the die probe stage.

FABS AND CAPACITY BY REGION

Of the 763 production-based and pilot-based worldwide fab lines, 44 percent are located in North America (see Figure 1). These fab lines have 32 percent of worldwide capacity, as measured in square inches of silicon (see Figure 2). Japan, on

FIGURE 1
Number of Fabs by Region*



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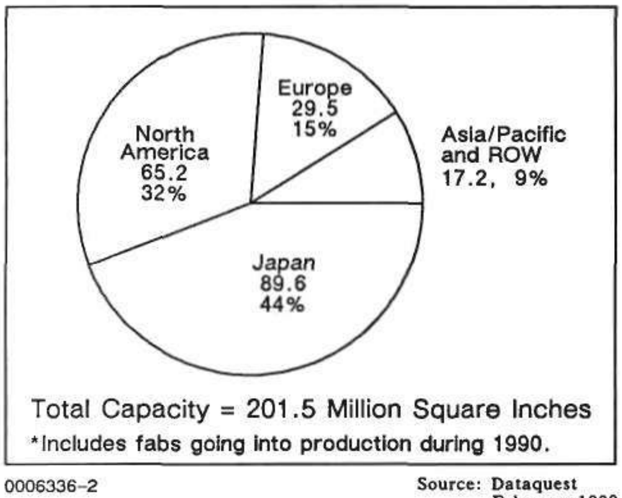
Source: Dataquest
February 1990

FIGURE 2
Capacity per Four Weeks*
(Millions of Square Inches of Silicon)



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Source: Dataquest
February 1990

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the other hand, has 30 percent of the worldwide fabs and 44 percent of the worldwide silicon capacity. The fabs in North America have an average capacity of 195,000 square inches of silicon per four weeks; this average capacity is the lowest of the four major regions. The fabs in Japan have an average capacity of 389,000 square inches of silicon per four weeks, representing the highest average capacity of the four major regions. The fabs in the Asia/Pacific-ROW region have an average capacity of 239,000 square inches of silicon per four weeks, and the fabs in Europe have an average capacity of 234,000 square inches per four weeks.

Capacity by Region and Wafer Size

Japan has the most 125mm and 150mm lines and also the largest capacity for processing 125mm and 150mm wafers in terms of wafer starts and millions of square inches of silicon (see Figure 3). Although there will be more 200mm lines in Japan (including those of IBM and Texas Instruments) than in North America by the end of 1990, North America still will have slightly more 200mm capacity (5.0 million verses 4.9 million square inches per month) than Japan (see Figure 3). IBM accounts for most of North America's 200mm capacity.

Because of aggressive plans for capacity expansion that are beginning to bear fruit in South Korea and Taiwan, by the end of 1990 there will be as many 150mm lines and more 150mm wafer capacity in the Asia/Pacific-ROW region than in Europe (see Figure 3). For 150mm wafers, Asia/Pacific-ROW will have 8.1 million square inches of capacity versus Europe's 5.5 million.

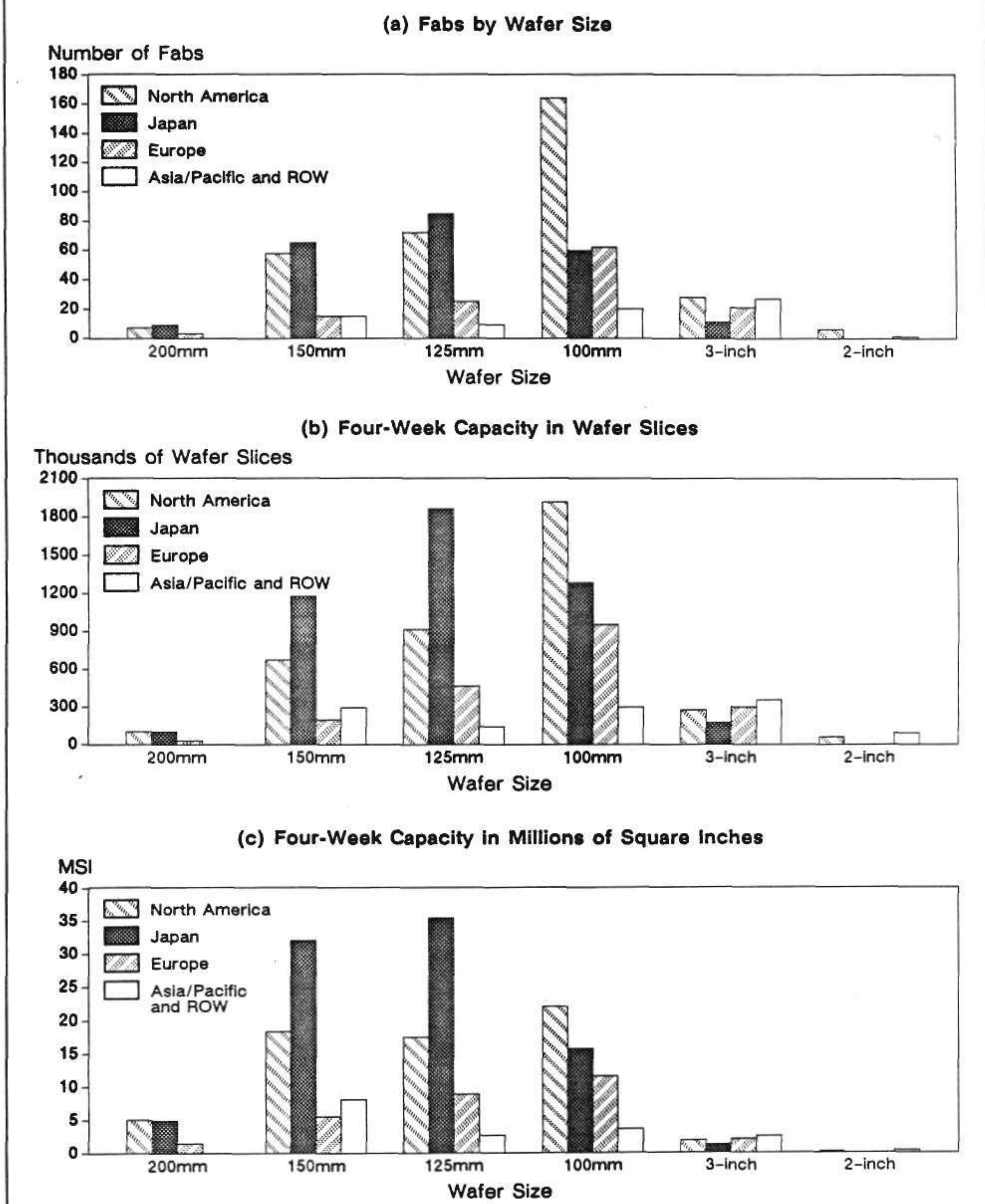
Dataquest Conclusions

The distribution of wafer sizes in North America and Europe indicate that these regions have most of their wafer start capacity on 100mm wafers. The distribution for Japan indicates that Japan has most of its wafer start capacity on 125mm wafers. This is a reflection of the fact that Japanese semiconductor companies generally have outdone their North American and European counterparts in capital spending throughout most of the 1980s.

The distribution of wafer sizes in the Asia/Pacific and ROW regions also reflects their capital spending patterns. The relative absence of 125mm capacity is because Asia/Pacific and ROW companies have developed aggressive capital spending plans after the introduction of 150mm wafer processing technology to the industry.

Mark T. Reagan

FIGURE 3
Worldwide Fab Comparison by Regions and Wafer Size



*Includes fabs going into production during 1990.

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Source: Dataquest
February 1990

Manufacturing
Productivity

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Research *Bulletin*

PRODUCTION AXIOM: SEMICONDUCTOR COMPANIES MUST DOUBLE REVENUE EVERY FIVE YEARS JUST TO STAY EVEN

PRODUCTION DOUBLES EVERY FIVE YEARS

Historically, semiconductor production has doubled every five years (see Figure 1). This rate of growth has resulted from the growing electronic equipment market, new applications for semiconductors, and increasing pervasiveness of semiconductors into existing applications. Dataquest expects this trend to continue: Worldwide production of semiconductors was $60 billion in 1989 and is forecast to be $121 billion in 1994. In order to stay even in the market share race, semiconductor companies *have* to double their revenue in five years' time.

PRODUCTION FORECAST

Semiconductor production is defined as the final sales value of all merchant and captive devices produced in the world. Assuming no inventory fluctuations during a year, semiconductor production equals the value of all merchant consumption plus the value of captive semiconductor production if sold on the merchant market.

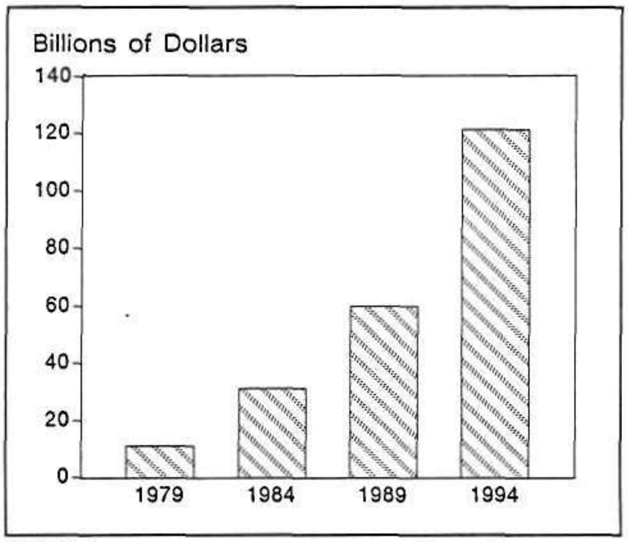
Worldwide Production

The history of semiconductor production for the period from 1985 through 1989 is shown in Table 1. The worldwide compound annual growth rate (CAGR) of semiconductor production for that period was 22 percent. The forecast for semiconductor production for the period 1990 through 1994 is shown in Table 2. The CAGR for this forecast period is slightly less than for the previous period (19 percent versus 22 percent). The reason for the higher CAGR in the previous period is the tremendous appreciation of the yen from 1985 to 1988, which we do not expect to reoccur within our forecast horizon.

Production by Region

The growth of semiconductor production in Asia/Pacific and in Europe will be much faster than in Japan and in the United States. From 1990 through 1994, Asia/Pacific will grow at a CAGR of 27 percent and Europe will grow at a CAGR of 26 percent. For the same period, Japan and the United States will grow at CAGRs of 16 percent and 19 percent, respectively. Because of these regions' high growth rates, we expect Asia/Pacific's and Europe's combined share of worldwide production to grow from 14 percent in 1988 to 22 percent in 1994.

FIGURE 1
Worldwide Semiconductor Production (1979-1994)



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Source: Dataquest
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TABLE 1
Worldwide Semiconductor Production by Region Merchant and Captive—Historical (Millions of Dollars)

	1985	1986	1987	1988	1989	CAGR 1985-1989
North America						
Merchant	10,411	12,129	14,116	17,226	18,609	16%
Captive	2,243	2,327	2,596	2,945	3,271	10%
Total North America	12,654	14,456	16,712	20,171	21,880	15%
Japan						
Merchant	10,500	14,524	18,824	26,488	28,834	29%
Captive	151	162	180	205	227	11%
Total Japan	10,651	14,686	19,004	26,693	29,061	29%
Europe						
Merchant	3,024	3,426	4,220	5,277	5,869	18%
Captive	379	405	451	512	568	11%
Total Europe	3,403	3,831	4,671	5,789	6,437	17%
Rest of World						
Merchant	406	756	1,088	1,868	2,522	58%
Captive	0	0	0	0	0	N/A
Total Rest of World	406	756	1,088	1,868	2,522	58%
Total Worldwide						
Merchant	24,341	30,834	38,251	50,859	55,834	23%
Captive	2,773	2,894	3,227	3,662	4,066	10%
Total Production	27,114	33,728	41,478	54,521	59,900	22%
Growth Rate	(15.6%)	24.4%	23.0%	31.4%	9.9%	

N/A = Not Applicable

Source: Dataquest February 1990

TABLE 2
Worldwide Semiconductor Production by Region Merchant and Captive—Forecast (Millions of Dollars)

	1990	1991	1992	1993	1994	CAGR 1990-1994
North America						
Merchant	17,806	20,557	25,654	34,068	36,582	20%
Captive	3,350	3,834	4,602	6,046	6,521	18%
Total North America	21,156	24,391	30,256	40,114	43,103	19%
Japan						
Merchant	28,141	30,877	36,599	47,391	50,790	16%
Captive	233	267	320	420	453	18%
Total Japan	28,374	31,144	36,919	47,811	51,243	16%
Europe						
Merchant	6,944	8,985	11,795	15,825	17,748	26%
Captive	582	666	800	1,051	1,133	18%
Total Europe	7,526	9,651	12,595	16,876	18,881	26%
Rest of World						
Merchant	3,125	4,220	5,359	7,028	8,158	27%
Captive	0	0	0	0	0	N/A
Total Rest of World	3,125	4,220	5,359	7,028	8,158	27%
Total Worldwide						
Merchant	56,017	64,640	79,408	104,314	113,278	19%
Captive	4,165	4,767	5,722	7,517	8,107	18%
Total Production	60,182	69,407	85,130	111,831	121,385	19%
Growth Rate	0.5%	15.3%	22.7%	31.4%	8.5%	

N/A = Not Applicable

Source: Dataquest February 1990

DATAQUEST CONCLUSIONS

Led by growth in Asia/Pacific and Europe, semiconductor production is forecast to continue to grow and double every five years. Dataquest believes that those semiconductor companies that have not doubled their revenue five years from now will fall further behind in the market share race.

George Burns

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Research *Newsletter*

DRAM PRODUCT LIFE CYCLES—A VIEW FROM THE INDUSTRY

INTRODUCTION

At the Dataquest Semiconductor Industry Conference held in October in Monterey, California, a half-day session was dedicated to the subject of DRAMs. Six speakers discussed DRAM topics that included DRAM product life cycles, manufacturing costs, average selling prices (ASPs), capacity, packaging trends, technical characteristics, and applications. This newsletter focuses on DRAM product life cycles, one of the DRAM topics presented at the conference.

The DRAM product life cycle for each new generation of DRAMs is a subject of great interest to Semiconductor Equipment Manufacturing and Materials Service (SEMMS) clients. A secure knowledge of DRAM product cycles helps participants at all levels of the electronics industry--including equipment and materials suppliers, device manufacturers, and device end users--better plan their future company activities.

Three of the invited speakers presented their views of DRAM product life cycles, which, in the interest of our clients, we present in this newsletter. David Sear, vice president, Standard Products Operations, Integrated Circuits Division, Fujitsu Microelectronics, gave Fujitsu's view; Dr. Tsugio Makimoto, director and general manager, Semiconductor Design and Development Center, Hitachi, presented Hitachi's view; and Robert J. Brown, senior vice president and group executive, Semiconductor Operations Group, Toshiba America Electronic Components, presented Toshiba's view. We also augment the speakers' viewpoints with Dataquest's perspective.

DRAM PRODUCT LIFE CYCLES

Figures 1, 2, and 3 show Fujitsu's, Hitachi's, and Toshiba's views of DRAM product life cycles, respectively. The figures show the life cycles of each DRAM generation and the projected worldwide unit demand throughout the DRAM's life cycle. The three figures probably were meant to present general industry projections rather than official company forecasts, and Dataquest does not want to manipulate these data to arrive at decisions unwarranted by the accuracy of the data. Nevertheless, significant differences exist among the general viewpoints of these companies, such that the reader should examine the charts in more detail. (The charts also use different scales, so the reader should be careful with direct comparisons of the charts.)

For Fujitsu, worldwide peak unit production for each new generation of DRAMs surpassed that of the previous generation. Toshiba's view is similar to Fujitsu's, at least for the 256K, 1Mb, and 4Mb generations. Hitachi's view is somewhat different: It projects that peak production, at least for the 1Mb, 4Mb, and 16Mb DRAMs, essentially is the same for each new generation and lower than the peak production for 256K DRAMs. Table 1 shows some rough data that Dataquest extracted from Figures 1 through 3. Using the 16Mb DRAM as an example, Fujitsu forecasts peak unit production to be 1,500 million units, twice Hitachi's estimated peak production of 750 million units.

Fujitsu estimates that worldwide DRAM demand will exceed 500 million units for each DRAM generation from 1Mb through 64Mb for six to seven years, while Hitachi estimates that worldwide demand will exceed 500 million units for only three to four years for the 1Mb, 4Mb, and 16Mb DRAM generations.

When Fujitsu's higher peak unit production and longer time for the DRAM generation to be above 500 million units is compared with Hitachi's lower peak production and shorter time above 500 million units, it is clear that Fujitsu forecasts a much larger number of units for each DRAM generation than does Hitachi.

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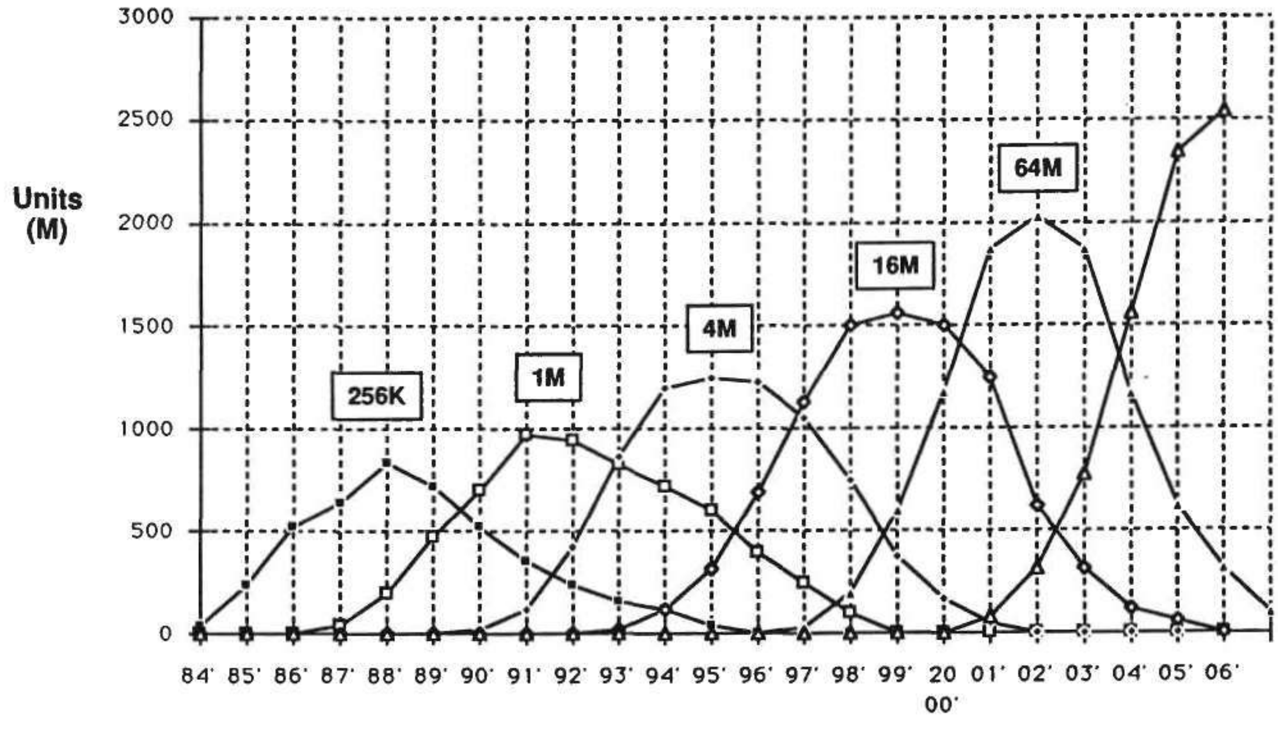
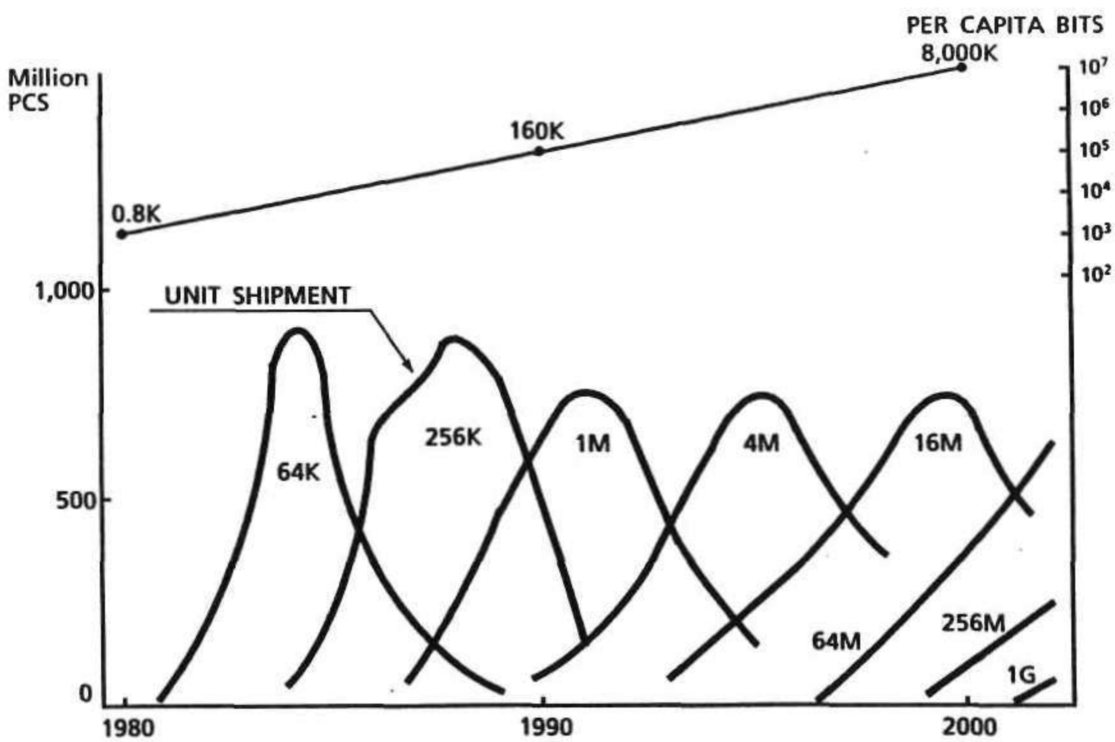
FIGURE 1
Fujitsu's Projected DRAM Life Cycle



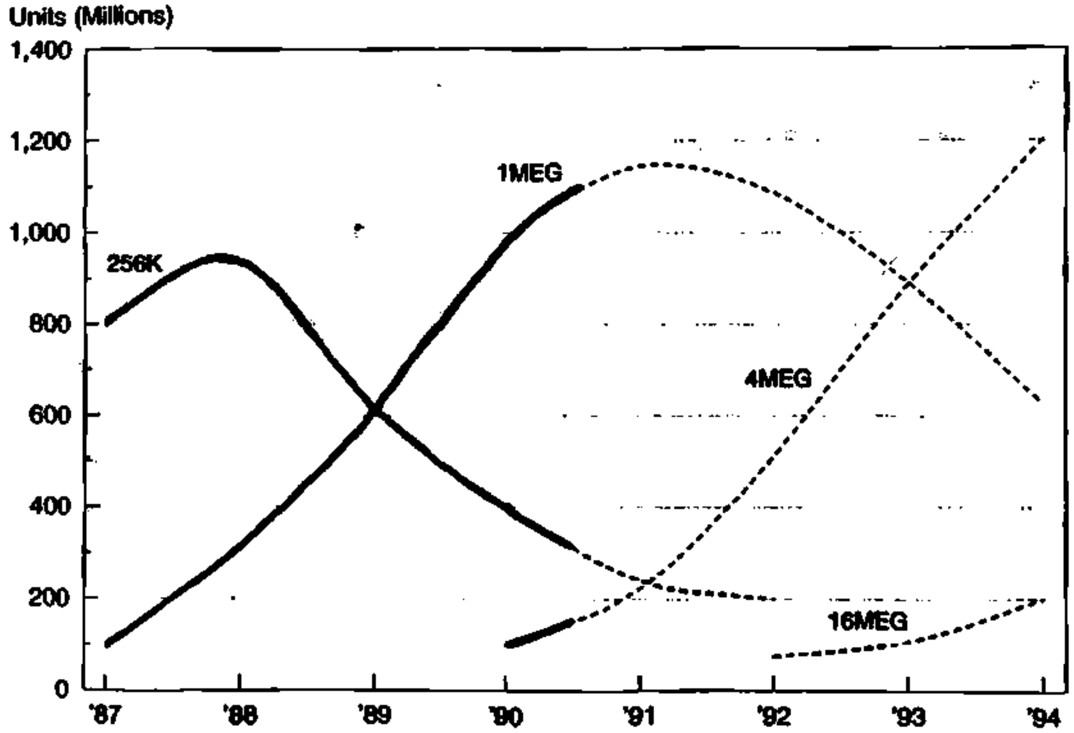
Source: Fujitsu

FIGURE 2
Hitachi's DRAM Trend



Source: Hitachi

FIGURE 3
Toshiba's DRAM Market Forecast



Source: Toshiba

Although these are only a few companies' views of the future, the fact that they are disparate leads to caution. The semiconductor industry in general needs to have a fairly consistent view of the future in order to avoid the cyclicality that has characterized the industry. For instance, if the consensus forecast is for high worldwide demand, then capital expansions are more likely to be made to meet the projections, and the companies making expansions will be able to share in the rising market. On the other hand, if actual demand turns out to be lower than was originally forecast, the industry will have an overcapacity situation with all the concomitant problems that such a situation brings to the semiconductor manufacturers and the equipment and material suppliers.

Similarly, if the forecast is for a lower worldwide demand, then fewer capital expansions will be made, and the companies moderating their expansions will not find themselves in an overcapacity situation. However, if the actual demand proves to be much higher than originally forecast, then the industry will find itself in an undersupply situation with all of the problems that entails for the end users of the devices.

Table 1 shows that the three companies agree on the year of peak unit production for each DRAM generation--1991 for the 1Mb, 1995 for the 4Mb, and 1999 for the 16Mb. Fujitsu estimates that the 64Mb DRAM will reach peak production between the years 2002 and 2003. The figures also show that DRAM generation life cycles for the 1Mb, 4Mb, and 16Mb devices are approximately nine to ten years or more.

DATAQUEST PERSPECTIVE

Dataquest's projections for peak unit production of the 64K through 4Mb devices also are shown in Table 1.

Dataquest estimates that the 1Mb DRAM will reach a peak unit production of 1,075 million units during 1991, which is similar to Fujitsu's and Toshiba's projections, but considerably higher than Hitachi's forecast of 750 million units. We believe that 1Mb suppliers currently are in an oversupply and overcapacity situation, which continues to drive down prices for 1Mb DRAMs. We also believe that major European and Japanese DRAM suppliers are cutting back production volumes of 1Mb devices. The number of cutbacks and the timeliness of these cutbacks may not be adequate to reduce the estimated oversupply for the

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TABLE 1
DRAM Market Trends—Different Views
(Millions of Units)

	64K		256K		1Mb		4Mb		16Mb		64Mb	
	Peak Year	Units at Peak	Peak Year	Units at Peak	Peak Year	Units at Peak	Peak Year	Units at Peak	Peak Year	Units at Peak	Peak Year	Units at Peak
Fujitsu	NA	NA	1988	800	1991	1,000	1995	1,200	1999	1,500	2002-2003	2,000
Hitachi	1984-1985	900	1988	875	1991	750	1995-1996	750	1999-2000	750	NA	NA
Toshiba	NA	NA	1987-1988	950	1991	1,150	NA	NA	NA	NA	NA	NA
Dataquest	1984	852	1988	963	1991	1,075	1995	1,200	NA	NA	NA	NA

NA = Not available
Source: Fujitsu, Hitachi, Toshiba, Dataquest (December 1990)

remainder of this year and 1991. With the increasing availability of and demand for 4Mb DRAMs, many end users may consider purchasing more 1Mb devices to protect their investments in products that require the 1Mb device.

Considering the 4Mb DRAMs, we estimate that peak unit production will occur in 1995 and will be more than 1,200 million units.

A number of semiconductor manufacturers have announced availability of 16Mb DRAM engineering samples starting in either the fourth quarter of 1990 or the first quarter of 1991. The manufacturers include Fujitsu, Hitachi, Matsushita, NEC, Samsung, Siemens, Texas Instruments, and Toshiba. Engineering complications still exist for the 16Mb DRAM, including the trench or stacked capacitor cells and standardized packaging dimensions. We believe that volume shipments of the 16Mb DRAM will not occur until 1992 and that peak production occurring in the years 1999 to 2000 is realistic.

Hitachi announced late last summer that it has a prototype of a 64Mb DRAM and is rapidly working toward a fully functional sample. It is unlikely that this sample will be available until after 1992.

DATAQUEST CONCLUSIONS

For equipment and materials suppliers, DRAM product life cycles indicate when each new generation of equipment and materials is required. Dr. Graydon Larrabee of Texas Instruments has estimated that development of manufacturing processes and production equipment for each new generation of semiconductor devices must begin about eight to ten years before the year in which volume shipments of the device first occur. For instance, the projections shown in Figures 1 and 2 indicate that volume shipments of the 64Mb DRAM will commence around 1997. This start date means that 64Mb DRAM processes and equipment must already be under substantial development, and, indeed, this is the case indicated by Hitachi's 64Mb DRAM announcement.

The eight- to ten-year development cycle also means that equipment and material suppliers need a long-term approach to R&D that includes both near-term and long-term projects. The challenge is how can the smaller equipment and materials suppliers generate sufficient R&D funds to accomplish such a strategy? The challenge extends to the smaller semiconductor manufacturers as well—are they making sufficient R&D investments in long-term projects to ensure their future survival? U.S. wafer fab equipment manufacturers and semiconductor manufacturers already are sustaining an R&D investment rate of about 14 percent of sales, which is among the highest of any industry.

Joe Grenier
Ione Ishii

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Research *Newsletter*

TECHNOLOGY TRENDS AND FAB COSTS: AN OVERVIEW

At the recent Dataquest Semiconductor Industry Conference in Monterey, California, several industry speakers alluded to the possibility of $1 billion fabs being built well before the end of this decade. The allusion was not toward an eagerly awaited prospect—rather, it was toward a prospect to be dreaded.

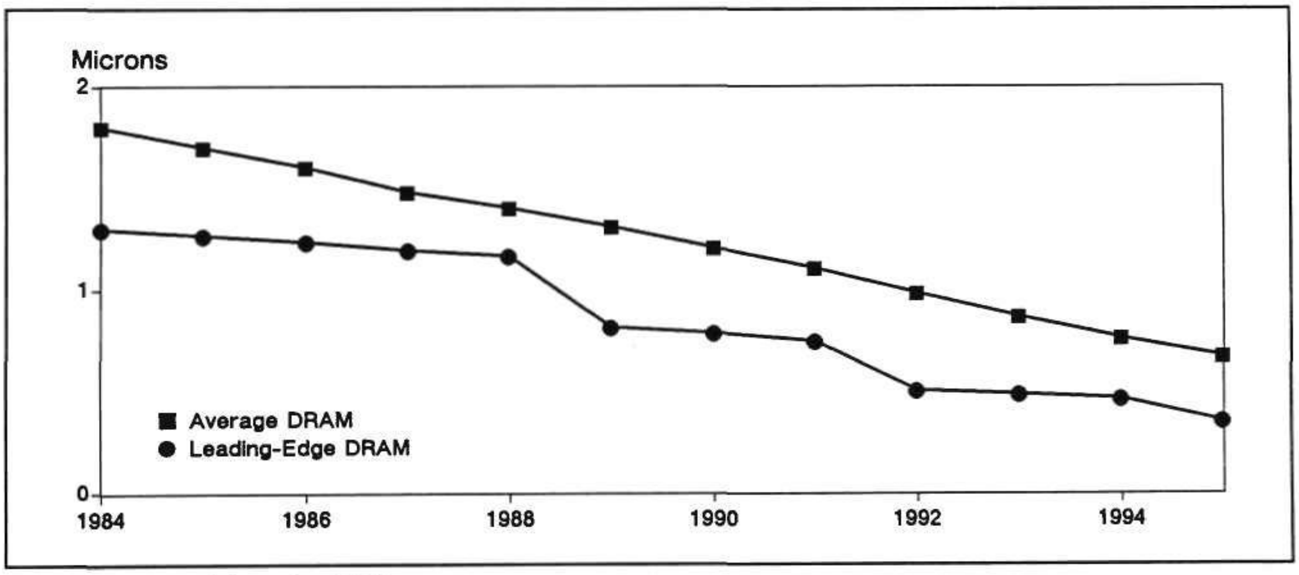
This newsletter examines some of the forces pushing DRAM fab costs up and lists some areas in which semiconductor manufacturers and their vendors may be able to keep fab costs from rising. The idea is to present a high-level overview of the main forces responsible for the inexorable push to higher manufacturing costs. Future Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS) newsletters will examine these forces in more detail.

TECHNOLOGY DRIVES FAB COSTS

Dataquest has identified five technical trends that have and will continue to drive fab costs up: decreasing line geometries, increasing die sizes, increasing mask levels, increasing process complexity, and increasing the levels of interconnect (see Figures 1, 2, 3, 4, and 5).

Figures 1 and 2 show the trends for historical and forecast line geometries and die sizes for leading-edge production DRAMs and average DRAMs through 1994. Leading-edge production DRAMs are defined as the most advanced generation of DRAMs in production, with at least 1 million units per year in volume. The line geometry of the average DRAM is a weighted average of the line geometries of all generations of DRAMs

FIGURE 1
DRAM Linewidth Trend



Source: Dataquest (November 1990)

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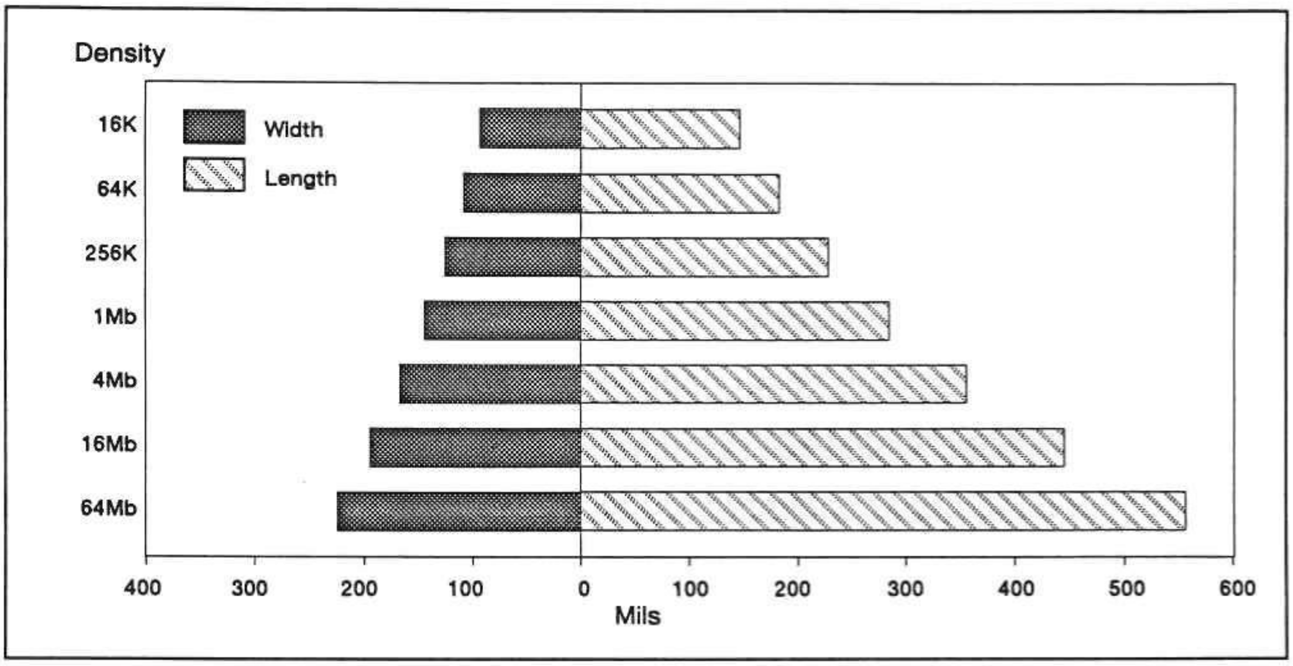
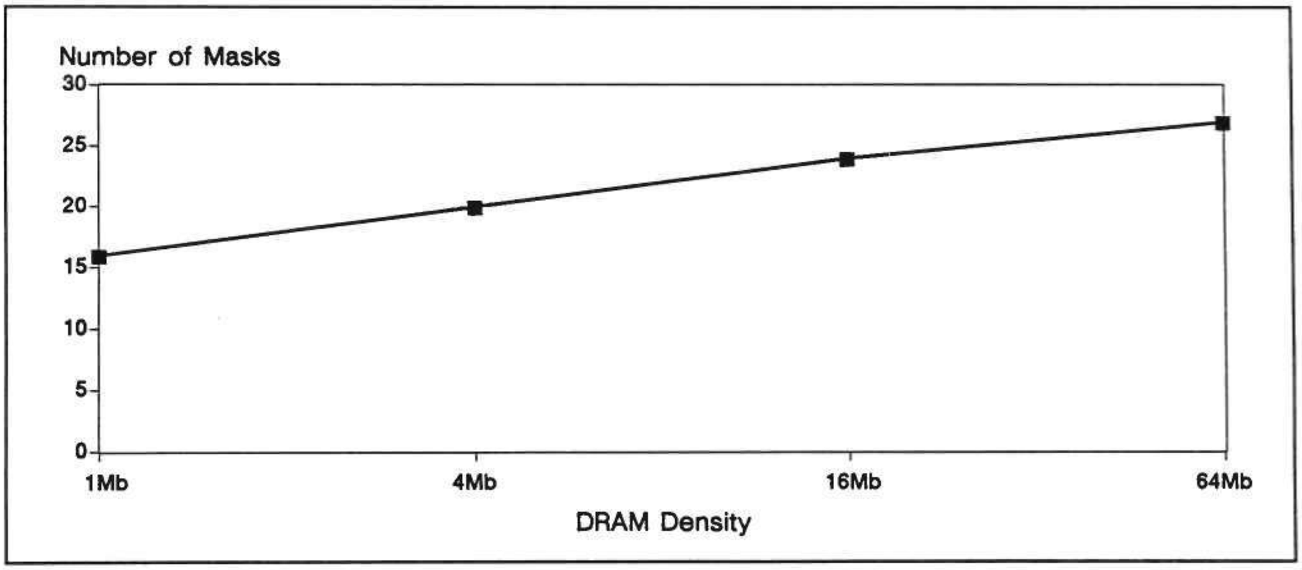
FIGURE 2
DRAM Die Dimensions—ISSCC Technical Papers



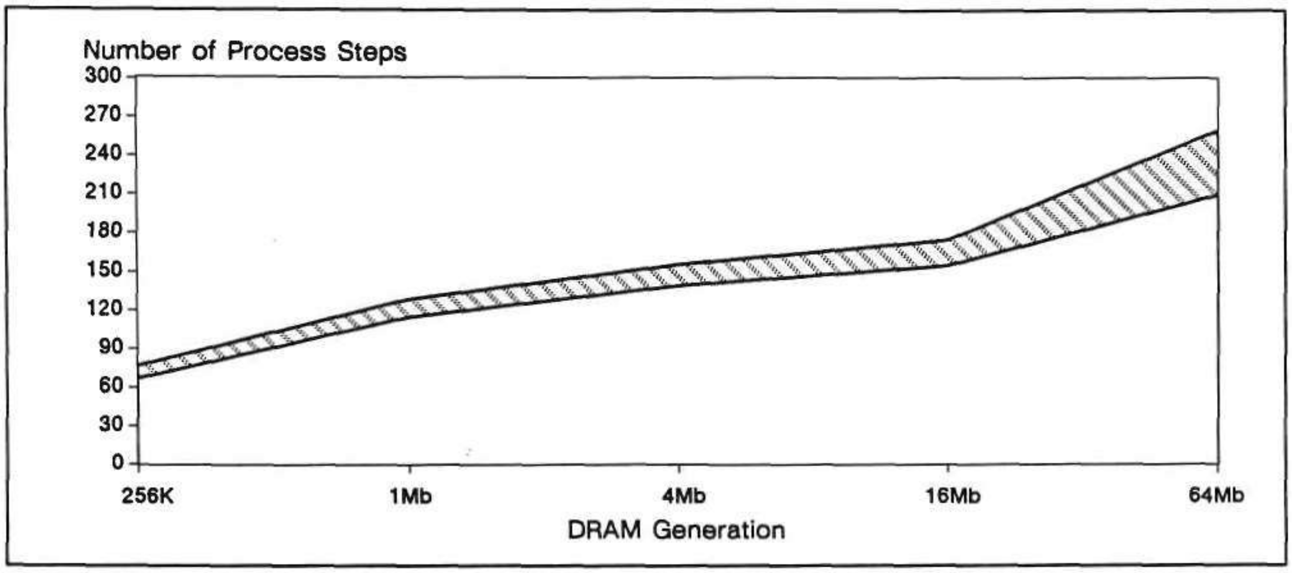
Source: ISSCC Technical Papers, Dataquest (November 1990)

FIGURE 3
DRAM Mask Levels



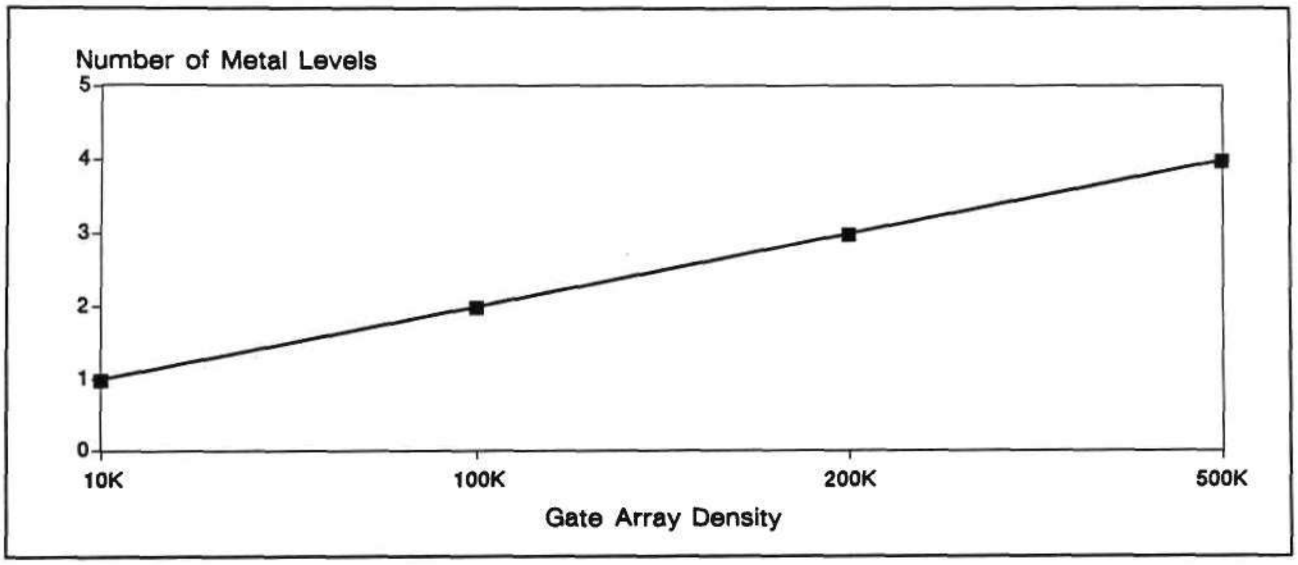
Source: Dataquest (November 1990)

FIGURE 4
Increase in Process Complexity—Number of Process Steps



Source: Dataquest (November 1990)

FIGURE 5
ASIC Fabs Drive Interconnect Technology—Number of Metal Levels



Source: Dataquest (November 1990)

currently in production. Today, this weighted average includes the generations of 64K DRAMs, 256K DRAMs, 1Mb DRAMs, and 4Mb DRAMs.

By 1994, leading-edge 16Mb DRAM production will be at 0.5-micron and have a die size of 86,000 square mils. Dataquest notes that at these sizes, the technical demands on advanced lithography tools will be very stringent—and expensive.

Not only will line geometries shrink to 0.5 micron, but because of increasingly complex device architecture, the number of DRAM mask levels will continue its historical rate of increase. Dataquest expects the number of mask levels for the 64Mb DRAM to reach 27 (see Figure 3).

Increasing the number of mask levels is a major factor in increasing the level of process complexity. One measure of process complexity is the number of process steps, i.e., the number of times that a wafer moves from one piece of process equipment to another. Figure 4 shows the range of the expected number of process steps. Dataquest believes that, on average, the total number of process steps per wafer will increase from approximately 130 for the 1Mb DRAM to approximately 250 for the 64Mb DRAM. (There are other measures of complexity that additionally count the major processes a wafer undergoes on one piece of equipment. For example, one move to a piece of track equipment could be counted as six or seven moves, depending on the track system's configuration. For purposes of this analysis, it would be counted as only one move.)

Metal interconnection on the chip also is becoming more complex, and both DRAM and ASIC devices will see a rise in metal levels. For example, 1Mb SRAMs, 4Mb SRAMs, and 16Mb DRAMs will use two levels of metal, and ASICs, which lead interconnect technology, will have four or five levels of metal (see Figure 5). Each interconnect level actually involves many deposition and etch steps and drives up process complexity as well as requiring expensive equipment.

INCREASING FAB COSTS

The cost of a state-of-the-art fab has risen from $30 million in 1970 to $300 million today (see Figure 6). Process equipment costs have risen from 40 percent of the total fab costs to approximately 70 percent. Because of the aforementioned increase in technical complexity, we expect fab costs to rise at an even faster rate in the future.

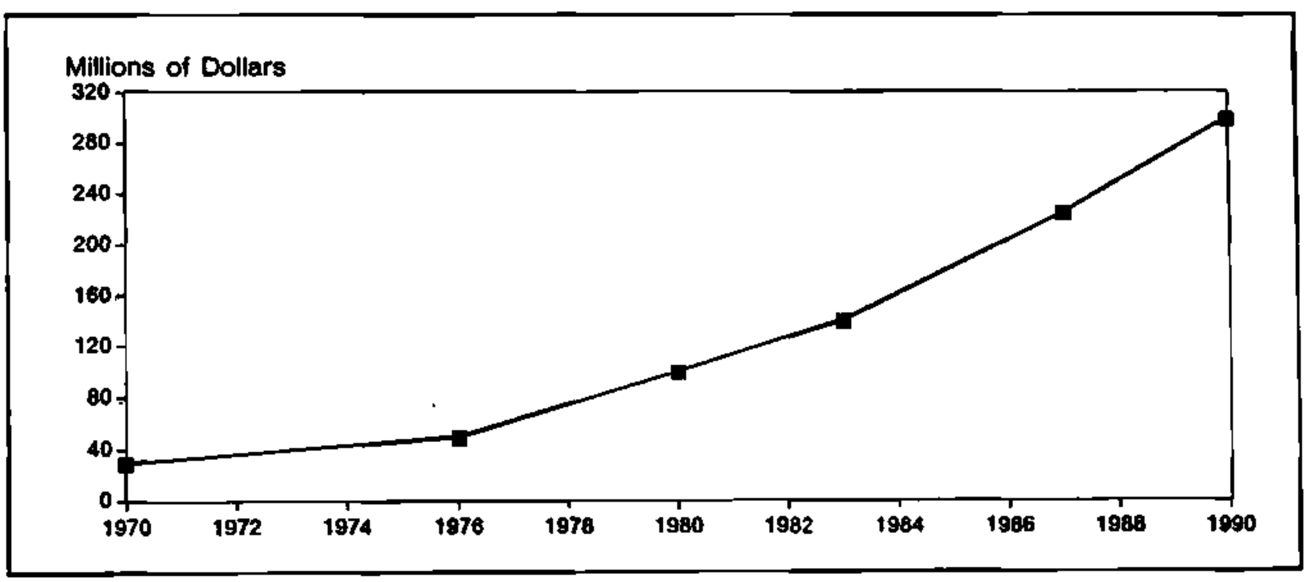
Dataquest analysts recently discussed the possible costs of 64Mb DRAM (circa 1996) fabs with several semiconductor manufacturers in Japan and in the United States (see Figure 7). From these discussions, as well as our discussions with clean room systems vendors and equipment vendors, we have concluded that the costs of a state-of-the-art fab will increase at a faster rate than the recent past suggests. Semiconductor manufacturers' estimates for 64Mb DRAM fabs ranged from $500 million to as high as $1 billion.

Taking the lower estimate as a conservative boundary, we believe that the cost of such a fab will rise at a compound annual growth rate (CAGR) of 15 percent from 1990 to 1996. By contrast, the CAGR of fab costs from 1970 to 1990 was 12 percent.

CAN A BILLION-DOLLAR FAB BE AVOIDED?

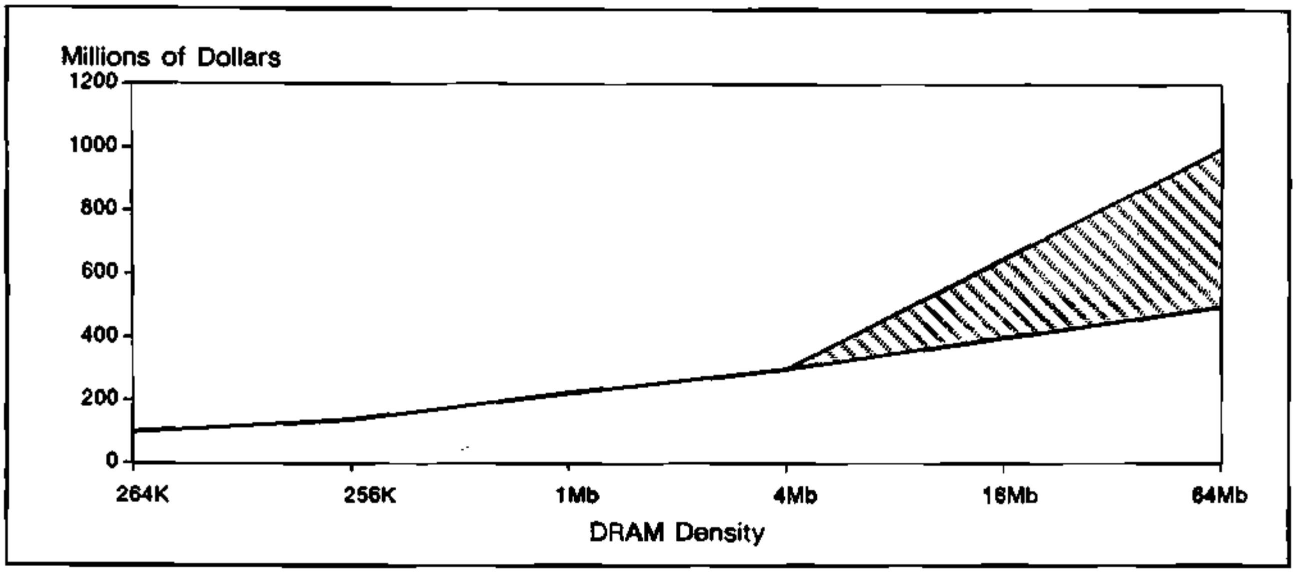
Although it is possible that clean room systems' costs such as air handling may be contained through new technologies such as SMIF isolation technology, clean room systems' costs are not the main factor in rising fab costs. Equipment costs and manufacturing complexity are the major factors driving up the costs of new facilities. Semiconductor companies already have begun to address these factors—and will continue to do so.

FIGURE 6
Building plus Equipment Costs for a High-Volume Fab Line



Source: Dataquest (November 1990)

Figure 7
Cost of a New DRAM Fab



Source: Dataquest (November 1990)

Containing Equipment Costs

In order to contain rising equipment costs, there are two areas in particular on which semiconductor manufacturers have set their sights: equipment uptime and throughput. Semiconductor manufacturers will continue to demand more throughput and uptime.

Equipment uptime is an area in which there has been progress in recent years. However, significant gains still can be made by reducing both scheduled and unscheduled downtime. Dataquest estimates that some types of equipment are down for either scheduled or unscheduled maintenance more than 30 percent of the time and that some mean time between failures are as low as 100 hours.

Ways in which throughput can be increased include the use of cluster tools to decrease cycle time and the implementation of automation and computer-integrated manufacturing by manufacturers in order to decrease equipment idle time.

Use of larger wafers also increases throughput. Most DRAM manufacturers are moving to 8-inch wafers now in order to increase the throughput for their 4Mb and 16Mb DRAMs. Some semiconductor manufacturers are beginning to discuss the next wafer size: will it be 10-inch? Or perhaps those manufacturers already using 8-inch wafers will skip the 10-inch wafer and instead jump to 12-inch wafers.

Taking Aim at Process Technology

Semiconductor companies also are taking a hard look at process complexity. They now are designing process technology for manufacturability from the beginning of the R&D phase. Semiconductor manufacturers that have designed manufacturability into their process development report dramatic increases in yields, lowered defect densities, and decreased cycle times. The net effect is to increase throughput of good devices out for a given equipment set.

Manufacturability is also a key concept in the design architecture of products that will be manufactured. Micron Technology is an example of a company that has benefited greatly from a simplified product architecture: it has been able to make its DRAMs with fewer mask levels and smaller die than have most other DRAM manufacturers. Because of this ability, Micron was able to use projection aligners in a mix-and-match manufacturing strategy for 1Mb DRAMs when most other DRAM manufacturers had moved on to the more expensive lithography tool. Although manufacturers probably will not be able to use projection aligners for more advanced DRAMs, equipment cost benefits probably will continue to accrue to manufacturers that have the simplest architectures.

Design for manufacturability also reduces development cycle time. A manufacturer that has designed for manufacturability is able to get a new product to market faster than a manufacturer that has not.

DATAQUEST CONCLUSIONS

Whether a $1 billion fab can be avoided is uncertain. Technology trends will continue to make manufacturing more complex. What *is* certain is that both device manufacturers and equipment vendors will be under pressure to contain costs. More than ever, manufacturers and vendors will have to work together. Equipment vendors and semiconductor manufacturers that can lower the cost per device produced will have a very powerful competitive advantage over manufacturers that cannot.

George Burns

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that go beyond either the level of detail contained in the newsletters or the scope of what is normally published in the newsletters. In order to provide complete decision support to our clients, Dataquest has a consulting activity available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Research Newsletter

LINE GEOMETRIES OF GATE ARRAYS AND DRAMS CONVERGE

INTRODUCTION

Line geometries of DRAMs have long been the benchmark by which the industry has judged its lithography needs. However, in recent years, the line geometries of gate arrays have been shrinking almost as fast as those of DRAMs. For example, in 1984, the line geometry of the average gate array and the leading-edge gate array lagged the line geometry of the average and leading-edge DRAMs by about two years. This lag is much shorter now, and Dataquest expects it to be less than one year by 1995.

MARKET-DRIVEN CONVERGENCE

Different Manufacturing Strategies Lead to the Same End

The reasons for this convergence are market driven on the gate array side. The number of usable gates is a competitive feature of gate arrays. There are several different strategies whereby manufacturers can increase the number of usable gates—one depending on shrinking line geometries.

If the percentage of total gates actually used (gate utilization) is constant, a manufacturer can increase the number of used gates by increasing the number of total gates. On the other hand, if a manufacturer is able to increase the gate utilization rate, the number of gates used can be increased without increasing the number of total gates. Table 1 lists the different strategies open to manufacturers in order to increase usable gates.

Strategies Can Be Mixed

These strategies are not exclusive. Manufacturers differ, however, on the mix of strategies that they adopt. Japanese manufacturers, for example, tend to emphasize increasing the number of available gates by shrinking line geometries and increasing die size. This is a technique that they have used very successfully in the DRAM market.

It is interesting to note that because manufacturers can mix the strategies listed in Table 1, a successful gate array manufacturer does not have to follow "the leading edge" in order to be successful. The important factor is the mix of strategies and how they work in bringing the customer the most usable gates in the fastest time. The smaller line geometries and maximum levels of metal are only means to this end.

FORECAST FOR LINE GEOMETRIES

Our forecast for the line geometries of DRAMs and gate arrays is shown in Figure 1. The forecast for leading-edge gate arrays is the smallest geometry that will be used by those manufacturers that follow the strategy of shrinking line geometries in order to increase the available number of gates. Those manufacturers that opt for the strategy of optimizing routing efficiency can get by with a smaller number of total gates and larger line geometries.

The year in which the leading-edge DRAM generation begins is the year in which that density sells 1 million units. The year that a leading-edge gate array family begins is the year in which that density reaches $1 million in sales.

DATAQUEST CONCLUSIONS

The choice of strategy to increase the number of usable gates has major implications for

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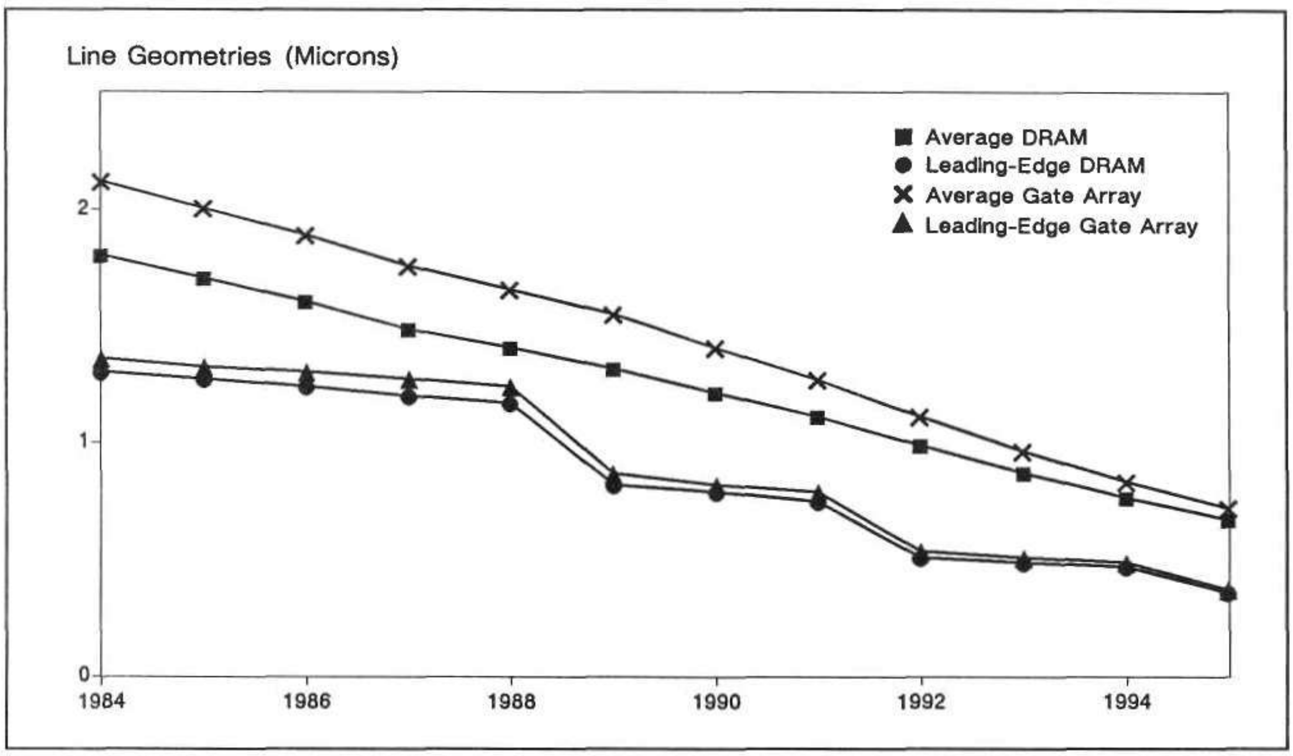
TABLE 1
Strategies of Increasing Usable Gates

Strategy	Characteristics
Decrease line geometry	Increases total available gate count Capital (lithography) intensive Uses base wafers Quick turn
Increase chip size	Increases total available gate count Design intensive Uses base wafers Quick turn
Increase levels of metal	Increases usable gates Capital (deposition/etch) intensive Smaller die Uses base wafers Quick turn
Develop more efficient routing algorithms	Increases usable gates Design intensive Smaller die Uses base wafers Quick turn
Add functional blocks, such as memory and peripherals	Design intensive Does not use base wafers All mask levels unique to functional block Is customer/system specific Circuit is optimized for function Not quick turn

Source: Dataquest (August 1990)

FIGURE 1
Converging Tecnologies—ASICs and DRAMs



Source: Dataquest (August 1990)

manufacturing and for equipment vendors. Shrinking line geometries and increasing levels of metalization are capital-intensive strategies. They are also strategies that rely on the use of base wafers. A manufacturer can mass produce base wafers and thereby drive down the cost. This should be an option only to those manufacturers certain that they can be the low-cost producers.

There are three strategies that are design intensive rather than capital intensive. These strategies increase die size and optimize routing algorithms using base wafers and would therefore have to compete in a mass-produced standard-product market. They, too, would have to be low-cost producers; however, because they are design intensive, they would not have the capital burden that small line geometries and increasing levels of metal would carry.

Finally, there is the strategic option of embedded functions. This option is design and capital intensive. But it does not use base wafers and, hence, is not a commodity product. Using embedded functions allows manufacturers to follow a niche rather than a commodity marketing strategy.

Clearly, no one strategy is head and shoulders above the rest. Dataquest believes that prudent manufacturers will be both design and capital intensive and will demand the maximum of uptime and throughput and the minimum of setup time from their vendors.

George Burns

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Research Newsletter

FUTURE SCENARIOS FOR THE CLUSTER TOOL EQUIPMENT MARKET

SUMMARY

Semiconductor manufacturers are evaluating cluster tools as a means of controlling ever-increasing process complexity and escalating fab costs. Dataquest believes that timely, open, distributed cluster tool standards benefit vendors as well as users of fabrication equipment. But the worldwide fab equipment industry is divided in its approach to defining interface standards for cluster tool equipment. Dataquest believes that open architecture worldwide cluster tool standards are essential to cost-effective submicron manufacturing in the future. This newsletter discusses some likely future scenarios for the cluster tool equipment market vis á vis the evolution of interface standards.

OPEN VERSUS CLOSED EQUIPMENT ARCHITECTURE

Semiconductor device and equipment companies clearly perceive the need for cluster tools as an enabling solution to the problems of ever-increasing submicron process complexity and skyrocketing fab costs. A controversy over cluster tool interface standards has embroiled the industry during the past year and shows signs of intensifying rather than being resolved. Essentially, the controversy is based on the adoption of current closed architecture standards versus open architecture standards. Although the ad hoc Modular Equipment Standards Architecture (MESA) group has folded its activities into the international SEMI/MESC industry trade organization, Dataquest believes that the worldwide equipment vendor community is still divided in its approach to the standards definition process.

SMALL VERSUS LARGE EQUIPMENT COMPANIES

Smaller US equipment companies perceive open standards based on the SEMI/MESC effort as being crucial to their survival. Large global equipment companies are less concerned about the evolution of open standards, because they already dominate the cluster tool market with closed architecture platforms. European and Japanese equipment companies that did not actively participate in the initial MESA efforts are concerned about the compatibility of their products with the SEMI/MESC standards. SEMI/MESC has to achieve a process of "buy-in" among its European and Japanese members in order for its standards to be effective. Consequently, the progress of the SEMI/MESC efforts has been slow. Meanwhile, closed architecture equipment vendors continue to penetrate the fast-growing integrated process system market.

IS SEMATECH AMBIVALENT ON CLUSTER TOOL STANDARDS?

Sematech may have added to the controversy by taking a somewhat ambivalent stand on the issue of cluster standards. Although Sematech supports the SEMI/MESC open standards effort, it recognizes that the increasing popularity of several existing proprietary cluster tools may lead them toward becoming de facto industry standards, thus endangering the viability of the SEMI/MESC open standards. Sematech may have also tacitly supported a closed architecture approach by awarding several Equipment Improvement Program (EIP) contracts to proprietary platforms currently offered

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by sole-source vendors. Sematech clearly is hedging its bets between today's entrenched market leaders and future open architecture tools. Such a Sematech strategy supports its mission of ensuring a viable US equipment industry infrastructure.

But while doing so, the larger question remains: Is Sematech effective in adequately representing the interests of fragmented, entrepreneurial US equipment companies? The small US equipment companies seem to think that Sematech ought to take a more proactive role in the evolution of the SEMI/MESC standards rather than adopt a neutral observer's role. Sematech also may find it difficult to arrest the diffusion of technology stemming from its EIP projects in today's globalized equipment industry market.

FUTURE MARKET SCENARIOS

Dataquest foresees several possible scenarios, with varying degrees of success, for the cluster tool market.

Scenario 1: Ideal Best-of-Breed Cluster Tool Market

In this "ideal" scenario, all process modules will conform to distributed, open-architecture standards. Semiconductor manufacturers can mix and match modules for their specific process applications. Dataquest views this scenario as unlikely because of the tremendous complexity in integrating process, software, communications, and control across scores of different equipment modules. Also, process ownership and performance guarantees are not possible in this market environment. Systems integrators that have the expertise and resources to integrate modules do not exist today.

Scenario 2: Semiconductor Manufacturers Procure Modules and Assume Ownership

A few large vertically integrated captive semiconductor companies in the United States and Japan have active equipment development efforts. It may be possible for these companies to design and build their own systems using standard process modules and wafer handling platforms. However, such companies are clearly the exception rather than the rule. Merchant semiconductor companies, by and large, are looking to their equipment vendors to provide integrated hardware and process solutions. Semiconductor companies are concerned more with increasingly complex fab logistics and time-to-market issues. They do not want to be burdened with the additional task of building their own fabrication systems; rather, they want a "one-stop shop" for hardware, process, service, and global support. Hence, Dataquest views this market scenario as unlikely also.

Scenario 3: Emergence of "Super" Equipment Companies with Global Technology and Service Capabilities

This scenario represents the status quo today. Dataquest has already observed the emergence of "super" equipment companies, which are globally positioned and have the deep pockets to invest in multiple new product developments. Such companies will continue to offer complete process solutions and support their customers on a global basis. However, the customer is locked into proprietary architectures and occasionally may have to make suboptimal choices that do not match his specific needs.

Dataquest views such a market scenario as undesirable because it will lead to a proliferation of incompatible standards, high costs due to proprietary sole-sourced technology, and the extinction of small, cash-strapped innovative module companies that cannot afford the high-platform development costs.

Scenario 4: Selective, Synergistic Partnerships between Equipment Companies

Dataquest predicts the emergence of selective partnerships between equipment companies with synergistic product and regional strengths. Such partnerships require open interface standards to be defined expeditiously by the SEMI/MESC group. In such a market scenario, one of the partners has to assume complete responsibility and offer a one-stop guarantee for the process and system reliability. The platform partner typically will assume the responsibility for the entire process. In such a case, the second module partner effectively acts as an OEM component supplier to the larger integrator company, which provides the critical process and platform modules. Trust, product synergy, and a global presence are essential ingredients to the success of such a market model.

Scenario 5: The Emergence of Regional Cluster Standards

This scenario envisions the evolution of a few (two or three) cluster tool standards in each semiconductor manufacturing region of the world. Thus the European, Japanese, and US equipment communities may develop standards that best meet their specific regional needs. Under such a scenario, we could see a combination of closed and open architecture cluster tools in the same fab. The prevailing logic behind such a scenario would suggest that a few cluster tool standards based on regionally specific alliances are preferable over a no-standards scenario.

DATAQUEST CONCLUSIONS

Dataquest believes that the emergence of timely, worldwide, open SEMI/MESC standards is a precondition to the widespread acceptance of cluster tools. In the absence of worldwide standards, semiconductor manufacturers will continue to pursue costly, custom process solutions for each device generation. We believe that a universal, best-of-breed cluster tool market scenario is unlikely to emerge quickly because of the daunting issues of submicron process complexity, integration responsibility, and lack of comprehensive standards.

It is more likely that the equipment industry may gravitate toward selective, synergistic alliances that augment the regional presence and product strengths of the companies involved. In such a cluster tool market scenario, the platform partner will act as the system integrator for the entire process. The smaller process module partner will serve as an OEM component supplier to the larger integrator. The emergence of open-architecture SEMI/MESC standards may allow pure platform vendors to serve as neutral wafer-handling system suppliers to numerous synergistic alliances involving small process module companies. Dataquest believes that the development of open cluster tool standards with distributed architecture is essential to the survival of the many innovative, entrepreneurial, process-oriented companies worldwide.

Krishna Shankar
Mark T. Reagan

Dataquest

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Research Newsletter

SEMICONDUCTOR PRODUCTION: TRULY GLOBAL

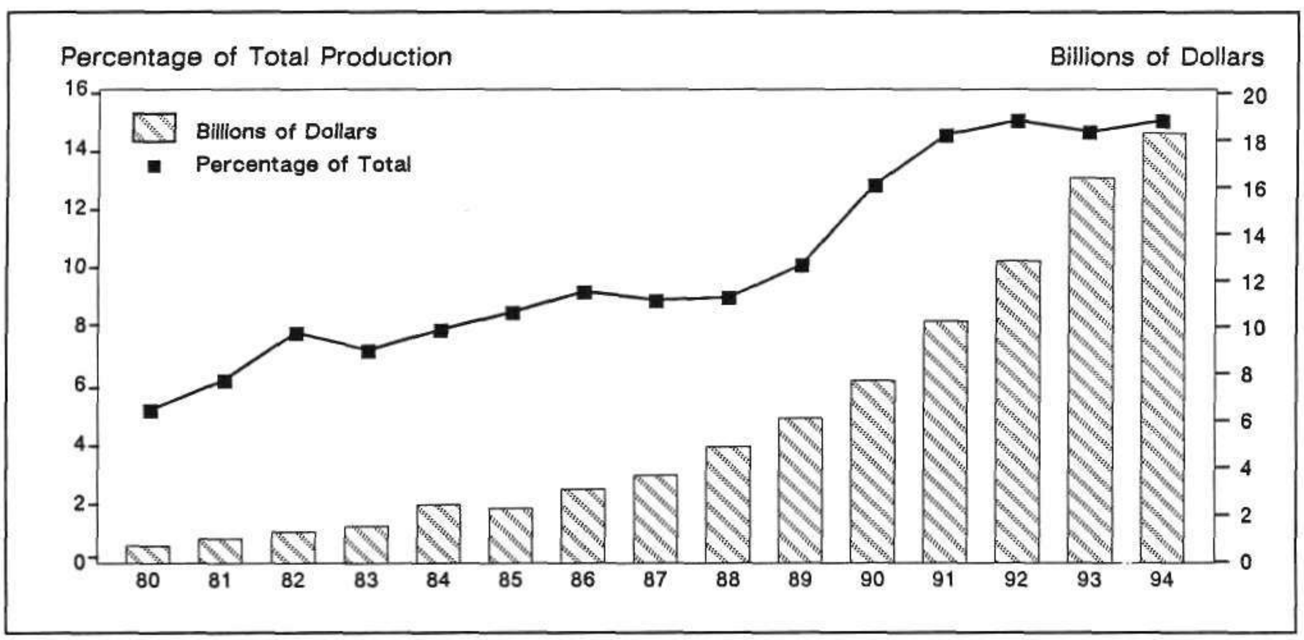
HOW BIG IS IT?

Although globalization is a term that easily comes to mind in our industry, few realize the phenomenon's true dimensions. One measure of globalization is the volume of the world's merchant and captive semiconductor production that is produced by offshore companies. Today, 10 percent ($6 billion) of the world's semiconductors are produced offshore. By 1994, Dataquest anticipates that 15 percent ($18 billion) will be produced offshore (see Figure 1).

Offshore companies, whether merchant or captive, are those with headquarters outside of the region in which they actually fabricate wafers. For example, Asia/Pacific, Japanese, and North American fabs operating in Europe are offshore producers in Europe.

In every region of the world, offshore manufacturers are producing ever-larger proportions of that region's semiconductor production (see Figure 2). The proportion of offshore production in Europe is particularly striking: In 1989,

FIGURE 1
Worldwide Offshore Semiconductor Production
(Billions of Dollars and Percentage)



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Source: Dataquest March 1990

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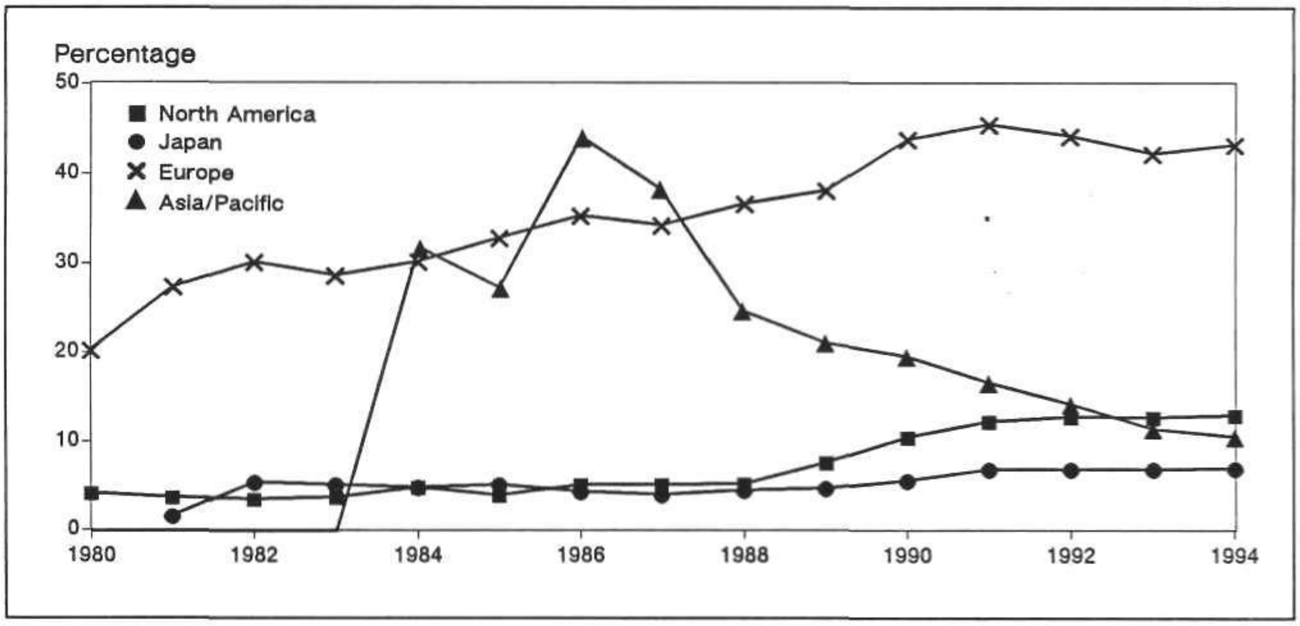
Figure 2
Percentage of a Region's Production Fabricated by Offshore Companies



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Source: Dataquest
March 1990

38 percent of all semiconductors (as measured in dollars) made in Europe were made by offshore manufacturers. By 1994, we expect this percentage to rise to 43 percent.

Who's Leading the Charge?

In the early 1980s, globalization was fueled by major U.S. companies (i.e., IBM, Motorola, and Texas Instruments) setting up and expanding fabs in both Japan and Europe. European semiconductor companies also participated in globalization through a combination of purchasing U.S. semiconductor companies and building fabs overseas; for instance, Thomson-CSF, before it merged with SGS, acquired Mostek and Philips acquired Signetics. SGS-Thomson also has extensive facilities in Singapore.

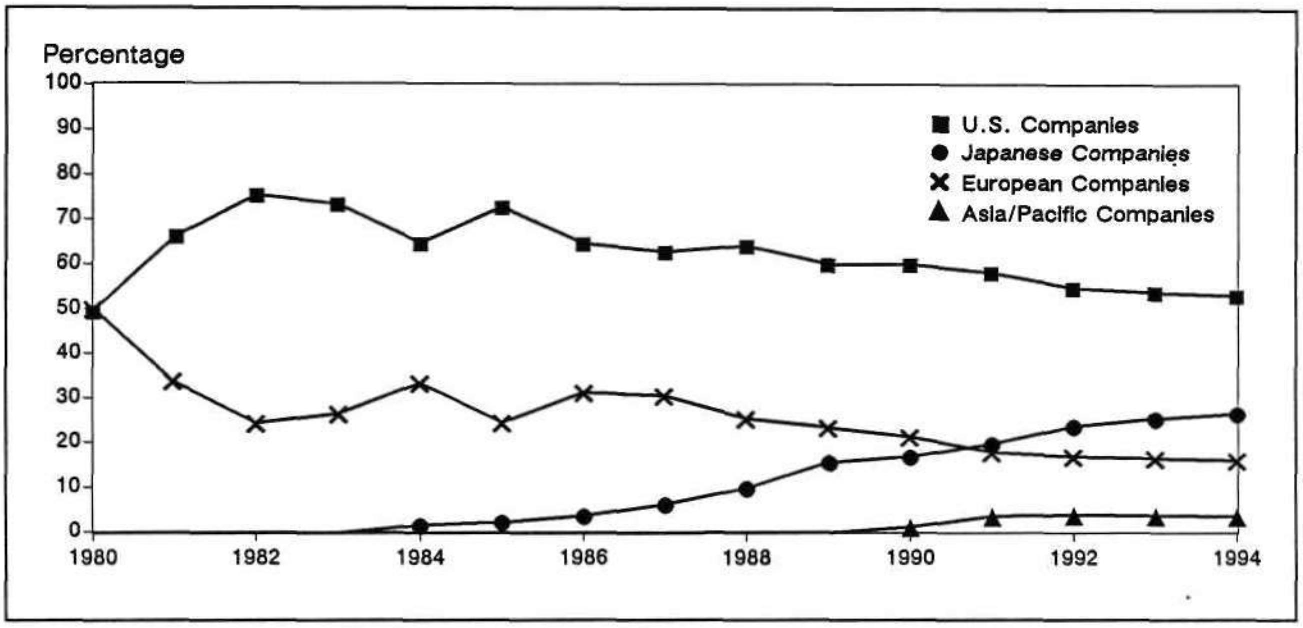
Today, U.S. companies are expanding vigorously in both Europe and Japan. Both Motorola and Texas Instruments either already have fabs in Asia/Pacific or are in the process of building them. Of the European companies, Philips recently expanded its offshore capability by acquiring majority ownership of Taiwan Semiconductor Company (TSMC).

The Japanese companies, however, are really fueling the explosion of offshore fabs in both Europe and the United States (see Figure 3). In 1989, Japanese companies accounted for only 16 percent or $960 million of the world's total offshore production of $6 billion, which is less than the European companies' share of 24 percent and not even close to the U.S. companies' share of 60 percent. By 1994 however, Japanese companies should account for 27 percent of the world's offshore production.

Dataquest Conclusions

Globalization is real and growing. Companies find it necessary both for marketing purposes (in order to be close to regional customers and to avoid trade friction) and to be world-class manufacturers. In the early 1980s, U.S. and European semiconductor companies led the charge toward globalization; today, the Japanese semiconductor companies are in the lead. By building their fabs in Europe and the United States, Japanese semiconductor manufacturers are helping correct trade imbalances and build local economies. As Japanese engineers meet with non-Japanese

FIGURE 3
Percentage of Total Offshore Production by Regional Companies



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Source: Dataquest March 1990

engineers and perhaps even change companies they are also sharing their manufacturing expertise.

It is likely, however, that Japanese semiconductor companies will continue their relationships with Japanese equipment and materials vendors as they build fabs in Europe and the United States. These vendors will then use this opportunity to set up regional service centers that will make them even more formidable competitors.

George Burns

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Research *Newsletter*

JAPANESE DRAM COMPANY UPDATE

INTRODUCTION

Manufacturers of 1Mb DRAMs started 1990 by launching a second round of production cutbacks. These cutbacks are but one of numerous strategic maneuvers to attempt to sustain current DRAM price levels. In this newsletter, Dataquest addresses recent announcements that concern these strategic maneuvers, both in the Japanese market and worldwide, in the fast-paced DRAM arena.

Recent cutbacks include those by Toshiba, the largest 1Mb DRAM supplier in the world, which cut its monthly production from 9 million units to between 7 million and 8 million units starting in January 1990. NEC also reduced its production from 6 million to 5 million units. Fujitsu and Hitachi both announced plans to cut their 4 million-unit production by 10 percent. Mitsubishi is cutting back production by 1.5 million units per month (it originally produced 4.5 million 1Mb devices). Oki Electric is lowering its unit production to 3 million, which is down by half a million. Table 1 lists these six top manufacturers' new production rates compared with the amount of units they previously produced. The table shows an 11 percent cutback for these companies.

Pricing is another issue; prices change so rapidly that a published Dataquest price quote becomes obsolete by the time it reaches our clients. To demonstrate these rapid changes, Table 2 lists the *I.C. Asia* historical pricing for 1Mb DRAMs from January 1989 through January 1990. However, the exchange rate did fluctuate during this time; therefore, we have included the monthly exchange rates for clarification.

Table 2 demonstrates the rapid fall of 1Mb DRAM prices; this decline began to escalate in the September/October 1989 time frame. The fluctuation in pricing from January 1989 to January 15, 1990, showed a 48.3 percent decline. Some, but hardly all, of the change can be attributed to the strengthening of the dollar, which increased in this same time period by nearly 19 percent. Reports indicate that 1Mb DRAM prices now range from $7.00 to $7.50 in the spot market in Taiwan. Within the United States, spot pricing has been reported to be between $6.00 and $6.50. Can Japanese pricing be far behind?

FURTHER BACKPEDALING

Hitachi Ltd. and Toshiba Corporation both have announced plans to postpone their original production schedules, which would have increased their 4Mb DRAM production to 1 million units per month, until late summer. Hitachi, NEC, and Toshiba currently produce 200,000 units per month. Bookings from U.S. manufacturers that use the 4Mb DRAMs in general-purpose computer systems and workstations reportedly have been growing steadily, although demand still seems to be falling short of expectations. The sharp drop in 1Mb DRAM pricing also makes the 4Mb DRAM

TABLE 1
Top Japanese Manufacturers' 1Mb DRAM Estimated Monthly Production (Millions of Units)

Company	Previous	Current
Fujitsu	4.0	3.6
Hitachi	4.0	3.6
Mitsubishi	4.5	3.0
NEC	6.0	5.0
Oki Electric	3.5	3.0
Toshiba	9.0	7.5
Total	31.0	25.7

Source: Dataquest
March 1990

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TABLE 2
Japanese Semiconductor Prices for 1Mb DRAMs (U.S. Dollars)

Date	Volume Price	Exchange Rate (Yen per US$1)
January 1989*	15.98	122
February 1989*	15.48	126
March 1989*	15.12	129
April 1989*	15.12	130
May 1989*	14.59	132
June 1989*	13.85	139
July 1989*	13.23	146
August 1989*	13.30	139
September 1989*	13.30	139
October 1989**	11.97	146
November 1989**	11.84	142
December 1989**	9.74	144
January 1990**	9.20	144
January 15, 1990**	8.26	145

*120ns
**100ns

Source: Dataquest
March 1990

appear to be priced too high. As of January 15, 1990, volume pricing for 4Mb DRAMs in Japan was reported to be in the ¥10,000, or $68.96, range.

In another indicator of the softening 1Mb DRAM market, Motorola Japan Ltd. announced its suspension of construction of a 1Mb DRAM wafer assembly fab that was slated to be built starting in October. The company had planned to build the fab on a 120,000-square-meter site in Sendai, Miyagi prefecture; these plans have now been shelved for perhaps another year. Reinstating the plans will depend on the recovery of the 1Mb DRAM market, as well as the growth in 4Mb market demand. The wafer assembly fab was to be adjacent to the Tohoku Semiconductor plant, which would have been the preprocessor.

ONE MAN'S SORROW, ANOTHER MAN'S GAIN

Some activities indicate that firms are positioning themselves for the next wave of demand. Oki Electric Industry Co., Ltd., states that its alliance with SGS-Thomson of France is becoming closer. The two companies plan to start manufacturing 1Mb DRAMs this summer at Thomson's Nancy, France, fab. Oki Electric processes the silicon wafers in Japan and sends them to the Nancy fab for assembly. The two firms are pleased and encouraged by their successful results in jointly producing 256K DRAMs. This joint venture with Thomson appears to be one of the most promising ways for Oki to establish an IC production base in the European Community (EC). Oki expects the joint production of 1Mb DRAMs to serve as a method of assessing a production base feasibility.

In an attempt to avoid the plummeting 1Mb DRAM prices, Mitsubishi has decided to shift its production away from 100ns 1Mb DRAMs. Mitsubishi is the first major DRAM supplier to abandon sales of the 100ns devices. The 60ns versions will account for 10 percent of Mitsubishi's 1Mb DRAM production, the 70ns type for 50 percent, and the 80ns type for the remaining 40 percent.

In the captive area, IBM Japan, Ltd., has completed installation of a submicron line that processes 8-inch wafers at its Yasu fab in Shiga prefecture and has started test production of 4Mb DRAMs and custom LSIs. The Yasu fab consists of three buildings. The 8-inch line requires an entire floor and includes an "ultraclean room," gas and chemical supply systems, and waste gas and effluent treatment systems. IBM Japan plans to start volume production by the end of this year. Its 4Mb DRAMs will be used exclusively for IBM's general-purpose computers and PCs.

Sony, which until now has elected not to compete in the DRAM field, plans to supply field memories for HDTV production. Product is scheduled to be available in 1995. The HDTV market, which has a large growth potential, will use a wide variety of specialty ICs. Field memories, which are basically DRAMs with an added image-processing function, account for the largest portion of HDTV's specialty needs. Sony plans to commercialize its 4Mb field memories based on a 0.5-micron process. Sony's decision could indicate that commercialization of field memories is about to begin and gives room for it to compete with other DRAM suppliers due to its competitive edge in the consumer electronics market.

Fujitsu currently is constructing a 4Mb DRAM production facility at its Iwate plant. The company plans to complete the facility by the end of March, with equipment to be installed at the beginning of the fiscal year (April 1990). The plant currently produces 256K DRAMs and 1Mb DRAMs.

Dataquest believes that the 1Mb DRAM pricing and market share war could affect 4Mb DRAM negotiations. Looming above this war, Dataquest sees the 16Mb DRAM coming closer to the "here and now." Mitsubishi Electric Corporation has revealed its plans to build a fab that specializes in 16Mb DRAM production in 1991. The production site is in Durham, North Carolina; the company already produces 1Mb DRAMs at a 1-micron wafer and assembly fab there. The new fab will use a 0.6-micron process and form another core of Mitsubishi's strategy to establish overseas production bases in the United States and Europe. Mitsubishi already has announced plans to construct a fab in Alsdorf, West Germany, that will be completed by the end of 1991 and will produce 4Mb DRAMs. The company also has announced its intentions to produce approximately $7 billion worth of semiconductors on a consolidated basis in 1997.

Hitachi Ltd. has announced that it is positioned to manufacture and ship samples of its 16Mb DRAM by the end of 1990. The company already has completed a prototype production line at its Kofu fab, Yamanashi prefecture, and will install a 0.5-micron process in order to start production this spring. Major competitors in the development race, including NEC and Toshiba, also are making progress in their prototype production. NEC is operating a 0.6-micron line at its Sagamihara fab, Kanagawa prefecture, and plans to start sample shipments in 1991. Hitachi's move surely will heat up the race to commercialize 16Mb DRAMs, as well as impact 4Mb DRAM pricing and volume production.

DATAQUEST ANALYSIS

MITI announced last December that it expects Japanese demand for 1Mb DRAMs during the first half of 1990 to increase to 89.7 million units—up 12 percent from the last half of 1989. MITI also reported that production during this period is likely to reach 211.3 million units, with 121.6 million units being exported. Considering the past reliability in MITI projections, Dataquest believes that further price erosion in the 1Mb DRAM and 4Mb DRAM segments is possible.

The one possible action that could stop the continuing drop in prices would be a DRAM shortage. Dataquest suggests that a shortage is possible, and if it happens, it will take place during the second half of 1990. While it would soften further price erosion, it also would bring back "1987 shock" and the panic buying, stockpiling, product allocations, and longer lead times associated with it.

South Korean manufacturers are likely to have a dramatic influence on pricing and supply. They have had tremendous success in obtaining market share in both the U.S. and Japanese markets. Unconfirmed rumors indicate that a contract price with Samsung brought 1Mb DRAM prices down to $5.

Mark T. Reagan
Ione Ishii

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Research *Newsletter*

JAPANESE CONSORTIA

INTRODUCTION

The Japanese have used consortia as a means of enabling companies to share the high risk and high cost associated with developing new technologies. In fact, more than 50 consortia related to the electronics industry now exist in Japan. Although other industrial countries also have organized government-sponsored consortia, the number of successfully executed Japanese consortia is noteworthy.

This newsletter discusses some of the motives for the Japanese to use consortia. It also examines why they have been so successful.

JAPANESE CONSORTIA: BORN OF NECESSITY

Following World War II, the Japanese government began the task of bringing the Japanese economy back from a state of nearly total depletion. Political influence and financial influence were widespread throughout the postwar period as Japanese government offices, such as the Ministry of International Trade and Industry (MITI), systematically proceeded to manipulate Japanese industries with little regard for such relatively trivial (at the time) issues as antitrust, intellectual property, and free trade principles. To a degree surprising even to itself, the Japanese government was successful in revitalizing the devastated economy to the extent that Japan now stands as one of the leading economic powers of the world. This success has had one negative repercussion, however; it is, as often happens, difficult to abandon a successful system. For MITI, relinquishing its authority has been particularly difficult as so much of its past glory has been directly related to its success in regulating industry. To this day, research and development (R&D) activity throughout Japan is still strongly influenced by MITI. Furthermore, high-technology industries in Japan receive roughly the same priority as do national security and defense in the United States; consequently, MITI can, in some sense, be thought of as the equivalent of a defense department.

Figure 1 presents an organization chart of the Japanese government in terms of its electronics R&D projects. MITI and the Science and Technology Agency (STA) are key organizations that conduct major technical R&D projects. Both of these institutions have unique roles in promoting joint research programs.

FORMATION OF A JAPANESE CONSORTIUM

Nowadays, many Japanese consortia start life as a concept of someone, or some branch, at MITI. The Japan Key Technology Center (Japan Key-TEC) is one such branch of MITI and was chartered in 1985 as a government mediator in arranging joint research consortia. Currently, Japan Key-TEC has approximately 70 ongoing research projects with 39 of these existing in the domain of the electronics technology sector. Some of Japan Key-TEC's active electronics research programs include the following:

- Research and development of basic technology for the second-generation optoelectronic ICs (OTRC)
- Research of electronic dictionary for natural-language processing
- Research of advanced information-processing image information system
- Research of basic coherent optoelectronic measurement technologies for coherent light communications

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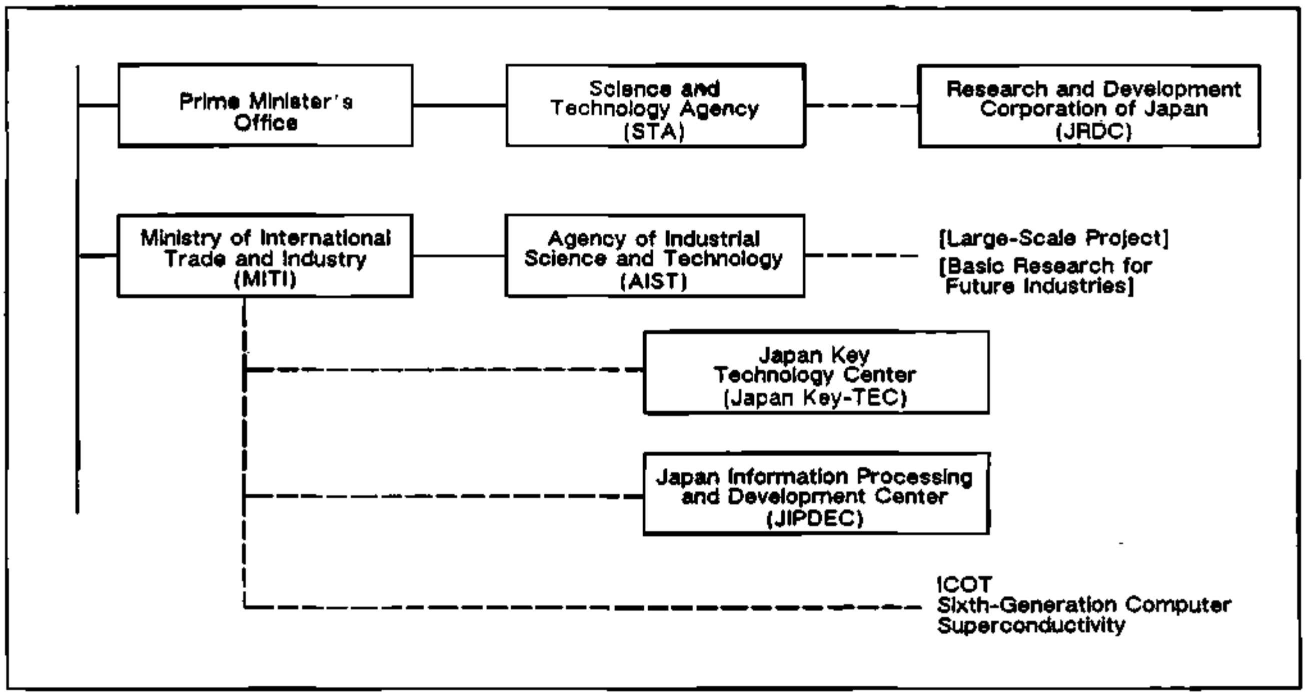
FIGURE 1
Japanese Government Organization Chart



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Source: Dataquest
January 1990

- Research and development of synchrotron radiation application technologies (SORTEC)
- Research and development of high-level artificial intelligence system description language
- Research on amorphous magnetic material and electronic devices
- Research and development of advanced technologies for large-area TFT circuitry

Japan Key-TEC's primary functions are to identify areas in which to establish consortia, to determine the administrative structure of the consortia, and to finance the consortia by locating funding sources within the government. Most consortia are superficially structured as companies, often even including an artificial name. Researchers usually come both from participating companies and from the government laboratories sponsoring the consortia.

Research and Development Corporation of Japan (JRDC) and Japan Information Processing and Development Center (JIPDEC) also conduct government-supported consortia in a similar manner to Japan Key-TEC.

JAPANESE VERSUS U.S. CONSORTIA

From the Japanese perspective, one of Japan's most successful ventures during the postwar period was the formation of government-sponsored consortia, sometimes referred to as "families" of companies. In past years, Japanese companies gained both government subsidies and captive markets as benefits of joining the various consortia. Such early practices led other countries to accuse Japan of regulating trade. These accusations were, in fact, well founded, as the Japanese government was aware of the economic trade-offs of a regulated trade policy and was willing to sustain the cost to home consumption in exchange for gains to its strategically designated producers. The government chose to intervene in the process of resource allocation rather than to allow the mechanisms of free trade to dictate this process. It did this, perhaps, because it was obvious that electronics, semiconductors, and related systems industries fit the Japanese economy and eventually would have been dominant industries in Japan under a free-trade policy anyway. The Japanese merely wished to accelerate the maturity of these industries.

Japan's electronics success has stimulated much controversy about the true value of the free-trade model. In particular, there is controversy in the United States as to whether consortia or some other practice was the key to success of the Japanese dominance in the electronics sector. In this regard, it is important to recognize that the success of Japanese consortia derived from not only effective administration but also certain cultural aspects of Japanese society. The Japanese historically have made social and cultural adaptations to offset their country's inherent lack of natural resources. Although these cultural adjustments are difficult to quantify, it seems apparent that modern high-technology industries are well matched to the Japanese adaptations. This matching is partly due to the fact that these industries require minimum natural resources, such as raw materials or land, and have beneficial spillover effects to established industries, such as automobiles and consumer electronics.

Although consortia were adopted long ago by the Japanese for somewhat different reasons than those now motivating U.S. companies to cooperate, it does appear that R&D consortia are a growing and necessary trend in advanced semiconductor manufacturing. By revising its interpretation of antitrust laws, the U.S. government has in essence embraced the Japanese government's informal waiver of such laws as applied to high-technology industries. However, emulating the Japanese consortia of past years may not be the ultimate solution in forging a stronger semiconductor industry in the United States.

Modern Japanese consortia are basically R&D organizations that are not without their share of problems. Funding for various projects frequently is plagued by bureaucratic inefficiency. The government's financial support, representing only one-sixth of the nation's total R&D budget, often is outweighed by its bureaucratic interference. As a result, research projects may be redundant or may overlap, with little horizontal interaction and communication between projects. In addition, these problems can be compounded by interagency competition, in effect creating more bureaucracy and infighting. Indeed, some companies probably retain their extensive consortia memberships just because traditional business philosophy requires them to maintain a good relationship with the government agencies. Such relationships are an asset in the Japanese business world, but they currently have less significance among western businesses.

DATAQUEST CONCLUSIONS

The Japanese have proven success with their implementations of high-technology consortia. These arrangements seem to be well matched to the Japanese business culture and the good-of-the-group mentality prevalent in Japanese society.

The semiconductor industry is somewhat unique in one aspect: Semiconductor manufacturing technology is growing faster than the companies producing this technology can comfortably afford. The result of this phenomenon is that chip producers are being forced to specialize. Diversification increasingly is provided by involvement in consortia, joint ventures, mergers, and acquisitions. Construction of a leading-edge high-volume manufacturing facility easily can cost a few hundred million dollars and clearly emphasizes the point that few companies can afford to fail if such a venture is undertaken by a sole investor. Diversification of R&D risk via consortia and joint ventures is a fact of life in present-day high-volume semiconductor manufacturing. However, a consortium aligning producers and users of semiconductors in a captive market arrangement, as some U.S. and Japanese consortia have been designed to do, has distinctly protectionist implications and should be avoided. Therefore, Dataquest concludes that consortia, although necessary, must be implemented with care. Simply modeling after the Japanese consortia will not guarantee success.

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Mark Reagan
Junko Matsubara

Forecast

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Research Newsletter

SOFT BUSINESS CONDITIONS PREVAIL IN THE WAFER FAB EQUIPMENT MARKET

LOOKING AHEAD

The wafer fab equipment market has experienced sluggish activity through the first half of 1990. The equipment industry has not yet seen any strong signs of an upturn in the second half of the year. Many semiconductor equipment companies have reported that their customers have temporarily delayed or suspended equipment purchases. Semiconductor industry book-to-bill ratios continue to send mixed signals regarding the state of the chip industry. It is natural for semiconductor manufacturers to carefully scrutinize their capital spending plans in light of uncertain market demand. Dataquest believes that the 1990 market will experience flat to negative 5 percent growth compared with 1989 in view of the current soft business conditions. This growth rate is in line with our prior forecast of 0.1 percent growth for wafer fab equipment in 1990.

Dataquest is in the process of revising its forecast for the 1991 wafer fab equipment market. We are assessing the impact of a number of factors in our forecast, including the political and economic uncertainties spawned by the current crisis in the Middle East. In the semiconductor arena, we are evaluating the possible foreshortening of the 4Mb DRAM life cycle because of substantial existing capacity for the 1Mb DRAM coupled with the recent news of pilot production as well as sampling of the 16Mb DRAM. These factors, among others, lead us to believe that our previous forecast of 24 percent growth for wafer fab equipment in 1991 will be revised downward.

In addition to slower growth than originally forecast, we believe that the pace of the 1991 upturn in the wafer fab equipment market may be gradual. If the current soft market conditions linger during the second half of 1990, the ramp-up in equipment purchases in 1991 may be slower than we had originally forecast. There is always a time lag between the semiconductor recovery cycle and renewed fab equipment shipments. We believe, however, that the industry is poised for the next big round of capital spending as semiconductor manufacturers gear up for submicron production in advanced 150mm and 200mm fabs. As in previous business cycles, the strength and longevity of this cycle will depend substantially on DRAM trends, computer industry trends, and new markets for device applications.

LOOKING BACK—A REVIEW OF 1989

The worldwide wafer fab equipment market grew 19.2 percent to $5,887 million in 1989. This growth rate is in excellent agreement with our previous forecast (second half 1989) of 18.4 percent growth. Table 1 presents the 1989 market survey results, based on our discussions with over 150 companies participating in 40 separate wafer fab equipment categories. These survey results are compared with our previous forecast on a category-by-category basis. Our forecast methodology is based on a tops-down analysis that relies on extensive discussions with industry leaders, our own industry insight and experience, and our historical databases. With the exception of a few equipment categories, Dataquest's prior forecast for the various segments of wafer fab equipment are very close to the market estimates as determined by detailed primary research.

Each of the major wafer fab equipment categories will be discussed in the following sections of this newsletter. Discussion will focus on a comparison of the 1989 market with our previous forecast and our analysis regarding any significant differences.

SEMS Newsletters 1990 Forecast

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Table 1
Worldwide Wafer Fab Equipment Market, 1989 Market and Prior Forecast (Millions of Dollars)

	1989 Market	Prior Forecast	Percent Difference
Lithography			
Proximity/Contact	20	20	0
Projection	94	152	(38%)
Steppers	1,191	1,084	10%
Direct-Write Lithography	70	70	0
Maskmaking Lithography	73	70	4%
X-Ray	5	12	(58%)
Total Lithography	1,453	1,408	3%
Automatic Photoresist Processing Equipment	325	282	15%
Etch and Clean			
Wet Process	306	289	6%
Dry Strip	116	110	5%
Dry Etch	636	650	(2%)
Ion Milling	9	9	0
Total Etch and Clean	1,067	1,058	1%
Deposition			
CVD	580	540	7%
PVD	377	400	(6%)
Silicon Epitaxy	72	60	20%
Metalorganic CVD	44	52	(15%)
Molecular Beam Epitaxy	73	100	(27%)
Total Deposition	1,146	1,152	(1%)
Diffusion	327	330	(1%)
Rapid Thermal Processing	28	27	4%
Ion Implantation			
Medium Current	139	153	(9%)
High Current	306	302	1%
High Voltage	23	22	5%
Total Implantation	468	477	(2%)
Optical CD/Inspection	187	221	(15%)
Other Process Control	485	469	3%
Factory Automation	195	153	27%
Other Equipment	206	202	2%
Total World Fab Equipment Market	5,887	5,779	2%
Percentage Growth	19.2%	18.4%	

Source: Dataquest (August 1990)

LITHOGRAPHY

The 1989 lithography market was $1,453 million, up 18 percent from its 1988 level. We had previously forecast the 1989 market to be $1,408 million, reflecting a 3 percent difference between the 1989 market and our forecast. There were, however, some differences in individual lithography categories that are discussed in the following paragraphs.

Contact/Proximity and Projection Aligners

The 1989 market for contact/proximity aligners of $20 million was right on with our previous forecast of the same level. However, Dataquest's previous forecast of a flat market for projection aligners was too aggressive. We had forecast the 1989 projection aligner market to be $152 million. Instead, the 1989 projection aligner market was $94 million, down 36 percent from its 1988 level of $148 million. Both equipment suppliers in this category had reduced sales in 1989, but Perkin-Elmer in particular was hard hit. Dataquest estimates that Perkin-Elmer's 1989 projection aligner sales were off more than 40 percent from its 1988 level. The uncertainty regarding the future of the company's optical lithography group contributed to its declining sales in an already soft market for projection aligners.

In our previous forecast, we had projected significant growth through 1994 in the category of projection aligners. Our aggressive growth scenario for this category included the SVG Lithography Micrascan system. We have decided instead to include this advanced 4:1 step-and-scan tool in the stepper category, and our 1989 stepper market estimates include the first shipments of this tool.

Both projection and contact/proximity equipment are very mature technologies in semiconductor device fabrication. Their markets are expected to continue to decline as a percentage of overall lithography spending for device fabrication in the future. New opportunities, however, are appearing outside of the fab front end—in particular, in the manufacture of multichip modules where contact/proximity and projection aligners are well suited for high-density interconnect patterning.

Steppers

The 1989 stepper market was $1,191 million, up 29 percent from its 1988 level. Dataquest had previously forecast the stepper market at $1,084 million. There was a significant level of activity in the stepper market in fourth quarter 1988 and first quarter 1989, particularly in Japan. The aggressive stepper market of 1988, in a sense, spilled over into the first part of 1989, resulting in a 1989 stepper market approximately 10 percent higher than we had previously forecast.

Maskmaking and Direct-Write Lithography

In 1989, the maskmaking lithography market (including traditional e-beam equipment as well as Ateq's scanning laser system) was $73 million, and the direct-write lithography market was $70 million. The size of the market in both cases was in excellent agreement with our previous forecast of $70 million for each of these segments.

X-Ray

The X-ray lithography market was $4.8 million in 1989. We were too aggressive in our previous forecast with an X-ray lithography 1989 market of $12.0 million. The plans for X-ray lithography continue to be pushed out now that the options for sub-0.5 micron lithography are multiplying. X-ray will have to fight for its share of the advanced technology R&D pie with a number of optical techniques (e.g., i-line with phase-shift masks, excimer, deep UV 1:1, and step-and-scan), in addition to e-beam lithography.

TRACK

The 1989 market for automatic photoresist processing equipment was $325 million, up 31 percent from its 1988 level. This segment of processing equipment grew more aggressively than we had forecast because of two factors: a higher-than-expected growth in the stepper market and an increase in the average selling price (ASP) of track equipment as new advanced systems with pick-and-place robotics became a larger part of the product mix.

ETCH AND CLEAN

The worldwide etch and clean equipment market (including wet process, dry strip/dry etch, and ion milling) experienced healthy growth, reaching $1,067 million in 1989. The etch and clean equipment market is driven by the increasing number of etching/cleaning steps needed in semiconductor processes to fabricate the increasingly complex submicron device structures. The ASP of etch and clean equipment also continues to increase due to more complex etch equipment and the emphasis on defect-free automation.

Wet Process

The wet process equipment market for 1989 was $306 million, which is close to our forecast of $289 million. The market grew 27 percent between 1988 and 1989. The move toward more robotic automation and the evolution of integrated wet processing systems were responsible for the robust growth of the wet processing equipment segment.

Dry Strip

The dry strip equipment market grew 23 percent from $94 million in 1988 to $116 million in 1989. Dataquest had forecast the 1989 dry strip equipment market to be $110 million. The move toward robotic automation for barrel batch strippers together with a higher ASP for single-wafer strippers was responsible for the healthy growth of the dry strip equipment market.

Dry Etch

The dry etch equipment market was $636 million in 1989, representing an increase of 17 percent over the 1988 market of $546 million. We had originally forecast the dry etch equipment market to be $650 million in 1989. Factors such as increasing number of dry etch steps in submicron processes and an increase in ASP were responsible for the growth of the dry etch equipment market. The move toward multichamber cluster tool-type equipment architecture significantly increased the dry etch equipment ASP. Magnetically enhanced reactive ion etch (MERIE) and electron cyclotron resonance (ECR) etch market segments experienced healthy growth due to the demanding requirements for submicron wafer fabrication.

DEPOSITION

The deposition equipment market, which includes chemical vapor deposition (CVD) and physical vapor deposition (PVD), is driven by the requirements of advanced multilevel interconnect technology. In addition to CVD and PVD equipment, the deposition category also includes epitaxial reactors for both silicon and compound semiconductor materials processing (MOCVD and MBE). The combined worldwide deposition equipment market grew by 18 percent from $969 million in 1988 to $1,146 million in 1989. Our prior forecast was for a 1989 deposition market of $1,152 million in 1989.

Chemical Vapor Deposition

The CVD equipment market continued its trend of banner growth in 1989. The market grew 27 percent from $456 million in 1988 to $580 million in 1989. Dataquest had forecast the 1989 CVD equipment market to be $540 million. Dedicated low-pressure tungsten CVD reactors, dedicated plasma-enhanced oxide/nitride CVD reactors, and vertical low-pressure CVD tubes were the high-growth CVD market segments. In addition, the CVD market continued to lead the migration toward flexible cluster tool architecture for integrated processing.

Physical Vapor Deposition

The PVD equipment market continued its strong growth in 1989 due to twin factors of increasing levels of aluminum-based metallization for multilevel interconnect processes and the steep ASP increases due to the evolution of cluster tool architectures. The 1989 PVD equipment market was $377 million. Our prior forecast for this market segment was $400 million.

Silicon Epitaxy

The 1989 market for silicon epitaxial (epi) reactors was $72 million, down 15 percent from the 1988 market of $85 million. The silicon epi equipment market is a mature business. New equipment sales are driven largely by capacity expansions. Consequently, there are large cyclic swings in equipment sales. In Dataquest's prior forecast, we had expected a sharper downturn for the silicon epi reactor market in 1989 with only $60 million in sales.

MOCVD and MBE

The combined market of MOCVD and MBE equipment was $116 million, down 5 percent from its 1988 level. We previously had forecast this combined equipment segment to grow in excess of 20 percent in 1989. The sluggish demand we observed for MOCVD/MBE equipment can be correlated to a flat market for gallium arsenide semiconductor devices, which resulted from uncertainty in certain segments of the end-use electronic equipment market. Dataquest anticipates that in the short term, MOCVD/MBE equipment for semiconductor applications will continue to experience slower growth than the overall wafer fab equipment market. However, renewed growth in the 1991 gallium arsenide semiconductor device market should help spur the MOCVD/MBE equipment market back onto a growth track.

DIFFUSION

The 1989 diffusion equipment market grew 11 percent from $295 million in 1988 to $327 million in 1989. Dataquest had originally forecast the 1989 diffusion tube market to be $330 million. The diffusion equipment market expansion in 1989 was due to the overwhelming shift to vertical tubes from horizontal tubes. The horizontal tube market continued to decline at the expense of high growth in the vertical tube segment. Vertical tubes offer advantages such as lower clean room footprint, easy automation, and better process control for thin-gate oxide processes. Even though overall diffusion tube unit shipments declined, the steep rise in the ASP of highly automated vertical tubes caused the overall diffusion equipment market to grow.

RAPID THERMAL PROCESSING

The rapid thermal processing (RTP) equipment market has yet to experience the substantial growth that was projected several years back. The market is in a transition from a standalone reactor strategy to an RTP module strategy for application in flexible cluster tools. Current applications for RTP equipment involve integration with other thin-film technologies such as CVD, PVD, and dry etch. The 1989 RTP market was $28 million, up 26 percent from its 1988 level of $22 million. Dataquest originally forecast the RTP equipment market to be $27 million.

ION IMPLANTATION

The ion implantation equipment market was $468 million in 1989, up 24.1 percent from 1988. There was only a negligible difference between the 1989 market and our previous forecast of $477 million. Most of the difference came from slightly slower growth than was previously expected in the medium current implanter equipment segment.

PROCESS CONTROL

The optical CD/wafer inspection equipment market was $187 million, up a modest 4 percent from its 1988 level. We had forecast a significantly stronger market in 1989 of $221 million. Several factors contributed to this difference. Dataquest believes that a sooner-than-expected technology jump from optical CD tools to CD scanning electron microscope (SEM) systems contributed to the negative growth observed for optical CD equipment in 1989. Dataquest also had expected more aggressive growth in dedicated wafer inspection equipment. This aggressive market scenario was based on the trend for semiconductor manufacturers to incorporate advanced automatic defect detection/inspection tools into their processing lines. According to Dataquest estimates, however, sluggish performance by one of the major players in this segment impacted overall market growth in 1989. In the next several years, however, as semiconductor manufacturers push aggressively into the submicron regime, Dataquest expects the CD and wafer inspection equipment markets to outpace growth in the overall wafer fab equipment market.

FACTORY AUTOMATION

Dataquest's estimate for the 1989 factory automation market was $195 million, up 50 percent from the 1988 level of $130 million. Previously, we had estimated this segment to be $153 million in 1989. The reasons for our revision to a higher level of growth in this segment include extensive computer integrated manufacturing (CIM) implementation to maximize equipment utilization and the rapid growth of automation control hardware and software to cater to the fast-growing cluster tool market.

DATAQUEST CONCLUSIONS

Dataquest anticipates that 1990 will be a year of flat-to-negative 5 percent growth for the wafer fab equipment market and that the 1991 upturn in the fab equipment market may be gradual. Wafer fab equipment companies have yet to see a sharp upturn in business conditions in the second half of 1990. A sluggish semiconductor device market and uncertainty in the political and economic arenas is causing semiconductor manufacturers to closely monitor their capital spending plans.

The silver lining in our market outlook is that the 1990 contraction in the wafer fab equipment market will be far less severe than the steep downturns observed in the past. As the semiconductor industry matures and becomes more global, the three pillars of semiconductor consumption, semiconductor production, and capital spending required to support future production are becoming more closely tied together in order to provide balance in the management of future growth. In a maturing semiconductor industry, the timing and strength of the recovery in 1991 will depend to a large extent on general macroeconomic conditions. As in previous equipment business cycles, DRAM trends, new device application markets, and new regional market development all will be important issues in the industry's recovery.

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Research *Newsletter*

A QUICK LOOK AT
APPLIED MATERIALS

This newsletter provides a quick look at the financial performance and recent company activities of Applied Materials, a major supplier of semiconductor wafer fabrication equipment. This newsletter is part of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

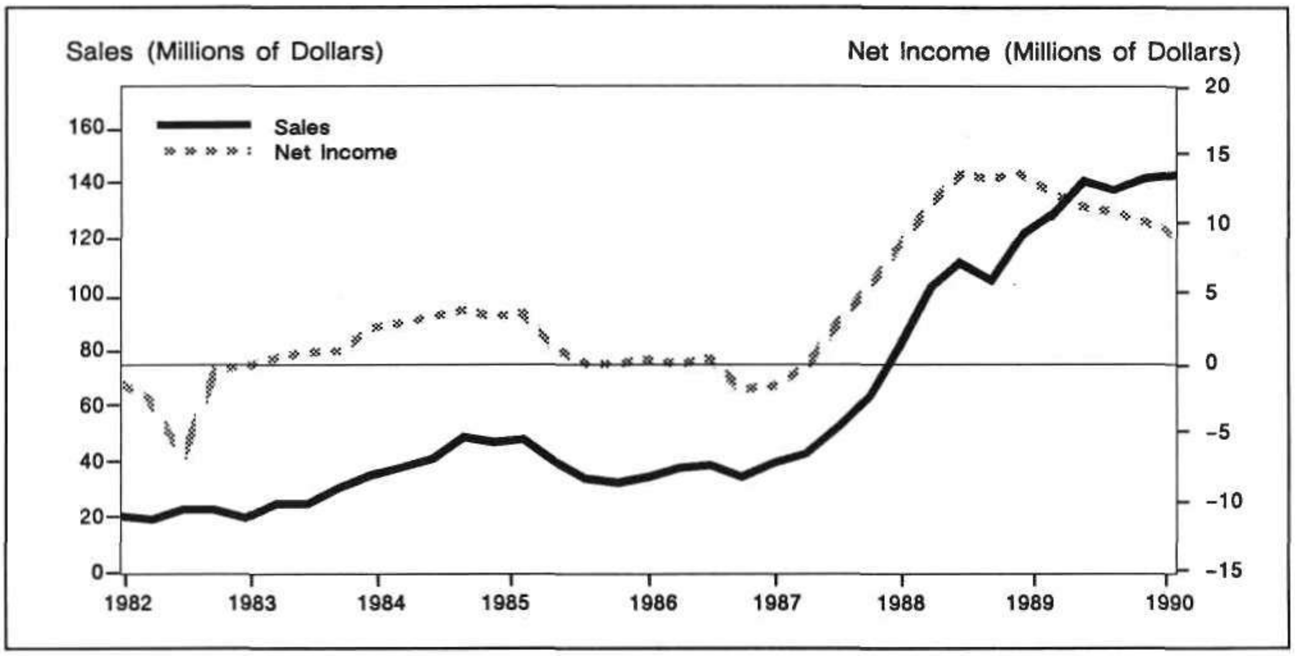
FINANCIAL REVIEW

Selected financial results for Applied Materials are presented here with no additional commentary or analysis. Figure 1 presents Applied Materials' quarterly sales and net income through the quarter ending July 29, 1990. Table 1 provides a summary of fiscal year (ending 10/31) sales, net income, R&D expenditures as a percentage of sales, and return on assets (ROA) for Applied Materials.

COMPANY HIGHLIGHTS

The following discussion highlights recent significant events for Applied Materials. Each factual statement highlighted by a bullet is

FIGURE 1
Applied Materials—Sales and Net Income by Quarter
(Millions of Dollars)



Source: Applied Materials' Quarterly Reports, Dataquest (September 1990)

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Table 1
Applied Materials—Fiscal Year Sales, Net Income, R&D as a Percentage of Sales, and ROA (Thousands of Dollars)

Fiscal Year (ends 10/31)	Sales	Net Income	Ratio of Net Income to Sales	Ratio of R&D to Sales	ROA
1982	90,830	(9,237)	(10.2%)	16.2%	(13.0%)
1983	105,527	3,065	2.9%	15.6%	3.3%
1984	168,400	13,728	8.2%	18.5%	10.9%
1985	174,595	9,187	5.3%	18.1%	6.4%
1986	149,261	1,860	1.3%	16.5%	1.2%
1987	174,444	336	0.2%	17.9%	0.2%
1988	362,758	40,020	11.1%	12.0%	14.0%
1989	501,846	51,484	10.3%	14.4%	13.3%
1990*	426,148	31,079	7.3%	NA	NA

*First nine months
N/A = Not available
Source: Applied Materials' Annual Reports, Dataquest (September 1990)

followed by a brief Dataquest analysis of the significance of the event.

- Applied Materials enters PVD market.

  In April 1990, Applied Materials announced its widely anticipated entry into the PVD equipment market with its Endura 5500 cluster tool platform. The system is targeted toward aluminum alloy and barrier metallization applications for advanced interconnect process. Applied has positioned this system to be the first offering in its MasterFab family of integrated processing systems for the 1990s. Dataquest views the Endura 5500 as a significant introduction because the system fills out Applied's thin-film market portfolio by offering an integrated PVD solution to complement the company's highly successful PE5000 CVD and dry etch systems.

- Applied Materials enters the metal CVD market.

  In September 1989, Applied entered the metal CVD market with the introduction of the Precision 5000 WCVD system for blanket tungsten deposition. This system is based on the highly successful PE5000 cluster tool architecture. Applied claims that the Precision 5000 WCVD system overcomes a number of problems in both film quality and operating efficiency that historically have limited the use of blanket tungsten in semiconductor manufacturing. Genus traditionally has been the market leader in tungsten CVD and has a large installed base of batch systems. Competition, however, is heating up in the fast-growing tungsten CVD market as other companies enter the marketplace.

- Applied Materials adds RTP from Peak Systems to its repertoire.

  Also in September 1989, Applied Materials announced the formation of an alliance with Peak Systems, Inc., a Fremont, California-based company engaged in the development and manufacture of rapid thermal processing (RTP) systems. Peak is a major supplier of automated RTP systems designed for the production environment. Dataquest believes that Applied's objective in entering this agreement is to extend the range of enabling technologies available to customers of its Precision 5000 equipment. Under terms of the agreement, Applied Materials will make an investment amounting to 10 percent ownership in the privately held Peak Systems.

- Applied Materials continues to pursue globalization strategy.

  Applied Materials has emphasized a strategy of globalization and partnering with key customers in the various regions of the world. Examples of such joint development agreements include Applied's technology development pacts with Samsung in South Korea and the ERSO research consortium in Taiwan. As the US wafer fab equipment market shrinks in relation to the worldwide market, Applied is devoting considerable efforts to expanding its international operations. In fiscal year 1989, Applied Materials derived 65 percent of its total sales from its international operations.

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Research Newsletter

A QUICK LOOK AT
FSI INTERNATIONAL

This newsletter provides a quick look at the financial performance and company activities of FSI International, a major supplier of semiconductor wafer fabrication equipment. This newsletter is one of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

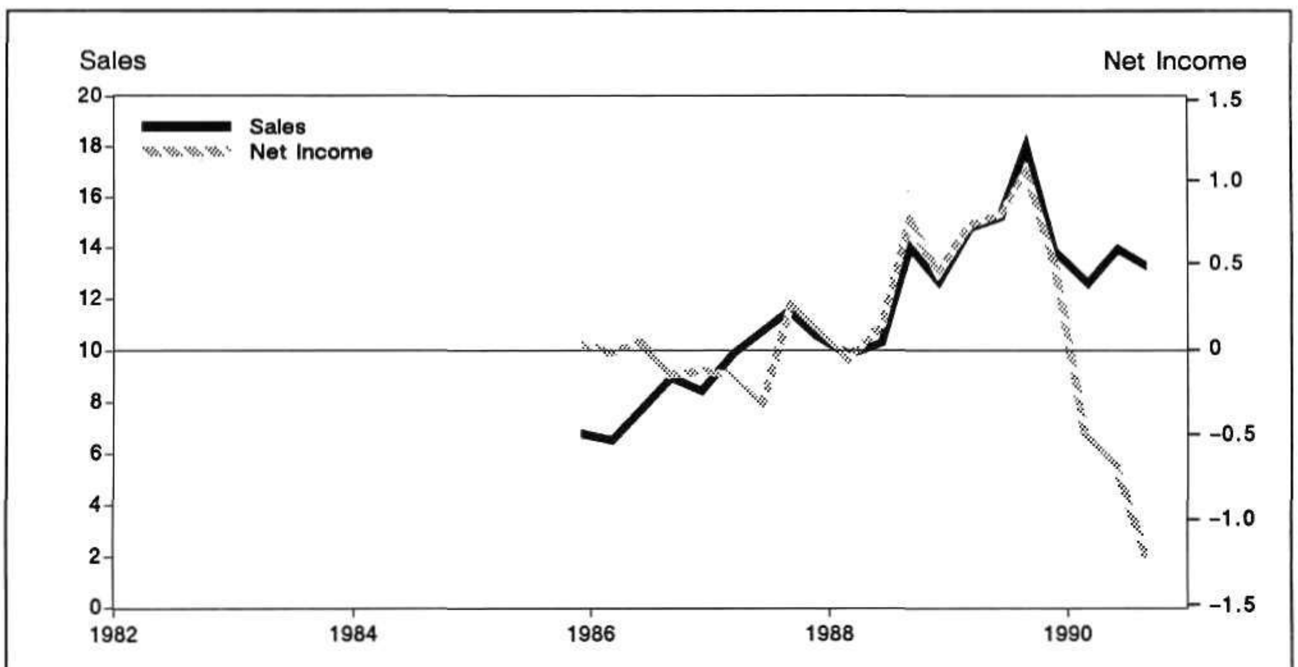
FINANCIAL REVIEW

Selected financial data for FSI are presented here with no comment or analysis. Figure 1 presents FSI's quarterly sales and net income through the quarter ending August 25, 1990. Table 1 provides a summary of fiscal year (ending 8/25) sales, net income, R&D expenditures as a percentage of sales, and return on assets (ROA) for FSI.

COMPANY HIGHLIGHTS

The following discussion highlights significant events for FSI.

FIGURE 1
FSI International—Sales and Net Income by Quarter (Millions of Dollars)



Source: FSI International Quarterly Reports, Dataquest (November 1990)

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TABLE 1
FSI International—Fiscal Year Sales, Net Income, R&D as a Percentage of Sales, and ROA

Fiscal Year (ends Aug.)	Sales ($K)	Net Income ($K)	Ratio of Net Income to Sales (%)	Ratio of R&D to Sales (%)	ROA (%)
1984	26,542	1,340	5.0	14.0	6.2
1985	37,094	2,275	6.1	14.1	9.7
1986	30,548	13	0	19.6	0
1987	41,048	(191)	(0.5)	15.6	(0.7)
1988	45,214	1,107	2.4	15.1	3.7
1989	61,594	3,154	5.1	12.3	8.2
1990	54,306	(1,749)	(3.2)	16.6	(5.1)

Source: FSI International Annual Reports, Dataquest (November 1990)

■ FSI International's business activities

Founded in 1973, FSI went public in January 1989, raising $6.7 million with its IPO. In 1983, wholly owned subsidiary FSI Japan was formed. FSI Japan modifies and manufactures equipment for the Japanese market; it has worked with Innotech, FSI's distributor in Japan, since 1987.

In 1984, FSI became the exclusive North American distributor for Convac of West Germany. In 1985, FSI signed an agreement to manufacture Convac's photoresist processing (track) equipment. In 1988, a second manufacturing agreement was struck with Convac. In January 1990, the agreements with Convac were terminated and replaced by an agreement with Texas Instruments' Process Automation Center (TI/PAC) to manufacture and distribute TI/PAC's Polaris track equipment worldwide. TI/PAC has been manufacturing photoresist tools for over 20 years.

FSI distributes its products in Europe through Metron Semiconductor Europa B.V., in which FSI has a 32.5 percent interest. In the Pacific Rim, its products are sold through the Metron Asia Group, in which FSI has a 45 percent share. For fiscal 1989, 40 percent of FSI's sales were foreign sales, of which Asia, including Japan, accounted for 17 percent and Europe accounted for 23 percent.

In 1986, FSI acquired Semiconductor Technologies, a manufacturer of megasonic cleaning equipment. In 1989, FSI entered into an agreement with the Hitachi Electronics Engineering Co. to market Hitachi's particle-counting systems in the eastern United States.

■ FSI International in the marketplace

FSI is a worldwide leader in the surface conditioning of wafers that employ both wet and gaseous chemistries for such process steps as clean, rinse/dry, etch, strip, and photoresist processing. FSI's main product lines and their percentage of fiscal 1989 revenue are centrifugal spray processors (40 percent), chemical delivery systems (14 percent), gas processors (6 percent), and track equipment (9 percent). Service, spares, and other products account for the remaining 31 percent.

Centrifugal spray processors, a technology pioneered by FSI in the early 1970s, include the Saturn, Titan, and Mercury acid processing systems; the Atlas solvent processing system; and centrifugal and downflow rinser/dryers. In 1985, FSI introduced the ChemFill automatic chemical management system to deliver chemicals from a remote bulk source to various end stations throughout the fab. The Excalibur gas processing system, also pioneered by FSI and introduced in 1987, removes oxide films using anhydrous HF/vapor etching chemistry.

FSI had manufactured Convac track systems for distribution in North America since 1986. However, FSI will began manufacturing TI/PAC's Polaris track system in 1990. The Polaris is a total automated lithography work cell approach to photoresist processing. Other products manufactured by FSI include immersion megasonic cleaners, DI water heaters, and the Vapitor IPA vapor dryer.

FSI is the only front-end equipment company to have received TI's Supplier Excellence Award for the past four years.

Joseph Grenier

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Research Newsletter

A QUICK LOOK AT
INTEL

This newsletter provides a quick look at Intel's semiconductor capital spending, R&D spending, capacity by line geometry, planned facilities, and recent company highlights as related to semiconductor manufacturing. This newsletter is part of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

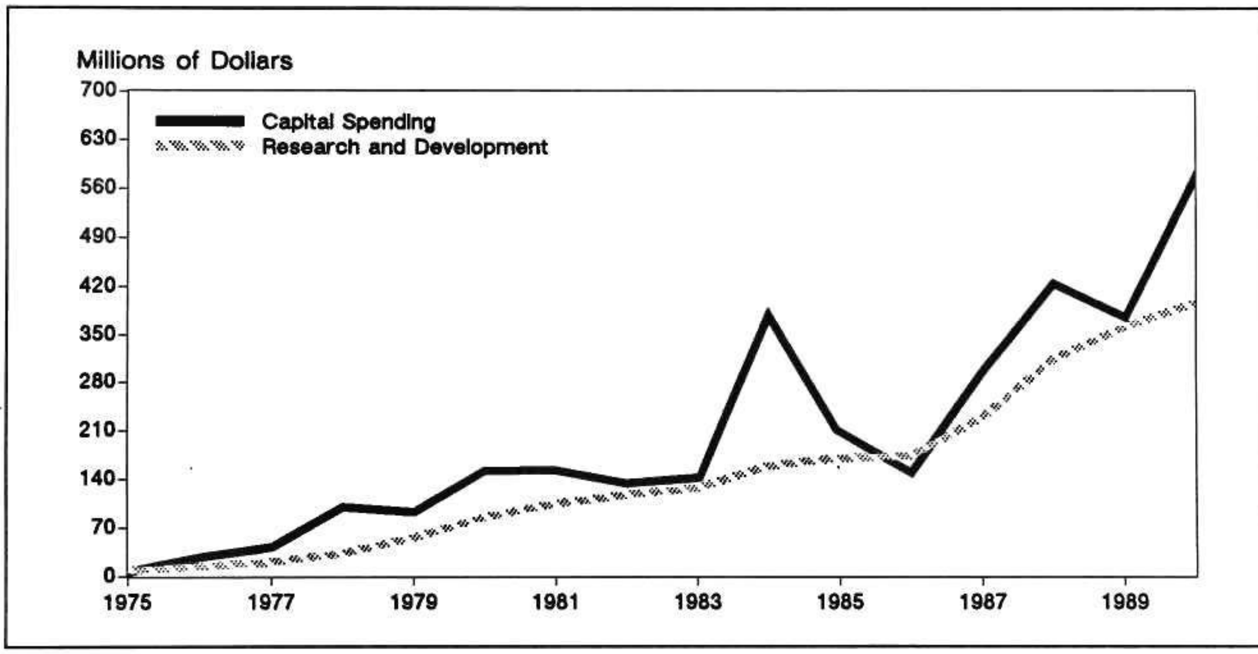
SEMICONDUCTOR CAPITAL SPENDING AND R&D SPENDING

Intel's semiconductor capital spending and semiconductor R&D spending by year is shown in Figure 1.

MANUFACTURING FACILITIES

A percentage distribution of Intel's existing worldwide semiconductor capacity by line geometries is shown in Figure 2. Additions to

FIGURE 1
Intel—Semiconductor Capital Spending and R&D Spending by Year (Millions of Dollars)



Source: Dataquest (December 1990)

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Intel's facilities in 1990 and planned additions beyond 1990 are shown in Table 1.

COMPANY HIGHLIGHTS

The following discussion highlights significant events for Intel.

- Santa Clara, California (D2)

  Intel's newest developmental fab, D2, is a memory and embedded control device development fab with 25,000 square feet of clean room. It was designed to develop the manufacturing processes to support three different technologies simultaneously: current generation down to 0.8 micron, 0.5 to 0.6 micron, and 0.2 to 0.3 micron. D2 was the first development fab in the United States to use Dr. Ohmi's submicron clean room concepts.

- Rio Rancho, New Mexico (Fab 9.1 and Fab 9.2)

  Intel added significant microprocessor and advanced logic capacity in 1990 to Fab 9.1. It also began equipping its submicron Fab 9.2 to produce microprocessors and other advanced logic devices. Intel expects to begin volume production in Fab 9.2 by the second quarter of 1991.

- Chandler, Arizona (assembly and test facility)

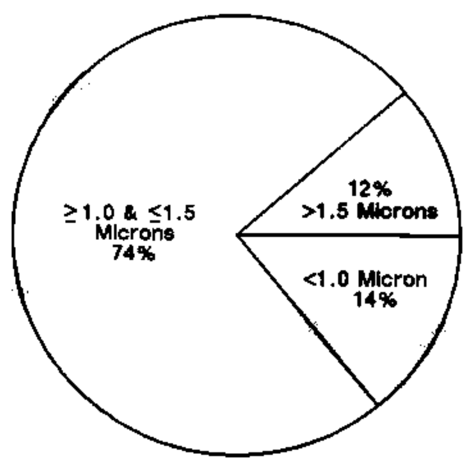
  Intel completed an assembly and test facility in Chandler, in 1990. It will be used to assemble and test R&D and prototype devices and leading-edge production devices.

- Livermore, California (Fab 3)
- Intel stated that its Livermore fab (Fab 3), which was going to be closed this year, will stay open an extra year to meet 80383SX demand.
- Leixlip, Ireland

  Construction of a systems manufacturing plant began at this site in 1990. Intel also plans to start construction of a wafer fab in 1991, which Dataquest expects to be an 8-inch facility. Chip production will begin in 1993.

George Burns

FIGURE 2
Intel—Existing Capacity by Line Geometry
(Percentage of Distribution)



Note: Capacity is measured by square inches of silicon.

Source: Dataquest (December 1990)

TABLE 1
Intel's Planned Facilities—1990-1993

Location	Products	Wafer Size	Year
Santa Clara, California (D2)	Nonvolatile memory technology development	6-inch	1990
Rio Rancho, New Mexico (9.2)	MPUs, EPROMs	6-inch	1991
Leixlip, Ireland	80486/80586 MPUs	8-inch	1993

Source: Intel

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Research Newsletter

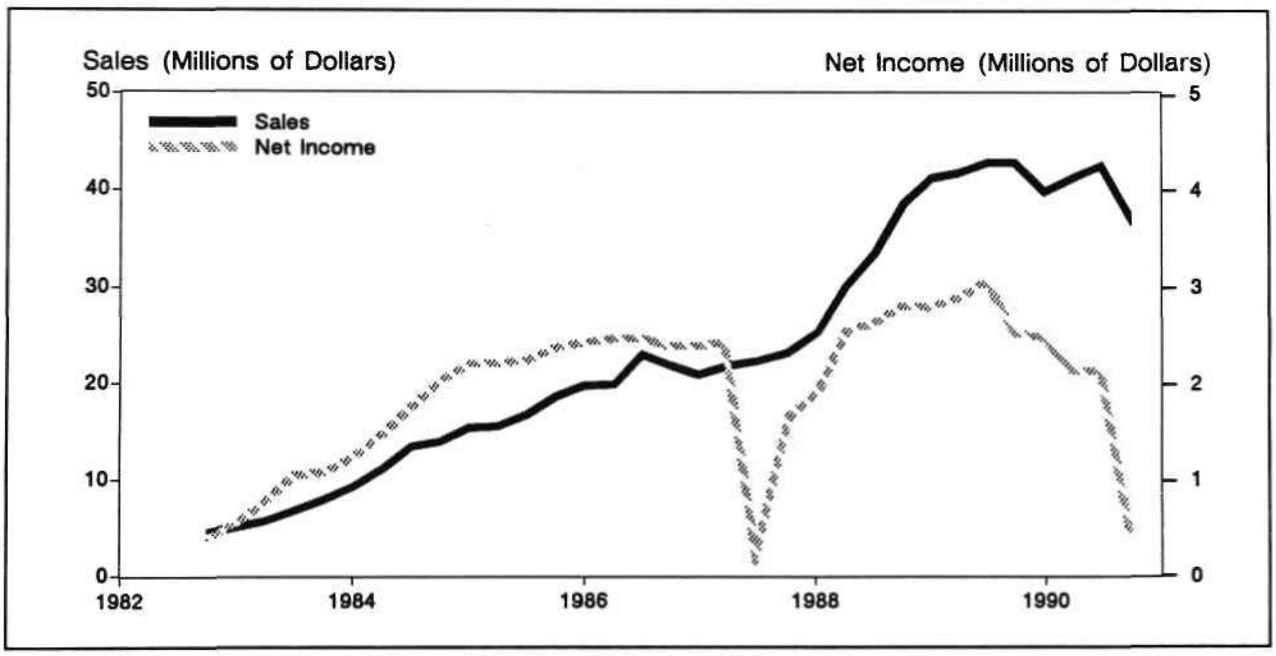
A QUICK LOOK AT
KLA INSTRUMENTS

This newsletter provides a quick look at the financial performance and recent company activities of KLA Instruments, a major supplier of semiconductor wafer fabrication equipment. This newsletter is one of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

FINANCIAL REVIEW

Selected financial data for KLA are presented here with no comments or analysis. Figure 1 presents KLA's quarterly sales and net income through the quarter ending September 30, 1990. Table 1 provides a summary of fiscal year (ending 6/30) sales, net income, R&D expenditures as a percentage of sales, and return on assets (ROA) for KLA.

FIGURE 1
KLA Instruments—Sales and Net Income by Quarter (Millions of Dollars)



Source: KLA Instruments' Quarterly Reports, Dataquest (December 1990)

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TABLE 1
KLA Instruments—Fiscal Year Sales, Net Income, R&D as a Percentage of Sales, and ROA (Thousands of Dollars)

Fiscal Year (Ends 6/30)	Sales	Net Income	Ratio of Net Income to Sales (%)	Ratio of R&D to Sales (%)	ROA (%)
1982	16,162	1,510	9.3	15.0	8.4
1983	23,396	2,928	12.5	13.1	8.4
1984	42,873	5,664	13.2	14.3	8.7
1985	62,878	8,802	14.0	17.1	10.9
1986	82,526	9,854	11.9	12.3	10.0
1987	88,194	7,489	8.5	9.8	6.5
1988	112,851	8,827	7.8	12.2	6.6
1989	165,459	11,678	7.1	15.2	7.3
1990	167,916	9,380	5.6	18.4	5.2

Source: KLA Instruments' Annual Reports, Dataquest (December 1990)

COMPANY HIGHLIGHTS

The following discussion highlights significant events for KLA.

- KLA Instruments' business activities

  Founded in 1975, KLA is a major manufacturer of automated optical inspection equipment primarily used by the semiconductor industry and manufacturers of printed circuit boards. The company's equipment product offerings are organized into four divisions: the Reticle and Photomask Inspection Division (RAPID), the Wafer Inspection System Division (WISARD), the Automated Test Systems Division (ATS), and the KLA Scanning, Inspection, and Classification Division (KLASIC). KLA's product-development activities are carried out in the United States (California), Germany, Israel, and Japan. Manufacturing operations are located in California, Germany, and Israel.

  In the late 1970s, the company formed a relationship in Japan with Tokyo Electron Limited (TEL) to sell and service its semiconductor products. This early relationship in Japan proved to be a significant component in building the company's international presence. In 1980, international sales totaled 18 percent of total revenue, compared with 7 percent in 1979. By 1990, international sales accounted for 53 percent, more than one-half of the company's revenue.

  The company's semiconductor equipment products perform optical defect detection on photomasks, reticles, and wafers; electrical defect detection on wafers and individual integrated circuits, linewidth and overlay measurements on wafers; and electrical probing on finished wafers. KLA's high-speed image-processing technology was the first to provide the semiconductor industry with automated defect detection of photomask, reticle, and wafer patterns. This achievement was significant because it allowed the subjective judgement of the operator to be eliminated from the inspection process.

- Recent significant announcements

  In October 1990, KLA Instruments' WISARD division introduced its second-generation wafer inspection system, the KLA 2110. The 2110 has significantly increased throughput and improved defect sensitivity compared with its predecessors in the 20xx family of automated defect inspection systems. The 2110 has been designed specifically for defect inspection of repeating pattern arrays such as DRAMs, SRAMs, EPROMs, EEPROMs, and gate arrays. The company views the 2110 as complementary with its other 20xx product offerings, which have full-pattern capability for all device structures such as logic.

  In September 1990, KLA and Nippon Mining of Japan announced that they had signed an agreement to form a new joint-venture company, KLA Acrotec Company, Ltd., for development of flat-panel display inspection equipment. The new company will be based in Japan and staffed by employees of KLA and Nippon Mining. The automated defect-detection technology of KLA is well suited for liquid-crystal and flat-panel display manufacturing, areas where it is critical to find and repair defects before processing is complete.

Joe Grenier
Peggy Marie Wood

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Research Newsletter

A QUICK LOOK AT LAM RESEARCH

This newsletter provides a quick look at the financial performance and recent company activities of Lam Research, a major supplier of semiconductor wafer fabrication equipment. This newsletter is one of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

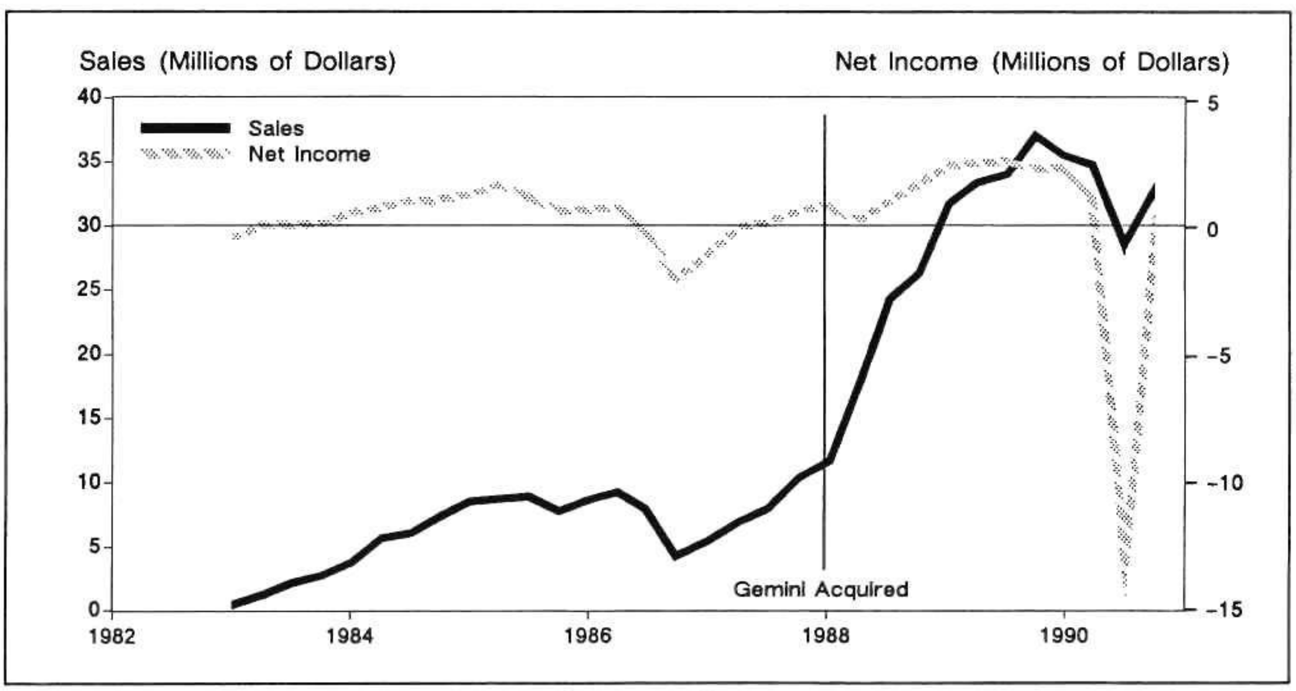
FINANCIAL REVIEW

Selected financial data for Lam are presented here with no comment or analysis. Figure 1 presents Lam's quarterly sales and net income through the quarter ending September 30, 1990. Table 1 provides a summary of fiscal year (ending 6/30) sales, net income, R&D expenditures as a percentage of sales, and return on assets (ROA) for Lam Research.

COMPANY HIGHLIGHTS

The following discussion highlights significant events for Lam.

FIGURE 1
Lam Research—Sales and Net Income by Quarter (Millions of Dollars)



Source: Lam Research Quarterly Reports, Dataquest (October 1990)

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TABLE 1
Lam Research—Fiscal Year Sales, Net Income, R&D as a Percentage of Sales, and ROA

Fiscal Year (ends 6/30)	Sales ($K)	Net Income ($K)	Ratio of Net Income to Sales (%)	Ratio of R&D to Sales (%)	ROA (%)
1983	5,141	(715)	(13.9)	24.8	(12.4)
1984	19,135	2,638	13.8	15.0	6.7
1985	34,447	5,367	15.6	15.0	11.2
1986	34,449	1,998	5.8	22.3	4.1
1987	25,486	(2,658)	(10.4)	30.4	(6.0)
1988*	74,963	2,505	3.3	21.0	3.8
1989	126,048	9,302	7.4	17.3	9.7
1990	137,260	(8,785)	(6.4)	19.4	(8.3)

*Fiscal years 1983-1987 include Lam's performance prior to the acquisition of Gemini. Fiscal years 1988-1990 include Gemini's performance as well.
Source: Lam Research Annual Reports, Dataquest (October 1990)

■ Lam Research's business activities

Founded in 1980, Lam Research went public in May 1984. In May 1983, Lam formed TEL-Lam, a 50/50 joint venture (JV) with Tokyo Electron Limited (TEL), to manufacture Lam's AutoEtch product line in Japan. In December 1986, Lam sold its 50 percent equity share to TEL, and the JV was converted to a five-year licensing agreement whereby TEL will pay Lam a 5 percent royalty fee on all AutoEtch products manufactured and sold by TEL.

In April 1987, Lam entered into an R&D agreement with Monkowski-Rhine Inc. (MRI) to develop chemical vapor deposition (CVD) equipment, and in April 1989, Lam acquired MRI. The new CVD system, called Integrity, was introduced in October 1990.

In October 1987, Lam entered into an agreement with Sumitomo Metal Industries Ltd. (SMI) whereby Lam has marketing rights for SMI's ECR systems in North America and Europe, and SMI has rights to market Lam's Rainbow line of etchers in Japan. In July 1989, SMI invested $5 million in Lam Research.

In February 1988, Lam merged with Gemini, a maker of epitaxial reactors; in June 1989, Lam entered into a technology transfer and licensing agreement with Canon that gave Canon manufacturing rights to the Gemini Tetron epitaxial reactor in Japan. In early 1990, Lam announced that it would phase out production of Gemini reactors.

Since August 1989, Lam has entered into three industry alliances: with Du Pont to develop new etch processes, with Sematech to develop an enhanced metal etch system, and another with Sematech to develop an ECR CVD system.

■ Lam Research in the marketplace

Lam's first product line was the AutoEtch series of single-wafer etchers that still is offered today in four versions for oxide, polysilicon, aluminum, and silicide applications. In May 1987, Lam introduced the new Rainbow series of etchers, which now are available in three versions for oxide, polysilicon, and aluminum applications. These products are advanced etchers designed for 0.5-micron 16Mb DRAM production. Rainbow has been quite successful—two years after introduction, the hundredth Rainbow was shipped, and today, Rainbow etchers account for about two-thirds of Lam's shipments.

Lam recently shipped its thousandth etch system. The company has been at the leading edge of single-wafer dry etch technology since the 1980s. Lam traditionally has been a leader in polysilicon and polycide etch applications and recently made significant efforts to capture the metal and oxide etch markets. In 1989, Lam received Texas Instruments' Supplier Excellence Award.

The new Integrity CVD system now is finishing extensive beta site testing with global semiconductor manufacturers. Integrity is a batch reactor targeted toward high-temperature thermal CVD applications such as BPSG and other reflow films. Film deposition, flow, and anneal all occur within the system's single chamber. Lam says that the system offers significant advantages in film quality and cost effectiveness over atmospheric and low-pressure CVD systems that currently are on the market. We believe that the Integrity system will serve as Lam's core deposition platform in the 1990s for other films such as thermal poly, thermal nitride, and CVD aluminum and tungsten.

Joseph Grenier
Krishna Shankar

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Research Newsletter

A QUICK LOOK AT MOTOROLA

This newsletter provides a quick look at Motorola's semiconductor capital spending, R&D spending, capacity by line geometry, planned facilities, and recent company highlights as related to semiconductor manufacturing. This newsletter is part of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

SEMICONDUCTOR CAPITAL SPENDING AND R&D SPENDING

Figure 1 graphically illustrates Motorola's semiconductor capital spending and semiconductor R&D spending by year from 1975 through 1990.

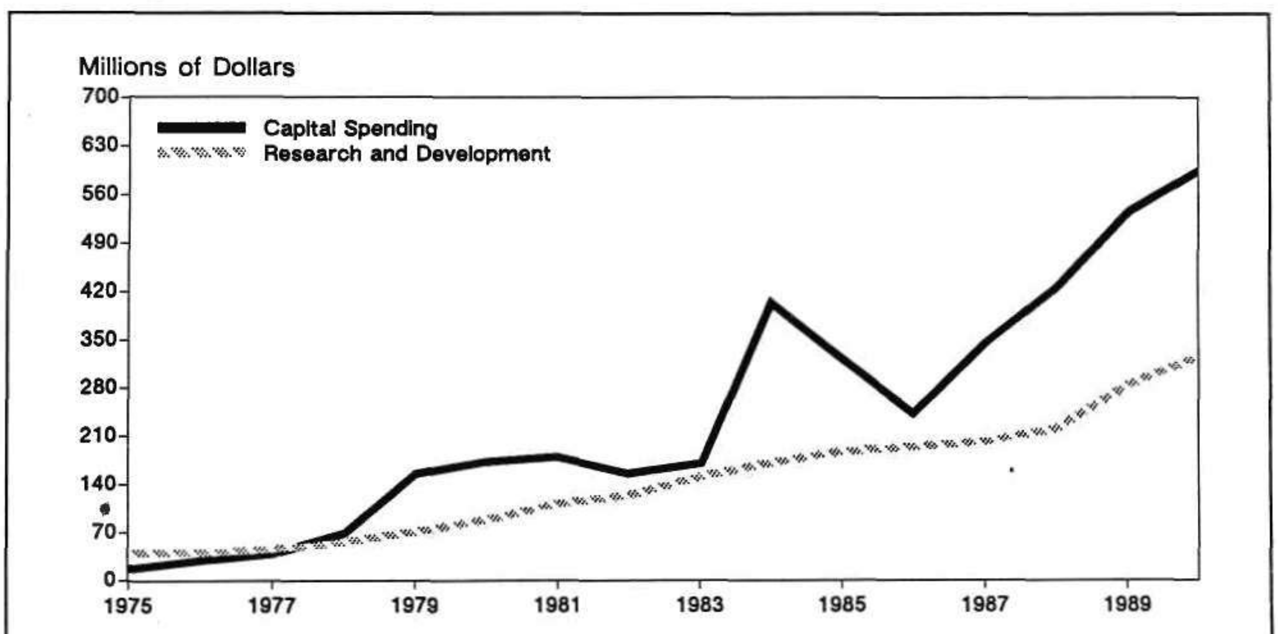
MANUFACTURING FACILITIES

Additions to Motorola's manufacturing facilities in 1990 and planned additions beyond 1990 are shown in Table 1. Figure 2 illustrates the percentage distribution of Motorola's existing worldwide semiconductor capacity by line geometries.

COMPANY HIGHLIGHTS

The following discussion highlights significant events for Motorola.

FIGURE 1
Motorola—Capital Spending and R&D Spending by Year



Source: Dataquest (November 1990)

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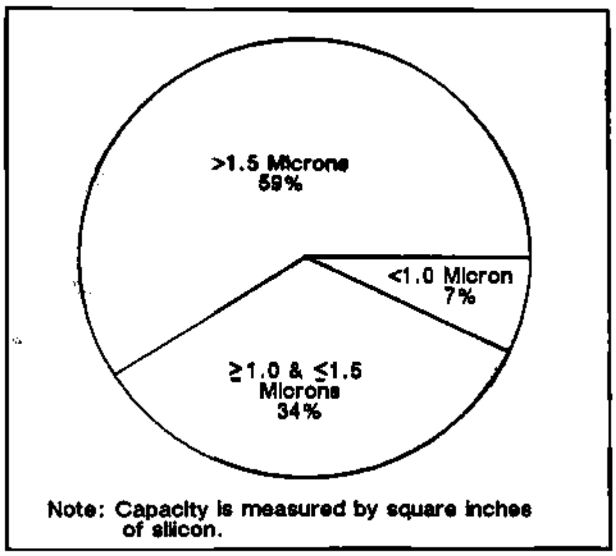
TABLE 1
Motorola's Planned Facilities—1990-1992

Location	Products	Wafer Size	Year
East Kilbride, Scotland[1]	DRAMs, SRAMs, MPUs	6-inch	1990
Seremban, Malaysia	Discretes, power	6-inch	1990
Hong Kong (Silicon Harbor)	Design, assembly, and test	NA	1990
Oak Hill, Texas	Memory, MPUs	8-inch	1991
Sendai, Japan[2]	4Mb DRAMs	6-inch	1991
Sendai, Japan	Assembly and test	NA	1991
Chandler, Arizona	ECL and BiCMOS, gate arrays	6-inch	1992
Chandler, Arizona	R&D line	6-inch	1992

NA = Not available
[1]Capacity expansion
[2]Motorola-Toshiba joint venture
Source: Motorola

FIGURE 2
Motorola—Existing Capacity by Line Geometry (Percentage of Distribution)



Source: Dataquest (November 1990)

- Oak Hill, Texas (MOS 11)

  This new fab is Motorola's first 8-inch wafer facility. It is scheduled to begin production of advanced memory and microprocessor devices in the latter part of 1991. Initial cost of this facility will be $250 million. Recent equipment orders for MOS 11 include Applied Materials CVD, etch, and implanter systems; Canon steppers; Lam Research plasma etchers; Silicon Valley Group track equipment and vertical reactors; and Varian implanters.

- Chandler, Arizona (R&D line and Bipolar 6)

  Bipolar 6, an ASIC fab designed for small lots and quick turns, will be built adjacent to Motorola's new ASIC R&D line. Motorola will be able to take devices from R&D to pilot to manufacturing, all within the same facility.

- Silicon Harbor

  The Silicon Harbor facility, located in Hong Kong, is a 326,000-square-foot facility that will house Motorola's Asia/Pacific headquarters, an advanced ASIC design center, and an assembly/test center.

- Plans for China facility

  Motorola is reported to be still interested in building an assembly/test facility in China—perhaps by 1992 in Tianjin.

- Toshiba joint venture

  Motorola's joint venture with Toshiba, Tohoku Semiconductor, is scheduled to begin production of 4Mb DRAMs at its Sendai plant in Japan in mid-1991. It is rumored that Motorola and Toshiba also will start construction of a joint-venture 4Mb DRAM plant in Europe in 1991.

George Burns

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Research Newsletter

A QUICK LOOK AT
NOVELLUS

This newsletter provides a quick look at the financial performance and recent company activities of Novellus, a major supplier of semiconductor wafer fabrication equipment. This newsletter is part of the "Quick Look" series of newsletters from Dataquest's Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS).

FINANCIAL REVIEW

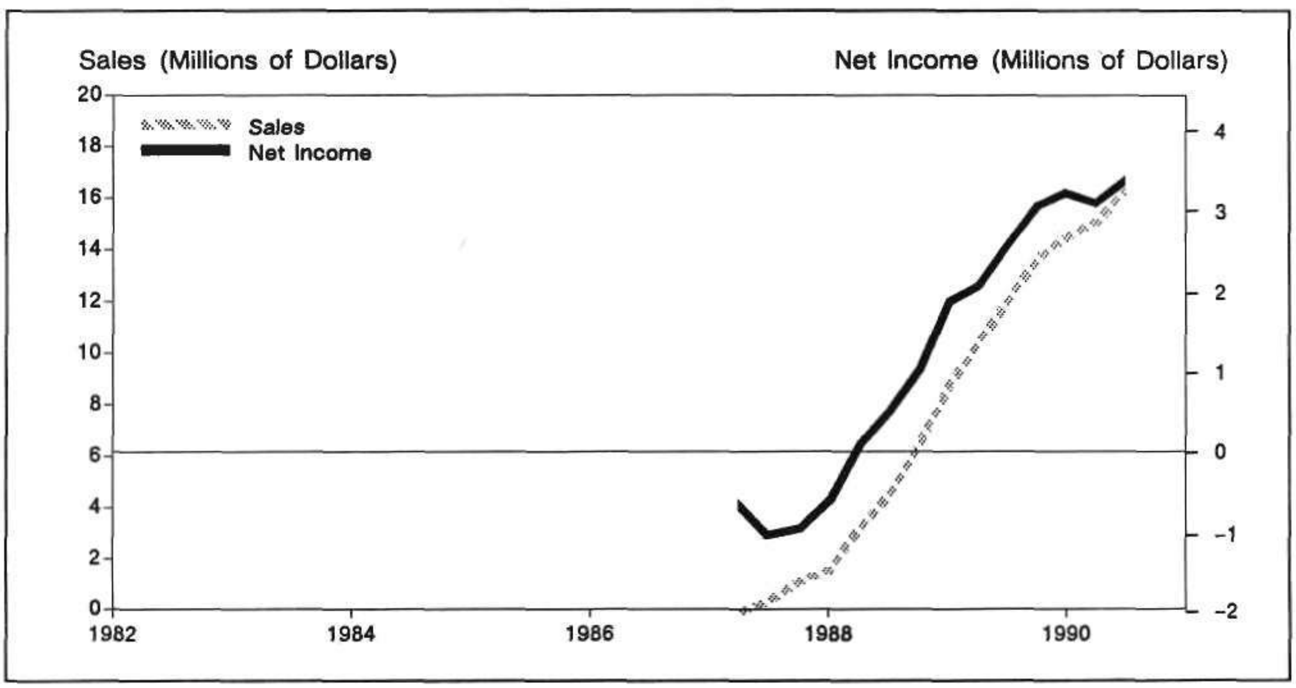
Selected financial results for Novellus are presented here with no additional commentary or analysis. Figure 1 presents Novellus' quarterly sales and net income through the quarter ending June 30, 1990. Table 1 provides a summary of fiscal year (ending 12/31) sales, net income, R&D expenditures as a percentage of sales, and return on assets (ROA) for Novellus.

COMPANY HIGHLIGHTS

The following discussion highlights recent significant events for Novellus.

- Incorporated in April 1984, Novellus was in the developmental stage until May 1987, when it shipped its first Concept One CVD system.

FIGURE 1
Novellus—Sales and Net Income by Quarter



Source: Novellus' Quarterly Reports, Dataquest (October 1990)

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Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

TABLE 1
Novellus—Fiscal Year Sales, Net Income, R&D as a Percentage of Sales, and ROA (Thousands of Dollars)

Fiscal Year (ends 12/31)	Sales	Net Income	Ratio of Net Income to Sales	Ratio of R&D to Sales	ROA
1985[1]	0	(462)	-	-	(47.9%)
1986	0	(1,744)	-	-	(31.0%)
1987	3,262	(3,150)	(96.6%)	33.9%	(66.7%)
1988	23,224	3,640	15.7%	9.7%	15.2%
1989	50,980	11,248	22.1%	10.6%	22.3%
1990[2]	31,744	6,669	21.0%	13.2%	11.5%

[1] From April 1984 inception to December 31, 1985
[2] First six months
Source: Novellus Annual Reports, Dataquest (October 1990)

Novellus shipped its 100th system in November 1989. The company completed its initial public offering (IPO) in August 1988, selling approximately 1.9 million shares at $8 per share. In May 1989, Novellus made a second public offering of about 1 million shares, netting $11.5 million.

- Novellus introduced the Concept One-200 with 200mm wafer capability in the fourth quarter of 1989.
- Novellus expanded its international operations in 1989 by opening a wholly owned subsidiary in Japan and a branch office in South Korea. In 1988 and 1989, Novellus' Far East sales of the Concept One were about 25 percent of its total worldwide sales. In 1987, its Far East sales represented only 15 percent.
- Novellus was selected by the Texas Instruments Semiconductor Group in January 1990 to receive its Supplier Excellence Award for 1989.
- Novellus introduced its Concept One-W blanket tungsten CVD system in September 1989. As the new challenger in the metal CVD market, Novellus will attempt to leverage its highly successful Concept One dielectric CVD equipment architecture by extending it to the new Concept One-W system. The Concept One-W uses the same sequential batch architecture as the original Concept One system, and Novellus claims that the Concept One-W architecture offers high-quality, cost-effective, production-worthy blanket tungsten CVD films. Novellus should benefit from the original Concept One's market success and cumulative field experience, but it has to climb the tungsten CVD production learning curve quickly. One way to do this is to use strategic partnerships with key customers in order to meet advanced device design-in time windows. Dataquest expects Novellus to introduce its MESC-compatible cluster-tool platform in 1991 and probably adapt its Concept One family to its cluster-tool platform. We believe that Novellus also may be actively pursuing strategic PVD and dry etch partnerships with other global equipment companies in order to quickly offer best-of-breed integration solutions for its cluster tool.

Joe Grenier
Krishna Shankar

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Research *Newsletter*

OPERATING INCOME AND R&D EXPENDITURES OF US SEMICONDUCTOR EQUIPMENT COMPANIES

INTRODUCTION

This newsletter takes a look at the operating income and R&D expenditures for 18 public US semiconductor equipment companies and 1 European equipment company. It also presents the idea that operating income and R&D expenditures together may be seen as a pool of funds that can be traded off against each other. Although most areas of wafer fab equipment are represented in this analysis, no lithography companies are included because the data are not publicly available.

OPERATING INCOME

Net income and operating income are measures of a company's profitability; return on assets and return on equity are others. Operating income (op income), which is discussed in this newsletter, is net sales minus cost of sales, SG&A expense, and R&D expenditures (see Table 1). It is the income before interest expense, any extraordinary items, and income taxes. Thus, it measures the efficiency of the company in its primary business of manufacturing and selling its products. When we compare op income from company to company, we are comparing similar items; when we compare net income, we are not.

Op income is necessary to provide funds for a company to self-finance growth. If a company does not have good op income, then it must turn to outside sources, either debt or equity, to finance its growth. However, with the financial community's current attitude toward high-tech industry, it has become harder and more costly to grow with the help of outside sources. On the other hand, a company with a good op income record will find it easier to raise funds in the marketplace when it needs to do so.

Figure 1 shows op income as a percentage of sales for 19 public companies. Novellus led the field in 1989 with 30.5 percent, closely followed by Cognex, a start-up machine-vision company. Most companies had positive op incomes except for Nanometrics and OSI, two struggling wafer inspection companies, and LTX, a test equipment company that showed a large deficit. The average op income for the 19 companies was 10.0 percent. Note that 4 of the top 5 performers were companies that have recently gone public: Novellus, Cognex, Genus, and BTU International. Also note that Applied Materials led the more established equipment companies with a 16.6 percent op income.

TABLE 1
Definition of Operating Income

Net sales
- Cost of sales
- SG&A expenses
- R&D expenditures

Operating income
- Interest expense (income)
- Extraordinary items
- Income taxes

Net income

Source: Dataquest (July 1990)

R&D EXPENDITURES

Figure 2 shows R&D expenditures as a percentage of sales for the same companies (except for Varian, as its R&D figures are not publicly disclosed). LTX led the list with an R&D expenditure

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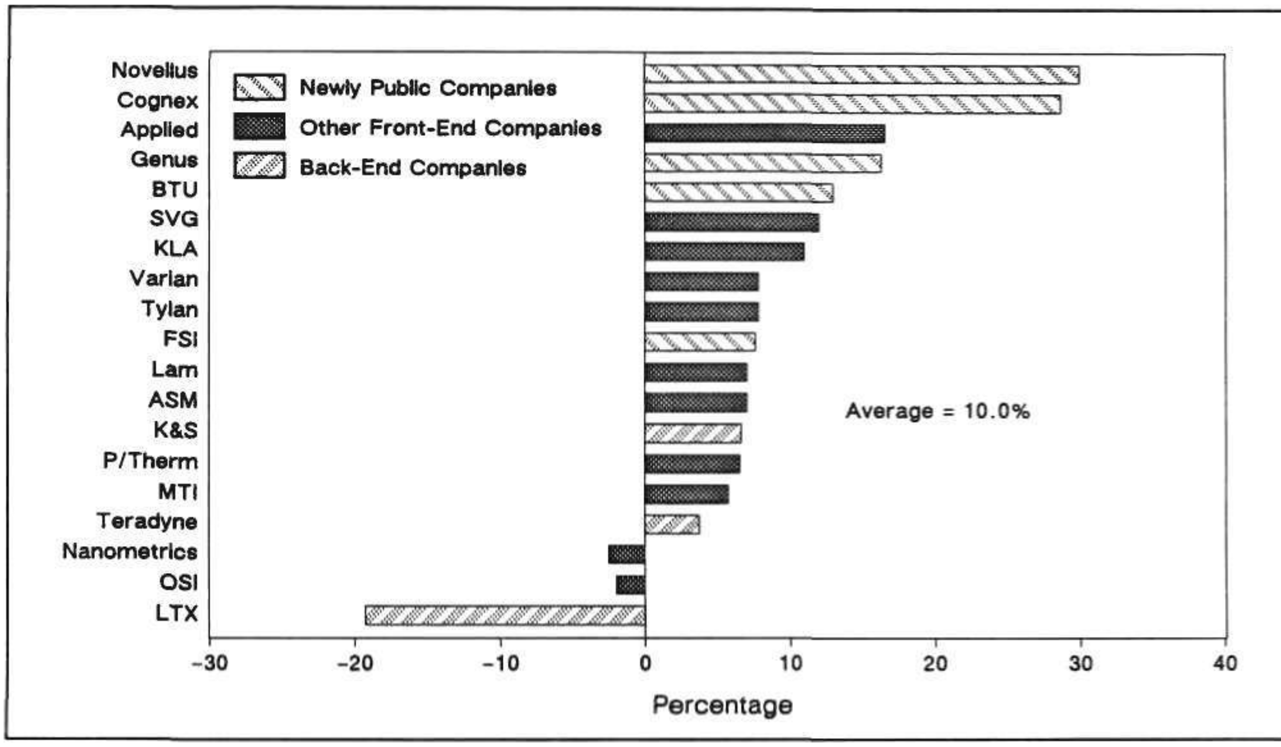
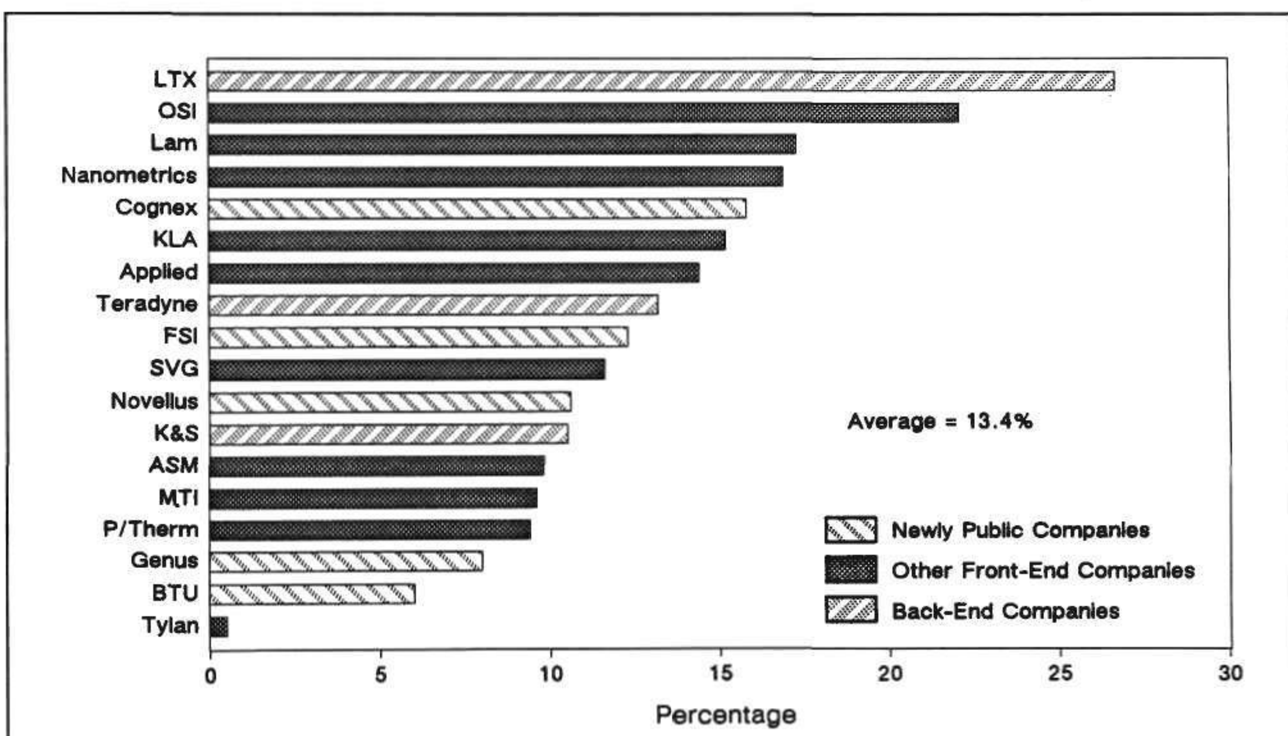
Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

FIGURE 1
Semiconductor Equipment Companies' Operating Income as Percentage of Sales



Source: Dataquest (July 1990)

FIGURE 2
Semiconductor Equipment Companies' R&D Expenditures as Percentage of Sales



Source: Dataquest (July 1990)

of 26.7 percent. Note that three of the top four companies were the bottom three companies when we looked at op income. Clearly, these companies had to sacrifice short-term profits to invest in new products in order to ensure their long-term survival.

Notice that four of the five companies that have recently gone public (Cognex, FSI, Novellus, Genus, and BTU) are all below the 13.4 percent average R&D expenditure for the industry. Cognex is the exception. Two of these companies, Genus (8.2 percent) and BTU (6.3 percent), are at the bottom. Recall from Figure 1 that Genus and BTU both had op incomes above the industry average, but here we see that their R&D expenditures are far below the industry average of 13.4 percent. Did these companies sacrifice long-term R&D for a more favorable short-term op income?

Also note that Lam, KLA, and Applied Materials all had R&D expenditures that were above average.

OPERATING INCOME AND R&D EXPENDITURES AS A POOL OF FUNDS

Operating income plus R&D expenditures can be viewed as a pool of funds to be traded off in the direction of either op income or R&D. For instance, if a company reduces its R&D spending, then its op income increases; conversely, if R&D spending is increased, then op income decreases. From the preceding discussion, we can assume that quite a few companies had to make these trade-offs in 1989.

The goal, of course, is to manage the company in such a way that these trade-offs do not have to be made—to ensure that optimum levels of both op income and R&D can be attained. But what are the optimum levels? They will vary from company to company, but one way of arriving at a benchmark is to use the 10.0 percent average industry performance for op income and the 13.4 percent average industry R&D investment. When we add these together, we get just under 24 percent.

Thus, a company must have a pool of funds of a least 24 percent of sales if it is to perform to industry averages for both op income and R&D. If its pool of funds is below 24 percent, it will have to make trade-offs in either profits or R&D and underperform the industry in one of these areas. Another way of looking at the situation is to say that companies above 24 percent are outperforming the industry and those below 24 percent are struggling to keep up.

Figure 3 shows the pool of funds, or the combined op income and R&D spending, that was available to the 18 companies in 1989. Here we see the problem. Only 6 of the 18 companies were able to exceed the 24 percent hurdle, and only Applied Materials, Cognex, and KLA outperformed the industry in both areas of op income and R&D. Genus and Novellus outperformed the industry in op income with 16.3 and 30.5 percent, respectively, but underperformed in R&D with 8.2 and 10.6 percent, respectively. It is interesting that both of these companies have gone public recently.

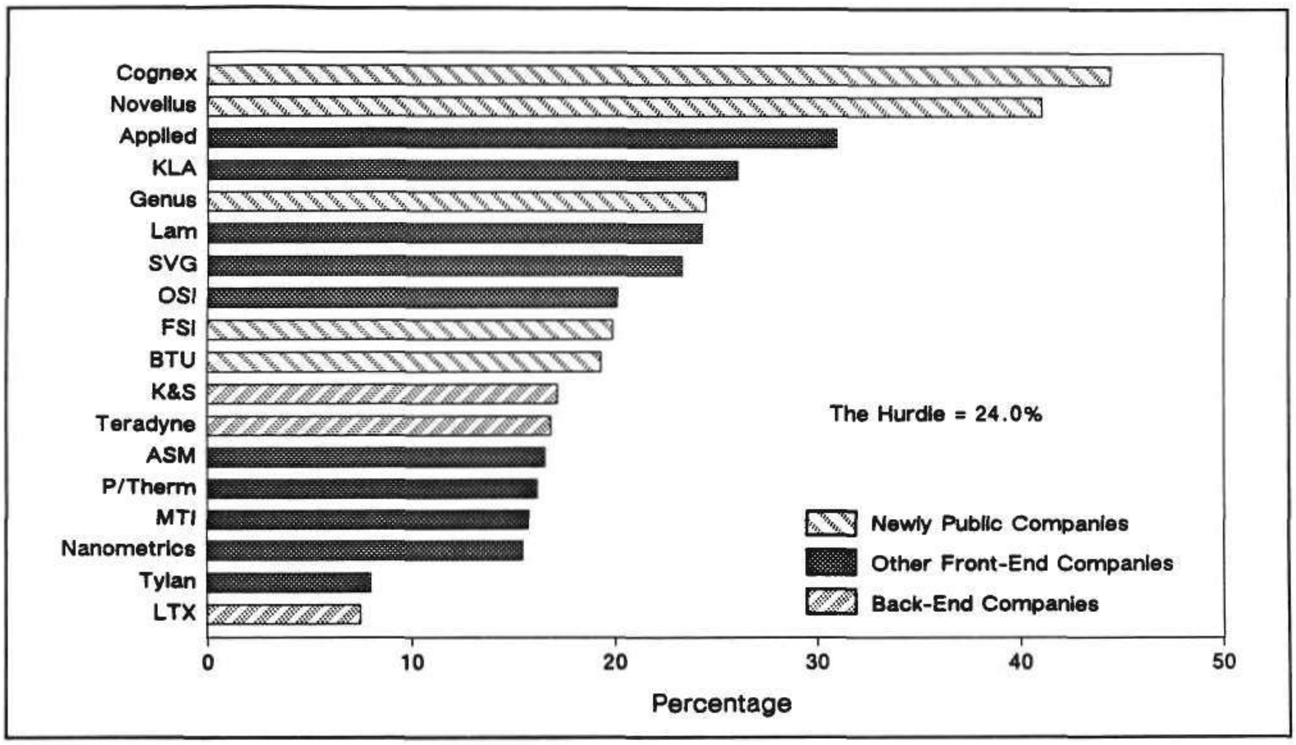
Lam, the remaining company in the top six, had above-average R&D spending of 17.3 percent, but it was at the expense of a 7 percent op income performance. Lam has said that it wants to be a $500 million company, so this trade-off is in line with that strategy.

The other 12 companies are all below the 24 percent hurdle, although Silicon Valley Group (SVG) is very close at 23.3 percent. Now that SVG has acquired Perkin-Elmer's lithography operation, it will be interesting to watch the company's performance in the ensuing years. The remaining 11 companies had to struggle to keep up with the industry in 1989. The equipment industry grew more than 20 percent in 1989, and if companies had to make trade-offs in a good year like 1989, what is going to happen in the flat year that we expect in 1990?

Figure 4 shows the actual dollar amount of the pool of op income and R&D funds; Applied Materials is out there all by itself with $156 million. This amount is larger than the entire sales of all but a few of the companies listed in the figure. Five of the top six companies are the familiar leaders in the wafer fab equipment industry, followed by the newly public fab equipment companies.

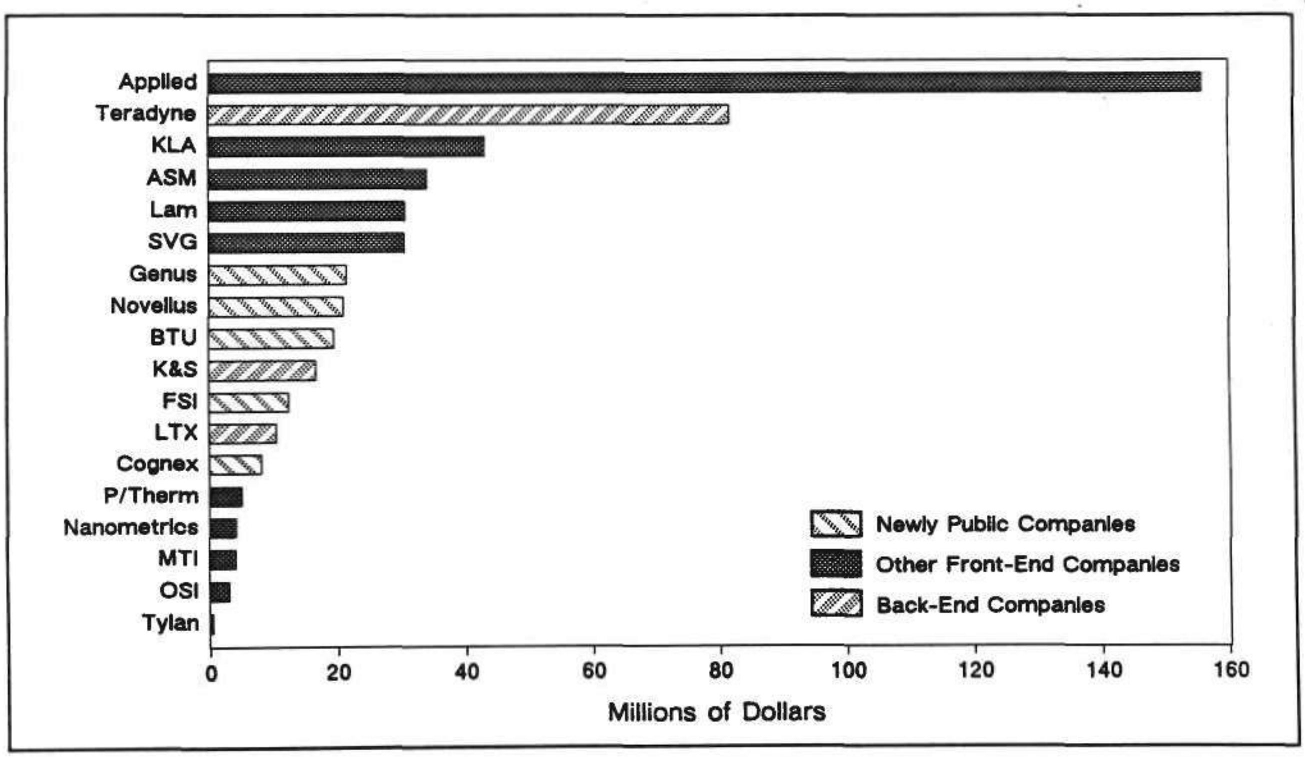
Figure 5 shows actual R&D expenditures for the same 18 companies. Again, Applied Materials is the leader with $72 million, followed by two test equipment companies. Note that Applied's R&D spending is more than three times that of Lam, its nearest competitor. It is also more than 10 times that of Genus and 13 times that of Novellus. Applied Materials has five product lines, averaging out to $14 million per product line, which is more than the entire combined R&D expenditures of both Genus and Novellus.

Figure 3
Semiconductor Equipment Companies' Operating Income Plus R&D Expenditures as Percentage of Sales



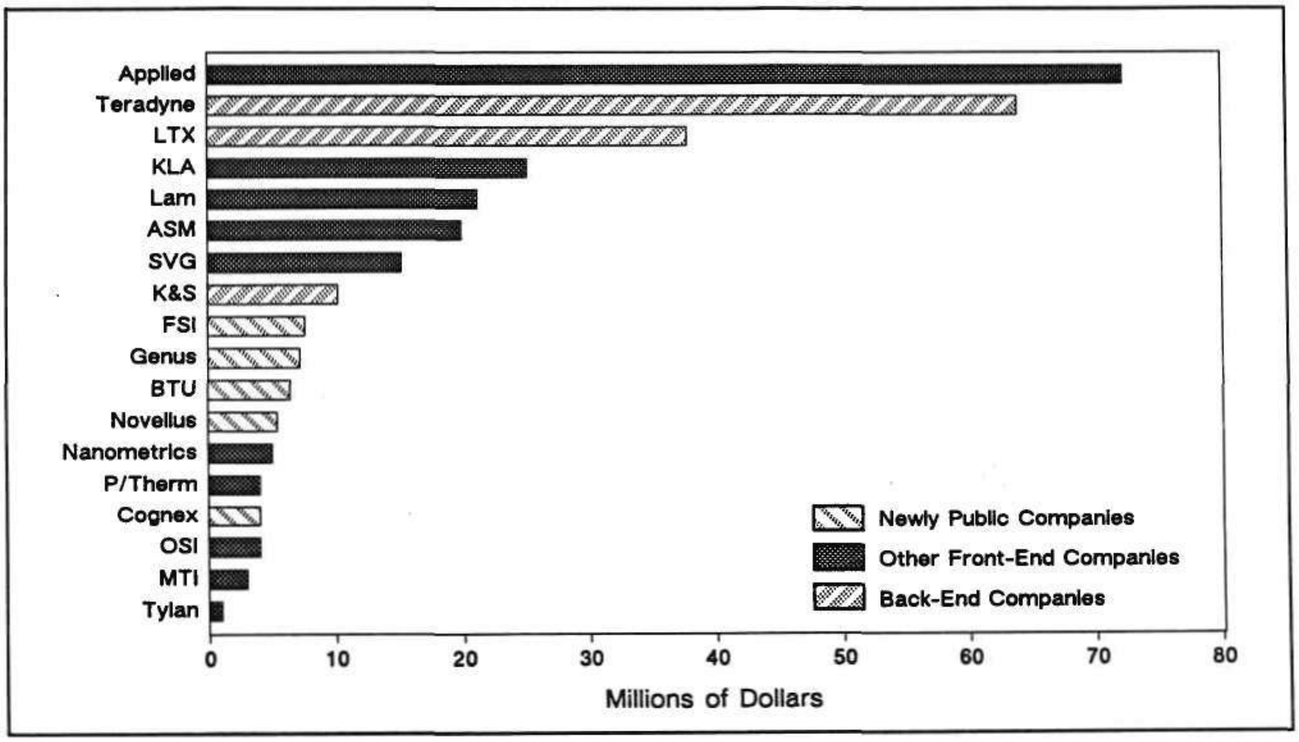
Source: Dataquest (July 1990)

Figure 4
Semiconductor Equipment Companies' Operating Income Plus R&D Expenditures



Source: Dataquest (July 1990)

FIGURE 5
Semiconductor Equipment Companies' R&D Expenditures



Source: Dataquest (July 1990)

SUMMARY

Some may disagree with the pool-of-funds concept presented here, but it is an attempt to bring together R&D and profits in the same discussion. We intuitively know that some companies are positioned better than others, but this concept makes the discussion more quantitative. It points out what a company's performance needs to be in order for that company to be an industry leader.

How does your company measure up to this analysis?

Joseph Grenier

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Research Newsletter

US SEMICONDUCTOR EQUIPMENT INDUSTRY PRODUCTIVITY—HOW DOES IT STACK UP?

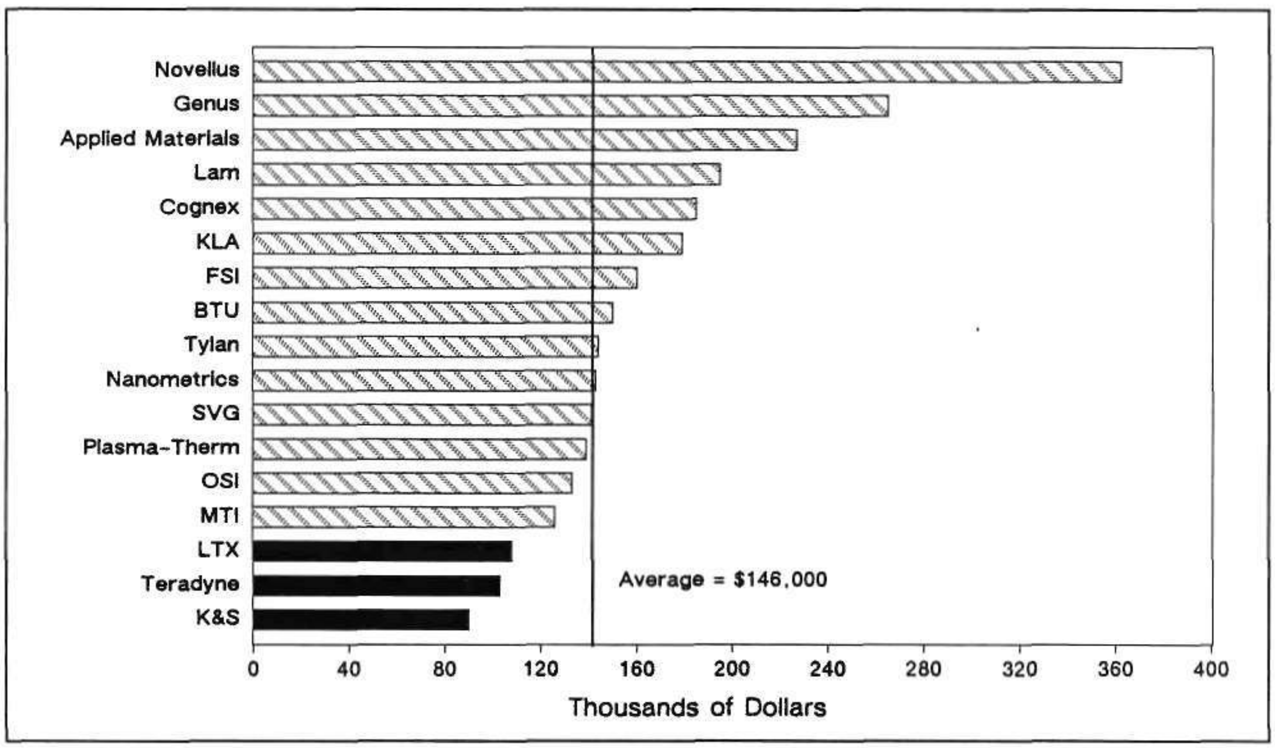
Although there are several measures of a company's productivity, one key measure is the sales per employee. This measure is defined as the total fiscal year sales of the company divided by the average number of employees who worked there during the year. This newsletter discusses sales per employee for various US companies that manufacture semiconductor equipment and compares these companies with other types of companies in the US electronics industry.

SEMICONDUCTOR EQUIPMENT COMPANIES

Figure 1 shows the sales per employee for 17 public US equipment companies. It ranges from a high of $362,000 for Novellus to a low of $90,000 for Kulicke and Soffa (K&S), with an average of $146,000 for the 17 companies.

Of the companies shown in Figure 1, 14 either manufacture front-end equipment or are OEM suppliers associated with front-end equipment and 3 manufacture assembly and test, or

FIGURE 1
US Semiconductor Equipment Companies
Fiscal 1989 Sales per Employee



Source: Dataquest (June 1990)

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back-end, equipment. Note that the 3 companies with the lowest sales per employee are the back-end companies: LTX, Teradyne, and K&S. When comparing the sales per employee for the 14 front-end companies with that of the 3 back-end companies (Figure 2), we see that the front-end companies have almost twice the productivity of the back-end companies: $190,000 compared with $102,000.

One reason for front-end companies' high sales per employee is that they are not vertically integrated in their manufacturing operations. Most front-end companies do not really manufacture products; rather, they assemble purchased components and complete subassemblies from a network of suppliers. Thus, they do not require a large manufacturing infrastructure to support their manufacturing operations. These companies essentially add value through the assembly and test of the purchased items.

In addition, note that companies with high sales per employee tend to provide equipment that has a high "process content" in the deliverable system to the customer. Clearly, the etch, CVD, and ion implantation systems of the top four companies (Figure 1) have more process content than the products of companies shown lower down in the figure; these companies' products tend to be more mechanical or have a lesser process content.

Does higher sales per employee translate into higher profits? Dataquest believes that there is indeed a correlation between the two. Figure 3 shows operating income (op income) as a percentage of sales coupled with the company's sales per employee. Companies with high op incomes also had high sales per employee, while companies with low op income also had low sales per employee. Further data analysis also confirms the connection between profitability and sales per employee.

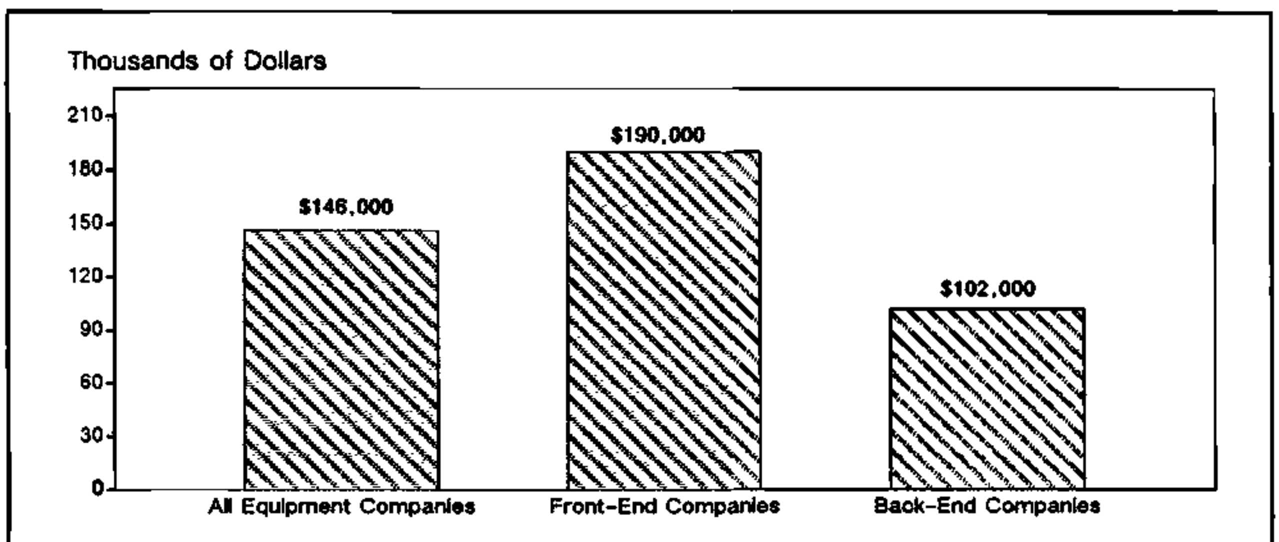
How Does the Semiconductor Equipment Industry Stack Up?

Figure 4 shows the sales per employee for US semiconductor equipment manufacturers, US semiconductor device manufacturers, US electronic equipment manufacturers, and IBM. As Figure 4 shows, the $146,000 sales per employee for US semiconductor equipment manufacturers compares very favorably with their associates in other segments of the US electronics industry.

The Fabulous Fabless

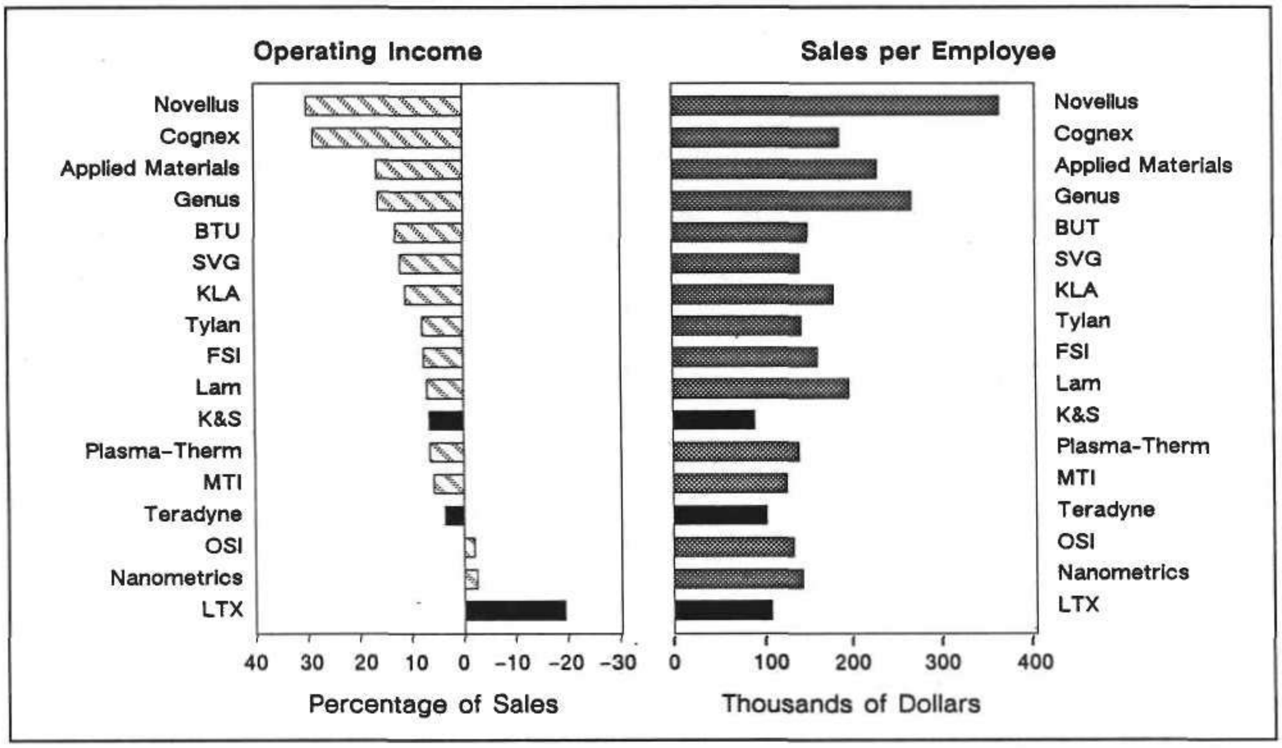
Figure 4 shows that the sales per employee for US semiconductor manufacturers is $99,000. However, when we examine the sales per employee for these companies in more detail, some interesting trends emerge. Figure 5 compares the sales per employee for semiconductor companies with fabs (fabbed companies) with semiconductor companies

Figure 2
US Semiconductor Equipment Companies
Front-End vs. Back-End
Fiscal 1989 Sales per Employee



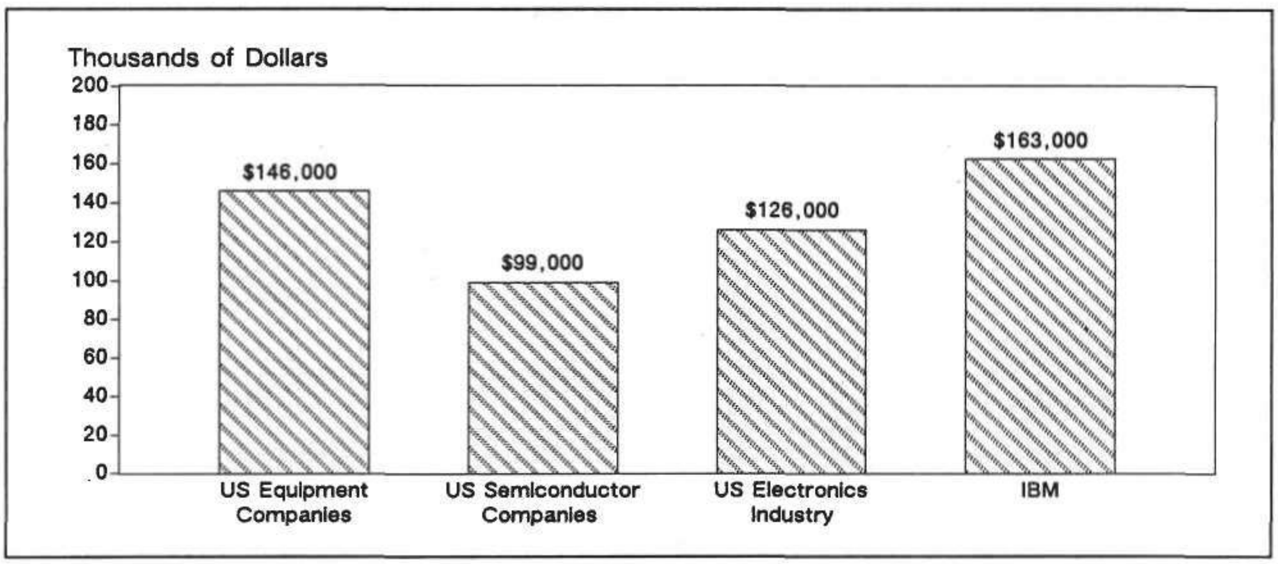
Source: Dataquest (June 1990)

FIGURE 3
US Semiconductor Equipment Companies
Fiscal 1989 Operating Income as a Percentage of Sales
Compared with Sales per Employee



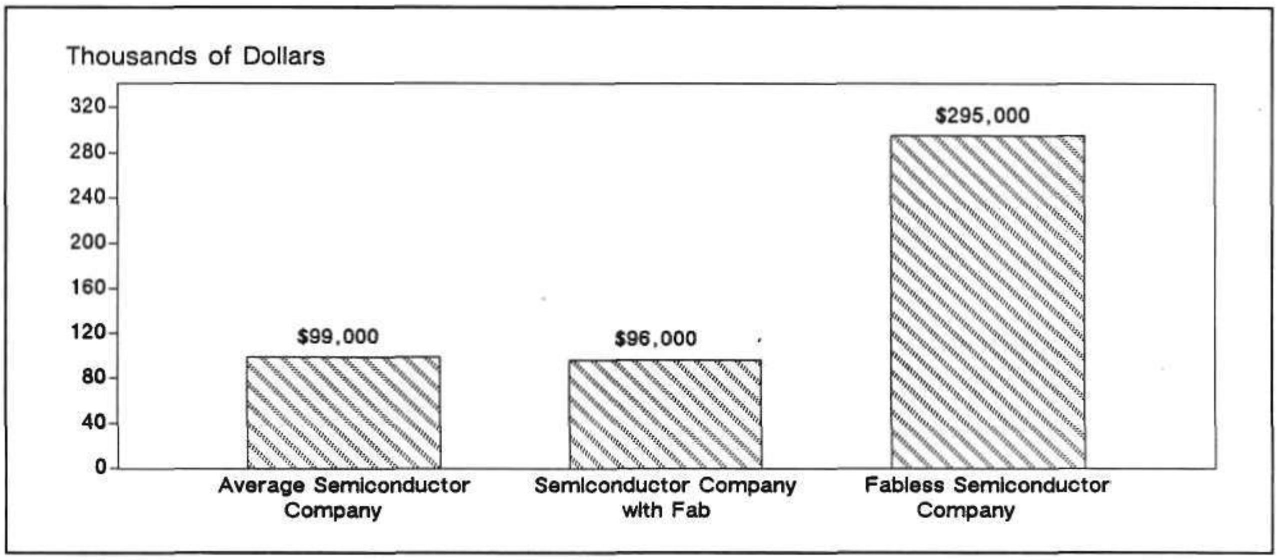
Source: Dataquest (June 1990)

FIGURE 4
How Do US Semiconductor Equipment Companies Stack Up?
1989 Sales per Employee



Source: EIA, Dataquest (June 1990)

FIGURE 5
The Fabulous Fabless
US Semiconductor Companies
1989 Sales per Employee



Source: Dataquest (June 1990)

without fabs (fabless companies). The average sales per employee for the fabbed companies was only $96,000 compared with $295,000 for the fabless companies; the difference between the two groups of companies is more than a factor of three.

The range of sales per employee for the fabbed companies was $47,000 to $210,000; the range for fabless companies was $163,000 to $540,000. If we disregard the fabbed company with the highest sales per employee (Cypress with $210,000), then the fabbed company with the highest sales per employee is just equal to the fabless company with the lowest sales per employee. Thus, there is virtually no overlap between these two groups of companies.

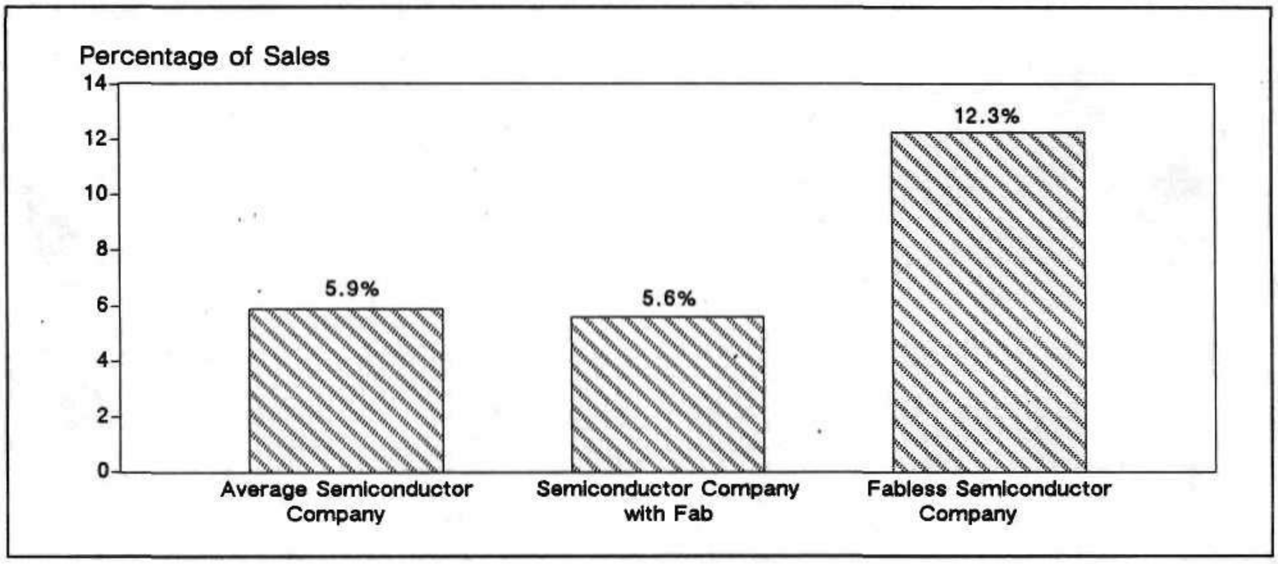
What about profitability? Figure 6 shows that the net income as a percentage of sales for fabless companies is more than twice that of fabbed companies. Again, a clear link exists between profitability and sales per employee. However, the real question really is not "what about profitability," but rather "how long can this level of profitability continue for fabless companies?" Is this level of profitability for the fabless companies an unstable situation that will eventually find equilibrium at a lower level as the fabbed companies begin to realize that they are, in effect, absorbing overhead that should be passed on to fabless companies in the form of higher wafer prices?

Also, how big can a fabless company become before it has to have its own fab? Is there, indeed, such a limit? Currently, fabless companies are relatively small and represent only a small percentage of overall semiconductor industry revenue. At a recent industry event, Jerry Sanders, chairman and CEO of AMD, said that "real men have fabs," which was countered by Gordon Campbell, president of Chips & Technologies, who said that "real men who want to make money don't have to own their own fabs." However, what will be the profitability of fabless companies when they mature and are forced to have their own fabs? Sales per employee for Chips & Technologies is seven times that of AMD, and it will be interesting to see if this ratio can be sustained.

EQUIPMENT COMPANIES AND FABLESS COMPANIES

An analogy exists between equipment companies and fabless semiconductor companies. Both are nonvertically integrated and fabless in the sense that they do not manufacture from scratch. Equipment companies assemble purchased parts and subassemblies into systems and deliver tested systems to the customer. Fabless semiconductor companies buy finished wafers and deliver tested ICs to

Figure 6
The Fabulous Fabless
US Semiconductor Companies
1989 Net Income as a Percentage of Sales



Source: Dataquest (June 1990)

the customer. Both types of companies add considerable value through their respective equipment or IC design process. Equipment companies add value by providing a high process content in the deliverable system; fabless device companies add value by providing a high performance content in the delivered IC.

Both front-end equipment companies and fabless companies have the highest sales per employee among their industry peers, and, as discussed, companies with the highest sales per employee also are the most profitable. One reason that these companies are more profitable is that they are able to charge higher prices for their products because of the high value added.

DATAQUEST CONCLUSIONS

Dataquest believes that there is a definite relationship between sales per employee and profitability, and although it is just one measure of a company's performance, it is an important one.

How does your company stack up? Company managers should continually look for ways to increase the productivity of their companies. The traditional make-or-buy analysis does not only apply just to considerations of whether or not to manufacture, but can be extended throughout the organization. Should a semiconductor company hire more service people to maintain its sophisticated equipment or buy service contracts from the equipment vendors? Should it make its own masks or buy them? Should a company hire another engineer or use a job shop for this particular task? A vast service and support industry is available to companies, which should take full economic advantage of this industry in make-or-buy decisions.

Several ramifications of the make-or-buy concept need to be explored carefully, but the goal of any company clearly is to add value. The more value added, the more profitable the company should be. Does a company add high value by doing a task itself, or is it only a low value-added task? If it is a low value-added task, the company should probably let somebody else do it for them.

Joseph Grenier

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Research *Newsletter*

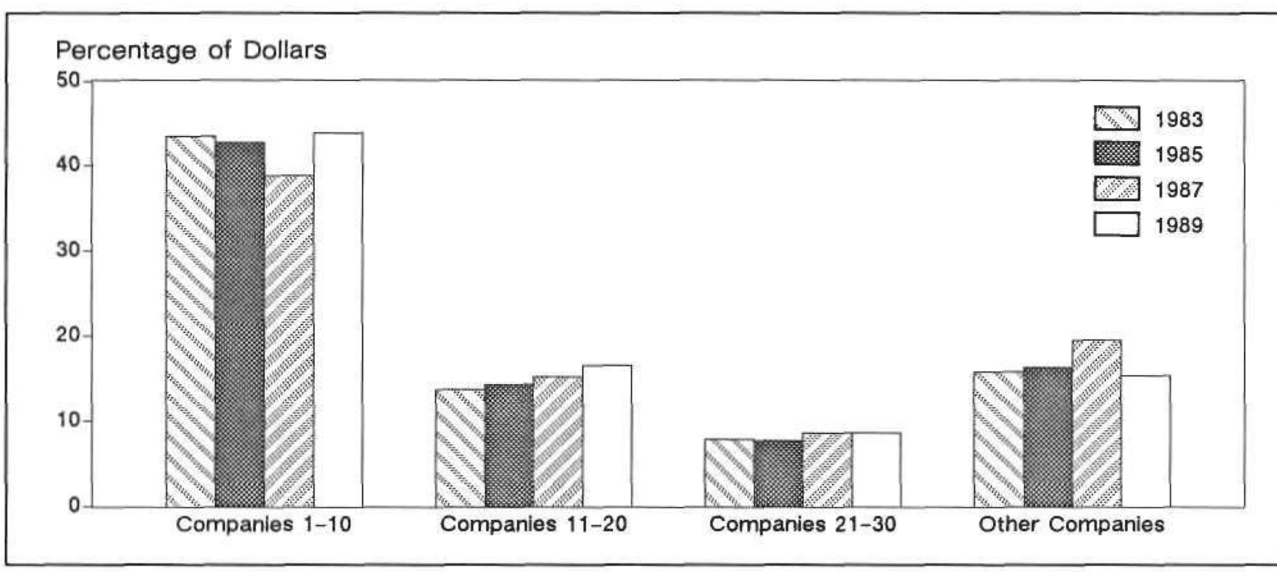
WAFER FAB EQUIPMENT COMPANY RANKING: HOW TO GET TO THE TOP TEN AND STAY THERE

Long-term success in the wafer fabrication equipment industry depends on a company's ability to provide equipment and technology for advanced device fabrication. At the same time, a company must manage its business operations through the roller-coaster business cycles of the semiconductor industry. This newsletter examines the companies that are the measure of success in the equipment industry: the top ten wafer fab equipment companies. In particular, it discusses the changes in the top-ten company rankings during the 1980s, how a company gets into the top ten, and, more important, what it takes to stay in the top ten of the wafer fabrication equipment industry.

COMPANY GROUP RANKINGS

Figure 1 illustrates the percentage of revenue share of the wafer fabrication equipment market on a yearly basis for four tiers of companies: the top ten companies, companies 11 through 20, companies 21 through 30, and the other companies (including another 72 to 108 companies, depending on the year). These companies manufacture the world's supply of equipment for the key segments of lithography, automatic photoresist processing equipment, etch and clean, deposition, diffusion, rapid thermal processing, ion implantation, and optical CD/wafer inspection equipment.

Figure 1
Company Share of the Wafer Fabrication Equipment Market
(Percentage of Dollars)



Source: Dataquest (August 1990)

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The top ten companies have held approximately the same share of the wafer fab equipment industry throughout the 1980s. One trend that is clear from Figure 1 is that the second-tier companies, ranked 11 through 20, have been steadily increasing share throughout the decade. It is from this group of companies that new members will emerge to replace a company on its way out of the top-ten ranking.

WHAT ARE THE TOP TEN COMPANIES TODAY AND HOW DID THEY GET THERE?

Table 1 presents the top-ten company rankings in the wafer fabrication equipment industry for 1983, 1985, 1987, and 1989. Five companies—Applied Materials, Canon, General Signal, Nikon, and Varian—have been in the top ten during each of those years. As shown in Table 1, Anelva ranked in the top ten in 1985, 1987, and 1989, and Hitachi was in the top ten in both 1987 and 1989. Three companies not listed in prior years are in the top ten of 1989—Tokyo Electron Ltd. (TEL), ASM Lithography, and Silicon Valley Group (SVG).

There are several distinct avenues by which companies have entered and maintained position in the top ten for wafer fab equipment. These strategies include the following:

- "Workhorse" product focus
- Right technology at the right time
- Diverse product offering
- Growth through acquisition

Nikon best exemplifies a growth strategy focused on providing equipment that is the workhorse of semiconductor device fabrication. Primarily through its sales of wafer steppers, Nikon moved from a ranking of sixth in 1983 to becoming the world's largest supplier of wafer fabrication equipment in 1987; the company still holds that position today. Similarly, Canon has maintained its presence in the top ten by offering a variety of lithography tools to the semiconductor industry.

ASM Lithography, also a manufacturer of wafer steppers, entered the 1989 top-ten ranking by having the right technology at the right time. The company was well positioned to provide i-line steppers when semiconductor manufacturers decided to make a significant commitment to i-line technology.

Applied Materials and Varian both are good examples of companies with diverse product offerings of systems for advanced device fabrication. This product diversity has been key to their successes in the wafer fab equipment industry. As semiconductor manufacturers reduce their number of qualified vendors, a diverse product offering allows an equipment company to provide one-stop shopping to its customers. Multiple products also provide a company with the flexibility to weather a slowdown in one segment of its business without having to dramatically cut resources for the entire company. An additional benefit of a diverse product offering is the synergy that can be achieved throughout the organization, from after-sale service and support to the development of new equipment and processes for a common environment such as the cluster tool market.

In the case of top ten companies Anelva and Hitachi, a diverse product offering is the result of having a semiconductor manufacturer as a parent corporation. This type of relationship has allowed these equipment companies to work closely with their semiconductor corporate parents (NEC and Hitachi, respectively) in the development of new technology.

One way for a company to reach a sufficient size to enter the top ten is to "buy its way in" through an acquisitions strategy. SVG entered the top ten for the first time in 1989. Its growth has been helped partly by its acquisition of Anicon in 1987 and Thermco in 1988. Its acquisition of Perkin-Elmer's optical lithography group in early 1990 further adds to its growing product offering of wafer fab equipment.

TEL also has experienced significant growth in its wafer fabrication equipment sales over the last several years. This growth was due in part to the acquisition of the outstanding share of two of its joint venture companies, TEL/Lam (in 1987) and TEL/Thermco (in 1988). In addition, TEL has aggressively pursued the development of advanced technology equipment spanning a wide product offering. The company also maintains two joint ventures in wafer fabrication equipment with Varian: TEL/Varian and Varian/TEL.

ON THE WAY OUT OF THE TOP TEN

Companies move into the top ten as other companies move out. The most noticeable departure from the top-ten ranking is that of Perkin-Elmer. As shown in Table 1, the company was the largest supplier of wafer fab equipment in 1983 and 1985 and ranked third worldwide in 1987. In 1989,

TABLE 1
Top-Ten Wafer Fab Equipment Company Rankings—1983, 1985, 1987, 1989
(Millions of Dollars)

Rank	1983		1985		1987		1989	
1	Perkin-Elmer	177	Perkin-Elmer	261	Nikon	234	Nikon	681
2	GCA	133	Canon	194	Applied Materials	176	Applied Materials	438
3	Varian	116	Varian	174	Perkin-Elmer	158	Tokyo Electron, Ltd.	293
4	Applied Materials	104	Nikon	165	Canon	144	Canon	252
5	Eaton	90	GCA	130	Varian	109	General Signal	184
6	Nikon	77	Applied Materials	130	Hitachi	85	Hitachi	165
7	Canon	77	Eaton	120	Anelva	84	Varian	165
8	General Signal	54	General Signal	106	ASM International	83	ASM Lithography	141
9	Kokusai	52	TEL/Thermco	79	General Signal	73	Anelva	140
10	ASM International	43	Anelva	77	Ulvac	69	Silicon Valley Group	127
	Top Ten	922	Top Ten	1,436	Top Ten	1,215	Top Ten	2,585
	Wafer Fabrication Equipment	2,119	Wafer Fabrication Equipment	3,356	Wafer Fabrication Equipment	3,135	Wafer Fabrication Equipment	5,887
	Percent Top 10	43.5%	Percent Top 10	42.8%	Percent Top 10	38.8%	Percent Top 10	43.9%

Source: Dataquest (August 1990)

amid speculation regarding the sale of its semiconductor equipment groups, Perkin-Elmer dropped to position 18 in the ranking. In 1990, Perkin-Elmer's optical lithography group was acquired by SVG and its former e-beam operation (now Etec Systems) was sold to a group of investors from the industry.

General Signal has been in the top-ten equipment company ranking throughout the 1980s. General Signal, however, may be unable to maintain a top-ten ranking in light of recent announcements of plans to divest itself of several of its semiconductor equipment companies, as well as the announced management buy-out of Ultratech Stepper. Dataquest believes that General Signal's strategy to run its wafer fab equipment companies as standalone operations has not made efficient use of the synergy between the various companies. This strategy, in turn, has impacted the ability of each of the individual companies to invest in new technology and grow their business in an increasingly competitive market environment.

How Big Is Big Enough?

An important factor to examine is the size of sales in an equipment company because this relates to its ability to fund R&D for advanced technology development as well as support and service its customers on an international basis. Table 2 presents the average sales for the four tiers of companies from Figure 1 for the years 1985 and 1989. In 1985, the average sales of the top-ten companies were 3.0 times larger than the companies ranked 11 through 20; by 1989, however, it was only a factor of 2.7. This observation is another way of looking at the trend shown in Figure 1: the increasing share of the second-tier companies. Another observation from Table 1 is that the average sales of the tier of other companies is not growing at nearly the same rate as those companies ranked in the top 30, which means that the big companies are getting bigger while the small companies are staying small.

Figure 2 illustrates the distribution of company revenue for the top 70 companies in 1985 and 1989. This distribution drops off very rapidly. In 1989, company equipment sales are under $45 million below the ranking of 30, under $20 million below the ranking of 35, and under $10 million below the ranking of 70. Beyond the rank of 35, the distributions for 1985 and 1989 are essentially the same. These data seem to indicate that a company must break through the $20 million barrier in equipment sales in order to generate sufficient income to propel the company onto a faster track for growth.

As an example of the importance of reaching a critical size in order to compete in the wafer fab equipment industry, Dataquest examines the fiscal 1989 financials of Applied Materials, the second largest supplier of wafer fab equipment. Applied Materials' fiscal 1989 R&D expenditure of $72 million is close to the 1989 calendar year equipment sales of Genus (rank 19) at $78 million. Applied's fiscal 1989 net income of $51 million is greater than the 1989 calendar year equipment sales of Tokyo Ohka, JEOL, or Novellus (rank 25, 26, and 27). Applied's ability to invest in the development of future technology assures its place as a major player in this industry.

Dataquest Conclusions

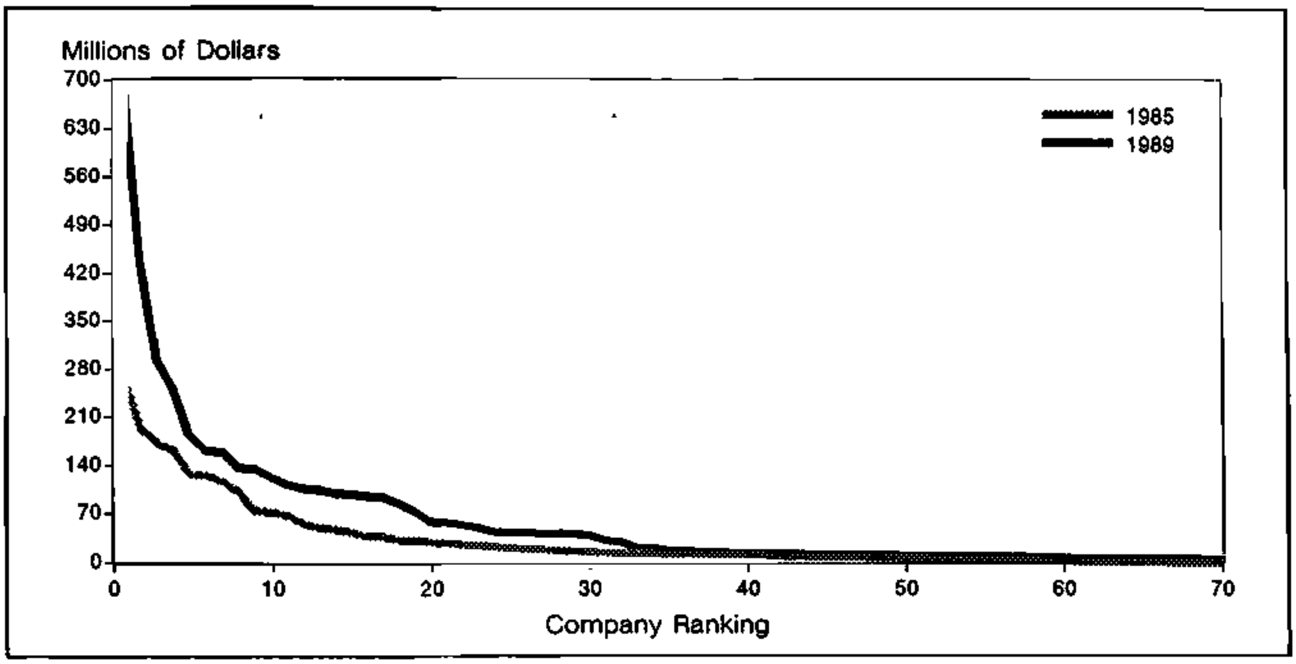
The size of a company clearly becomes increasingly important as the wafer fab equipment industry matures. The large companies are getting larger while the small companies are staying small. Dataqust expects further consolidation in the equipment industry to occur throughout the 1990s as the

Table 2
Average Sales of Ranked Wafer Fab Equipment Companies—1985 and 1989
(Millions of Dollars)

	1985	1989	CAGR 1985-1989
Companies 1-10	144	259	15.8%
Companies 11-20	48	97	19.2%
Companies 21-30	26	50	17.8%
Other Companies	6	9	10.7%

Source: Dataquest (August 1990)

FIGURE 2
Size Distribution by Sales of Wafer Fabrication Equipment Companies—1985 and 1989 (Millions of Dollars)



Source: Dataquest (August 1990)

cost of developing new products and doing business on a global scale takes its toll. For most small companies, it will be difficult to generate a sufficient income stream to develop competitive products for advanced device fabrication. A small company's strategy for growth in the 1990s should revolve around unique and creative technology or niche applications outside the scope of the larger equipment companies. Partnerships and alliances with the larger equipment companies also will provide the extra support that some small companies will need to survive.

Peggy Marie Wood

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Research Newsletter

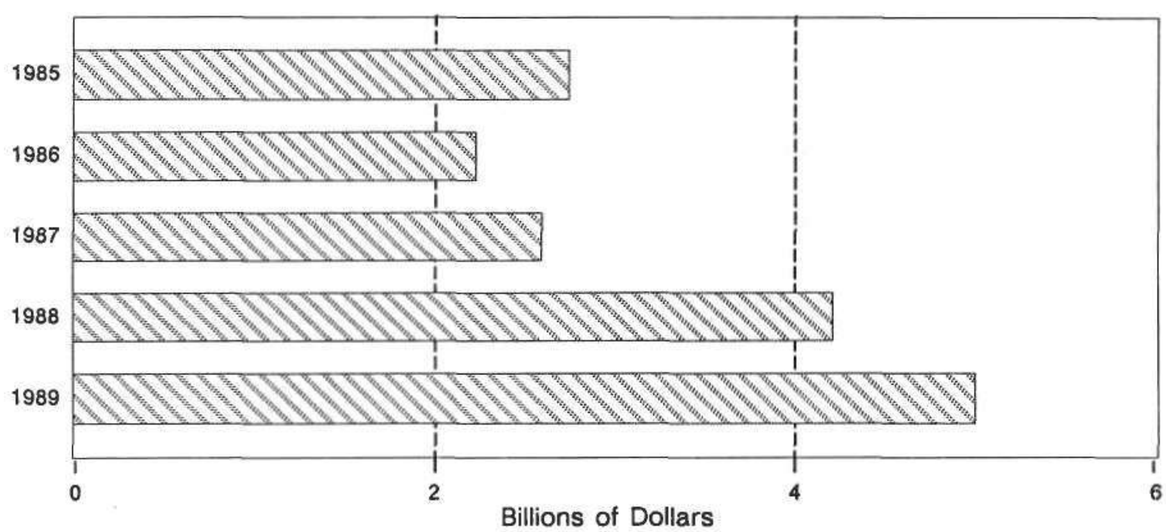
EQUIPMENT TECHNOLOGY OWNERSHIP IN THE 1990s: JAPANESE EQUIPMENT COMPANIES TAKE THE LEAD

In 1989, Japanese manufacturers of wafer fabrication equipment took the lead in supplying advanced processing equipment to the worldwide semiconductor industry. This newsletter examines recent changes in regional equipment company share and discusses the implication of the gains of the Japanese equipment industry across a broad base of equipment technology.

WORLDWIDE WAFER FAB EQUIPMENT MARKET

Figure 1 presents the wafer fab equipment market for the key equipment segments of lithography, automatic photoresist processing equipment, etch and clean, deposition, diffusion, rapid thermal processing, ion implantation, and optical CD/wafer inspection equipment. These equipment categories represent the key technologies required to produce advanced integrated circuits. This worldwide market was $4,992 million in 1989. Not included in this market are the categories of other process control equipment, factory automation, and other miscellaneous equipment used in the front end. These segments, in turn, represented an additional $895 million, to bring the total worldwide wafer fab equipment market to $5,887 million in 1989.

FIGURE 1
Worldwide Market for Key Segments of Wafer Fab Equipment*
(Billions of Dollars)



*Includes all lithography, automatic photoresist processing equipment, etch and clean, deposition, diffusion, rapid thermal processing, ion implantation, and optical CD wafer inspection equipment

Source: Dataquest (August 1990)

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WORLDWIDE WAFER FAB EQUIPMENT MARKET BY REGIONAL OWNERSHIP OF EQUIPMENT COMPANY

Table 1 presents the worldwide market for key segments of wafer fab equipment shown in Figure 1 by regional ownership of equipment companies for the years 1985 through 1989. Although the majority of joint-venture equipment companies are located in Japan and service that market exclusively, we choose to report these companies in a separate category rather than bundle them with the other Japanese companies. That is because the products offered by these joint-venture companies represent technological contributions of US as well as Japanese corporations. All of the joint ventures represent joint ownership between US and Japanese companies, with the exception of one Japanese/European joint venture.

An examination of Table 1 shows an increase in Japanese company share of 15 percent during the years 1985 and 1989, while US company share declined by the same amount. It is very important when evaluating these figures and trends to remember that the yen underwent significant appreciation during this time period, from 238 per dollar in 1985 to 139 per dollar in 1989. Yen appreciation in this time period tends to overstate the sales of Japanese equipment companies when the world wafer fab equipment market is measured on a dollar basis. However, in 1989, when the yen underwent depreciation relative to the dollar, the Japanese equipment companies still increased their share of the wafer fab equipment market at the expense of US equipment companies.

The emergence of the Japanese equipment companies as the leading suppliers of wafer fabrication equipment is best evaluated when measured on the basis of unit shipments rather than revenue. Table 2 illustrates the increasing dominance of the Japanese equipment companies by presenting on a percentage basis the unit shipments of the regional companies for the years 1985 and 1989. In particular, specific equipment categories that represent key wafer fabrication technology are presented in Table 2.

Table 2 shows that, with the exception of one category, Japanese equipment companies have increased their share of unit shipments between 1985 and 1989 while US equipment companies have experienced a decline. The stepper category shows the most significant erosion of US company participation, with a reduction in worldwide unit shipment share of 36 percent in five years. The categories of dry etch, tube CVD, and diffusion show an increase in Japanese company share, in part at the expense of joint venture companies. This phenomenon can be explained by the acquisition of the outstanding shares of two joint venture companies, TEL/Lam and TEL/Thermco, by Tokyo Electron Ltd., in 1987 and 1988, respectively. In ion implantation, two Japanese/US joint venture companies, TEL/Varian and Sumitomo/Eaton Nova, represent a significant share of the worldwide medium- and high-current implanter market. These two companies, which operate in Japan, have increased their share by 9 percentage points in the last five years at the same time indigenous Japanese equipment companies have expanded their efforts in ion implantation. This increase translates to a loss of 20 percentage points for US equipment companies in this category.

The one exception to the general trend illustrated in Table 2 is the category of nontube CVD. Nontube CVD is one of the few areas in which US companies dominate. This domination is a result of

TABLE 1
Worldwide Market for Key Segments of Wafer Fab Equipment*
by Regional Ownership of Equipment Company
(Percentage of Dollars)

	1985	1986	1987	1988	1989
US Companies	55%	52%	46%	44%	40%
Japanese Companies	31	33	38	43	46
European Companies	9	12	12	10	10
Joint-Venture Companies	6	4	4	4	4
Total	100%	100%	100%	100%	100%

*Includes all lithography, automatic photoresist processing equipment, etch and clean, deposition, diffusion, rapid thermal processing, ion implantation, and optical CD/wafer inspection equipment Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (August 1990)

TABLE 2
Worldwide Wafer Fab Equipment Unit Shipments by Regional Ownership of Equipment Company, 1985 and 1989 (Percentage of Units)

	US Companies	Japanese Companies	European Companies	Joint-Venture Companies	Total
Steppers					
1985	49%	51%	1%	0	100%
1989	13%	78%	9%	0	100%
Dry Etch					
1985	63%	30%	3%	4%	100%
1989	57%	40%	2%	1%	100%
Nontube CVD					
1985	62%	27%	11%	0	100%
1989	77%	18%	5%	0	100%
Tube CVD					
1985	43%	15%	29%	12%	100%
1989	30%	30%	36%	4%	100%
Sputtering					
1985	61%	25%	14%	0	100%
1989	54%	33%	13%	0	100%
Diffusion					
1985	39%	14%	9%	38%	100%
1989	32%	49%	12%	7%	100%
Medium and High-Current Implanters					
1985	64%	15%	0	21%	100%
1989	44%	25%	1%	30%	100%

Source: Dataquest (August 1990)

their lead in developing nontube low pressure CVD (LPCVD) and plasma-enhanced CVD (PECVD) reactors. In contrast, European and Japanese companies dominate the traditional tube CVD market. Nontube reactors are expected to replace tube CVD processes for submicron device applications. Companies that focus on developing nontube CVD reactors for submicron processes should continue to gain market share in the future.

DATAQUEST CONCLUSIONS

As the semiconductor industry pushes deeper into the submicron regime, the continuing development and dominance of fabrication technologies such as patterning, deposition, and metallization are key to survival and success within the wafer fab equipment industry. As shown in this newsletter, the Japanese equipment industry is strong across a wide base of advanced equipment technology. Dataquest believes that the Japanese equipment companies have taken the lead and are well positioned to maintain that edge in the years to come. As Japanese semiconductor companies continue to globalize their manufacturing efforts, either through offshore fabs of their own or through joint technology/manufacturing ventures with others, the "buy" decisions for wafer fab equipment will be strongly influenced by decisions made in Japan. This influence will favor the Japanese equipment companies, which dominated their home market with a 74 percent share in 1989.

US and European equipment companies have a great deal to accomplish if they wish to increase their market share in the 1990s. They must compete by focusing significant R&D effort on advanced device processing technology. They must continue to globalize their own operations in order to be able to service a customer base that itself is becoming global in nature. Finally, US and European equipment companies either must overcome the momentum that the Japanese equipment industry has established in the 1980s or else resign themselves to being content to follow the leader through the 1990s.

Peggy Marie Wood

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Research Newsletter

US WAFER FAB EQUIPMENT MARKET CONTINUES ITS DOWNWARD SPIRAL

SUMMARY

The US wafer fabrication equipment market is continuing its downward spiral. This indicator is just one of many pointing toward a declining US semiconductor manufacturing industry. Japan and the Asia/Pacific regions have emerged as industry powerhouses for semiconductor manufacturing in the 1990s. After a weak year of capital spending in 1989, Europe is gearing up to invest in the 1990s in European fabs that comply with the 1992 doctrine of domestic semiconductor content. All major world industrial powers, with the exception of the United States, have articulated synergistic industry/government strategies for nurturing leading-edge semiconductor manufacturing.

Dataquest estimates that the US regional share of the worldwide wafer fabrication equipment market has shrunk from 38 percent in 1985 to 29 percent in 1989. Japan and the Asia/Pacific region together accounted for almost 60 percent of the 1989 worldwide fab equipment market. Dataquest believes that semiconductor manufacturing factories represent the heartbeat of the Information Age. The United States' heartbeat is weakening.

REGIONAL WAFER FABRICATION EQUIPMENT MARKET TRENDS

Figure 1 illustrates the regional distribution of the wafer fab equipment market between 1985 and 1989. The worldwide wafer fab equipment market has steadily grown at a compound annual growth rate (CAGR) of 15 percent from $3.4 billion in 1985 to $5.9 billion in 1989. The increasing size of this significant global market reflects the increasingly capital-intensive nature of advanced device fabrication. Japan and the Asia/Pacific regions have experienced the strongest growth over the past five years. Japan commands an astounding 45 percent share of the $5.9 billion 1989 world market. Such sustained levels of capital spending support Japan's stature as the largest semiconductor production and consumption market in the world.

The emergence of South Korea and Taiwan as world-class semiconductor competitors is reflected in the phenomenal CAGR of 40 percent for the Asia/Pacific-ROW (Rest of World) wafer fab equipment market between 1985 and 1989. In 1989, for the first time ever, the Asia/Pacific-ROW fab equipment market was larger than the European fab equipment market. Although the US market has grown at a CAGR of 8 percent between 1985 and 1989, its growth has been dwarfed by the higher levels of capital spending in the Pacific Rim region. The European, Japanese, and Asia/Pacific-ROW markets together account for 72 percent of the total worldwide fab equipment market. Thus, a US wafer fab equipment company automatically forfeits more than 70 percent of its total available market if it does not have a strong international presence.

Dataquest cautions that yen appreciation between 1985 and 1989 will appear to overstate the dollar-denominated Japanese equipment market. We note that the yen appreciated 55 percent between 1985 ($1 = ¥238) and 1988 ($1 = ¥130). However, the Japanese equipment market maintained 45 percent of the worldwide fab equipment market in 1988 and 1989 in spite of yen depreciation between 1988 and 1989 ($1 = ¥139). The higher growth rates of the combined Japan and Asia/Pacific equipment market relative to the US market between 1988 and 1989 emphasizes the growing importance of the Pacific Rim as a key semiconductor manufacturing region.

SEMS Newsletters 1990 Equipment Database

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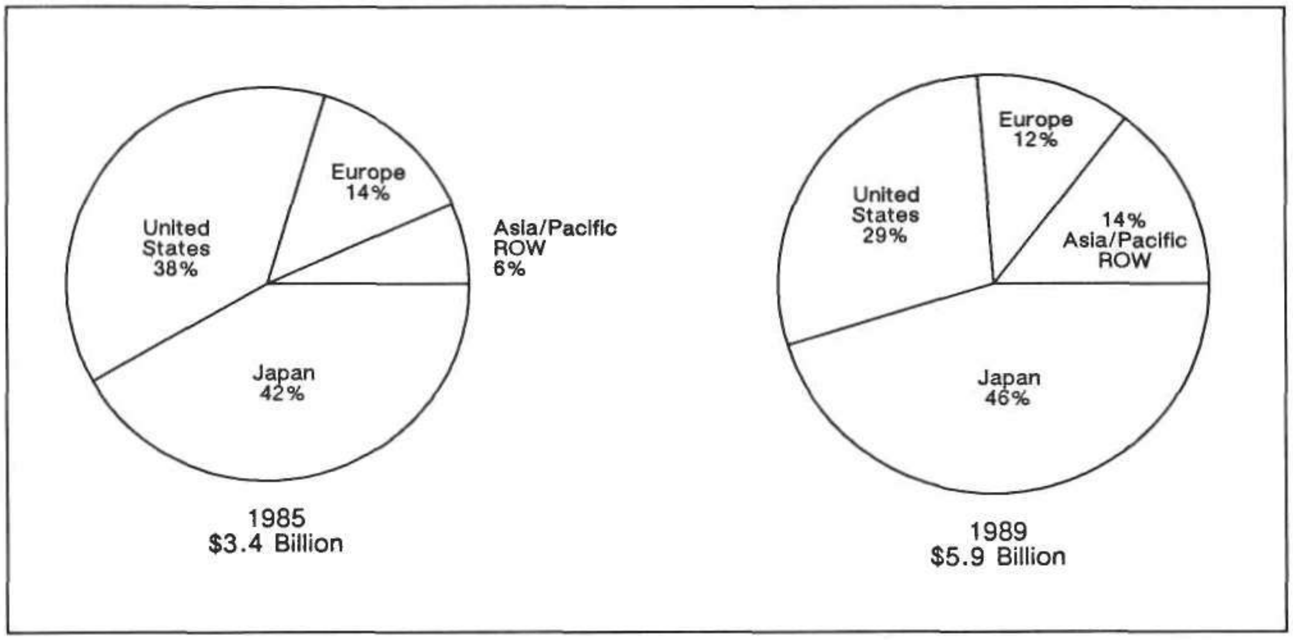
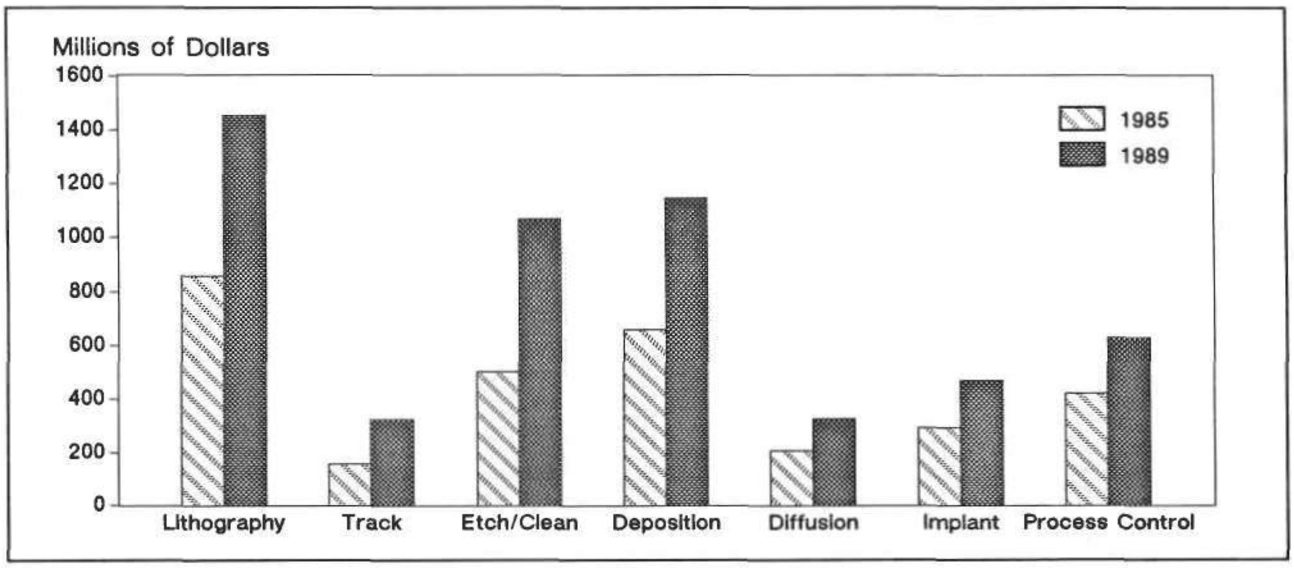
FIGURE 1
Fab Equipment Market by Region



Source: Dataquest (August 1990)

FIGURE 2
Growth of Key Equipment Markets Worldwide Between 1985 and 1989



Source: Dataquest (August 1990)

WORLDWIDE MARKETS FOR KEY FAB EQUIPMENT CATEGORIES

Figure 2 illustrates the growth of key segments of the worldwide fab equipment market between 1985 and 1989. The lithography equipment market has traditionally been the engine pulling the fab equipment technology train. This market has grown at a CAGR of 14 percent between 1985 and 1989. The lithography market has grown as a result of increases in stepper unit shipments as well as average selling prices (ASPs), which increased due to the demanding requirements of submicron imaging. The automatic photoresist processing equipment market (track equipment) has grown at a CAGR of 20 percent between 1985 and 1989 due to rapidly tightening requirements for resist film-coating quality.

Etch/clean equipment and deposition equipment have emerged as key bottlenecks in the race toward submicron processes. These two markets have gained importance as the semiconductor industry migrates toward new materials and processes for submicron multilevel interconnect technologies. The CAGRs for the etch/clean and deposition equipment markets have outpaced the CAGR for the lithography equipment market between 1985 and 1989. Dataquest believes that three engines—lithography, etch/clean, and deposition equipment—will be needed to pull a longer, costlier fab equipment technology train into the submicron era.

The diffusion, ion implant, and process control equipment markets have increased between 1985 and 1989 due to increasing device complexity entailing more dopant profile tailoring, automated inspection, metrology, and process monitoring.

REGIONAL DISTRIBUTION OF KEY FABRICATION EQUIPMENT SEGMENTS

Table 1 provides a snapshot of the fab equipment market revenue, by region, between 1985 and 1989. The dominant theme that emerges from a perusal of this table is the gradual decline of the United States as a semiconductor manufacturing

TABLE 1
Regional Distribution of Key Equipment Markets, 1985-1989 (Percentage of Dollars)

	United States	Japan	Europe	Asia/Pacific-ROW	World
Total Lithography					
1985	37	44	12	6	100
1989	27	45	11	16	100
Automatic Photoresist Processing Equipment					
1985	43	34	14	8	100
1989	28	45	12	15	100
Total Etch and Clean					
1985	46	37	12	5	100
1989	30	48	11	11	100
Total Deposition					
1985	38	39	17	6	100
1989	33	41	15	11	100
Diffusion					
1985	32	44	17	7	100
1989	26	40	14	20	100
Total Implantation					
1985	27	48	15	10	100
1989	20	54	9	18	100
Total Process Control					
1985	40	42	12	6	100
1989	34	42	13	11	100

Source: Dataquest (August 1990)

region. In contrast, the Japan and Asia/Pacific regions combined are continuing to rise in prominence as a dominant semiconductor manufacturing region. Japan is the largest market for most of the key fabrication equipment technologies. The Asia/Pacific region is overtaking Europe in capital spending for many key equipment technologies.

Dataquest has verified that the Japanese and Asia/Pacific-ROW equipment markets show the same growth trends using unit shipments instead of dollars as a measure. The US market exhibits a declining trend regardless of whether we measure it in units or in dollars. Basically, the trend toward a shrinking US equipment market and a growing Japan and Asia/Pacific equipment market persists even when we eliminate the currency appreciation factor by using unit shipments as a measure.

The DRAM business continues to be the dominant technology driver for each equipment generation due to high production volumes, process complexity, and intense price competition in the global marketplace. Most US companies have forfeited their access to volume-based production technologies by virtue of exiting the DRAM business. Most new US semiconductor start-up companies have elected fabless strategies in order to avoid the crippling capital costs associated with submicron fabs. European semiconductor companies are attempting to get back into the DRAM race through alliances and industry/government consortia such as JESSI. Is it any wonder, then, that the US fab equipment market continues to decline?

DATAQUEST CONCLUSIONS

Dataquest believes that the US semiconductor manufacturing industry is continuing its steady decline. Consequently, the US regional share of the worldwide fab equipment market has continued to decline, even though the worldwide fab equipment market has grown over 70 percent from $3.4 billion in 1985 to $5.9 billion in 1989. Most of the growth has occurred in the Japan and Asia/Pacific regions, which now account for almost 60 percent of the world fab equipment market. Japan and South Korea's dominance of the volume-driven DRAM business ensures key roles for these countries in driving the fab equipment market. Europe's 1992 doctrine of domestically fabricated chips is bound to lead to healthy growth in the European fab equipment market over the next few years.

A semiconductor equipment company will need to have a global presence in order to gain market share in an increasingly international fab equipment market. Strategic technology partnerships with key customers, together with global service capabilities, will be the differentiating factors for success in the equipment market of the 1990s. Dataquest believes that equipment companies must establish a strong presence in the strategic Japan and Asia/Pacific region in order to exploit leading-edge windows of opportunity driven by the omnipresent DRAM business.

Krishna Shankar

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Research Newsletter

LITHOGRAPHY STRATEGIES: PUSHING THE LIMITS—X-RAY LITHOGRAPHY

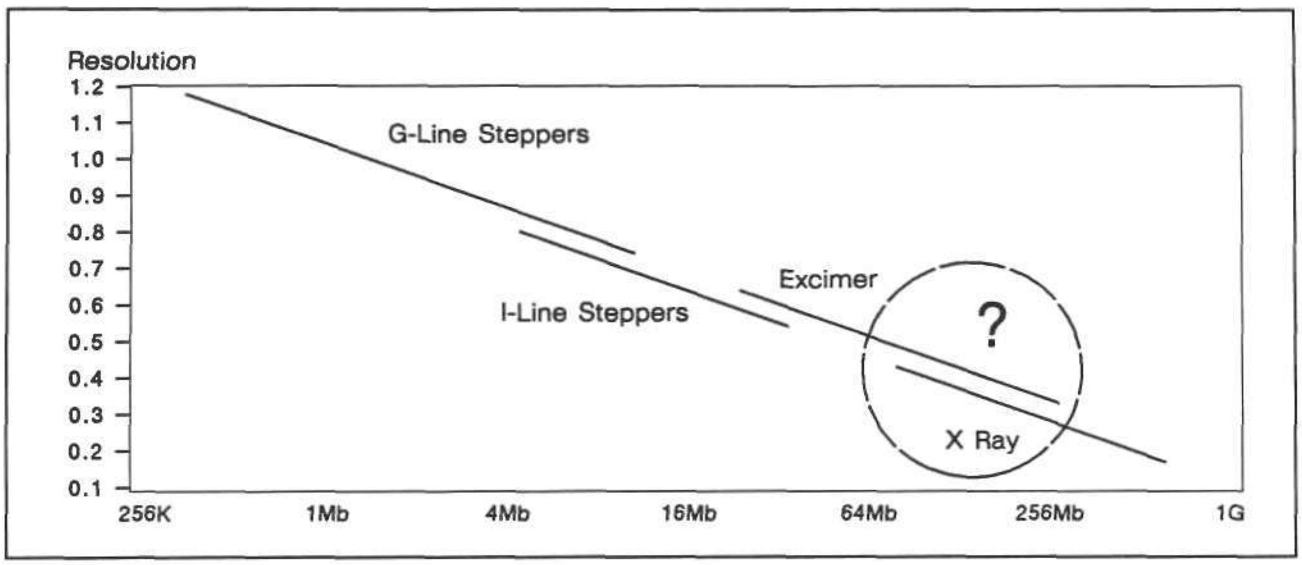
On October 8, 1990, a panel session on lithography strategies in the 1990s was held as part of Dataquest's Semiconductor Industry Conference in Monterey, California. This newsletter highlights several of the significant points discussed by Robert Hill, Functional Manager for Advanced Lithography Systems Development at IBM's Advanced Technology Center in East Fishkill, New York, as part of his presentation on X-ray lithography strategies.

WHY X-RAY?

Mr. Hill began his presentation by agreeing with other lithography experts that optical lithography will be viable for processing 0.20- to 0.25-micron geometries and may ultimately even be used down into the 0.10-micron regime (see Figure 1). He pointed out, however, that resolution is not the limiting factor in optical lithography. The problem is the accompanying decrease in depth of focus (DOF) that occurs as manufacturers strive to produce smaller geometries with optical lithography systems. Mr. Hill noted that the decrease in DOF has caused semiconductor manufacturers to resort to manufacturing tricks in the optical arena, which involve additional processing steps and additional defect susceptibility. X ray offers essentially much greater DOF and the resolution required for advanced device applications, particularly DRAMs.

In addition to high resolution and increased DOF, Mr. Hill noted that X-ray lithography uses much simpler and more robust photo process steps.

FIGURE 1
Worldwide Lithography Tooling Trends



Source: IBM Corporation, Dataquest (December 1990)

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For example, at IBM, ten levels of 0.5-micron CMOS have been fabricated, all with a single-level X-ray resist. Mr. Hill sees no reason why this cannot be extended to the 0.25-micron regime. He believes that simpler process steps that do not require the use of multilevel resist systems to achieve lower resolution, coupled with the greater defect insensitivity of X ray, will allow manufacturers to achieve lower manufacturing costs.

Unfortunately, as Mr. Hill pointed out, there is no free lunch in the lithography business; there are several disadvantages associated with X-ray lithography. For synchrotron X ray, there is the high initial cost of the synchrotron X-ray facility that must be made three to four years before it will be used. Also, a general reluctance to change from optical to X-ray lithography exists because it represents a major technological change. Mr. Hill believes that substantial improvements in cost must be demonstrated in order to justify the technology jump from optical to X ray. Finally, X-ray lithography requires a much more complex 1X mask technology than the industry currently uses.

KEY ELEMENTS OF X-RAY LITHOGRAPHY

X-ray lithography is a rather complex system. The key elements of this system include the mask, the stepper, the resist, and the X-ray source. In the case of a synchrotron source, there is another element—the beam line—between the stepper and the synchrotron storage ring. In addition, an expensive facility is required to house the ring and the steppers, and finally, a safety program must be developed for operating the system. (Mr. Hill noted that IBM currently is developing standards in the area of X-ray lithography safety, because it is one of the first companies in the world to install an industrial synchrotron source.)

X-Ray Mask Status

Mr. Hill believes that the mask is the most critical element in the development of X-ray lithography systems. The X-ray mask comprises the substrate, the absorber, and the mask frame. Mr. Hill noted that a variety of different mask substrates currently are in use, including boron-doped silicon (used by IBM and others), silicon nitride (used by several Japanese companies), silicon carbide (used by several European companies), and diamond (work sponsored by DARPA). Gold is the preferred absorber material, although there is some activity in the use of tungsten, tantalum, and combinations of the two metals. Standardization of the mask frame currently is being pursued by the National Institute of Standards and Technology (NIST) under DARPA auspices so that masks can be used interchangeably among the various stepper manufacturers and maskmakers. In the area of maskmaking equipment, Mr. Hill pointed out that e-beam systems are considered to be standard for patterning X-ray masks. For inspection and repair of 1X X-ray masks, several tools are under development by both KLA Instruments and Micrion as part of programs sponsored by DARPA.

X-Ray Sources

Mr. Hill commented that the source is the element in X-ray that tends to get everybody's attention because it is the first industrial use of synchrotrons in the world. The main X-ray synchrotron sources today include the IBM/Oxford storage ring (installed in the fourth quarter of 1990), the Aurora ring being prepared by Sumitomo Heavy Industries, and a number of other Japanese compact storage rings. Several warm rings also exist, including the warm ring operated by SORTEC in Japan. Mr. Hill pointed out that the warm ring best suited for lithography in the United States is the Maxwell Brobeck ring that is being prepared for Louisiana State University.

In addition to synchrotron sources, there are several other sources including electron impact (Nikon and SVG Lithography), laser-heated plasma sources (Hampshire Instruments), gas plasma sources (Karl Suss), and exploding wire sources (some limited research activity). Not much has been done yet with two other types of X-ray sources: transitions radiation sources (bombarding a foil with electrons to produce X rays on the other side) or X-ray lasers.

X-RAY PROGRAMS

Mr. Hill pointed out that a number of X-ray lithography programs exist worldwide right now; the main one in the United States is at IBM. It was started in IBM's Research Division in 1980, and the company is bringing up a full X-ray facility as part of its Advanced Technology Center in East Fishkill. Also in the United States, DARPA is funding a number of X-ray technology support programs as well as source programs, such as the one at Hampshire Instruments. The primary X-ray lithography programs in Japan include NTT's as well as that of the SORTEC group, which currently has a warm ring operation that it is starting to use for lithography. Mr. Hill noted that the Europeans initially were the furthest ahead in the development of X-ray lithography technology. The Fraunhofer Institute in Berlin has had two rings that it has used: BESSIE, a large warm ring, and COSY, a compact synchrotron orbital system. (Dataquest believes that with JESSI's decision to pursue optical lithography in lieu of X ray for the 64Mb DRAM, X-ray lithography research in Europe has slowed somewhat. Dataquest understands, however, that a new research institute in Itzehoe, near Hamburg, is being established to pursue X-ray lithography research. Thus, Germany continues to be the center of X-ray lithography research in Europe.)

Extendability of X Ray

One of the frequent questions asked regarding X-ray lithography is: Where does the industry expect it to come into use? Mr. Hill expects it to be used in the 64Mb to 256Mb DRAM region. He pointed out that extendability of the technology also is an issue, not so much because of the diffraction limit, but because as the manufacturer moves to smaller geometries and gets near the diffraction limit, the gap between the mask and wafer shrinks. Mr. Hill noted that how far X-ray lithography can be extended will depend primarily on how far off the wafer the manufacturer can place the mask. Mr. Hill believes that the gap between wafer and mask is probably somewhere in the 6- to 10-micron region, which will correspond to approximately 0.15-micron processing for very complex patterns. In the area of ultimate resolution capability, Mr. Hill noted that Dr. Henry Smith at MIT has demonstrated 400-angstrom (0.04-micron) isolated lines using X ray. Mr. Hill believes that more experiments are need in this area.

Summary

To summarize his presentation, Mr. Hill noted that X-ray lithography is a viable technology today and that the shorter wavelengths of X ray offer substantially better DOF and resolution than do optical systems. The gap that can be maintained between the mask and wafer will determine the limits of proximity X ray. While the 1X mask technology still represents a significant technical challenge, Mr. Hill strongly believes that X-ray lithography will result in simpler, more defect-free processing at a lower cost to the semiconductor manufacturer.

Peggy Marie Wood

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Research Newsletter

LITHOGRAPHY STRATEGIES: PUSHING THE LIMITS—E-BEAM LITHOGRAPHY

On October 8, 1990, a panel session on lithography strategies in the 1990s was held as part of Dataquest's Semiconductor Industry Conference in Monterey, California. This newsletter highlights several of the significant points discussed by Dr. Neil Berglund, special assistant to the president and executive director of Marketing for Etec Systems (Hayward, California), as part of his presentation on e-beam lithography strategies.

E-BEAM LITHOGRAPHY FUNDAMENTALS

At the beginning of his presentation, Dr. Berglund noted that regardless of which lithography technology is used by semiconductor manufacturers today and in the future, e-beam technology will continue to be a fundamental part of the process. It is a key technology because it provides patterning capability for the maskmaker in optical and X-ray applications and provides direct-write capability for the semiconductor manufacturer.

MASKMAKING

Maskmaking equipment is on the same path as steppers or other key fab equipment in that for every new generation of DRAMs (typically a three-year cycle), the industry needs a major increase in improvement in equipment performance. Dr. Berglund pointed out that with systems as complex as e-beam lithography tools, this improvement is becoming more difficult to achieve.

He emphasized that semiconductor device manufacturers need to view maskmaking as an integral part of their process because there are subtle trade-offs between what happens on the mask and what happens on the wafer. To illustrate this point, Dr. Berglund presented his outlook for the integration of maskmaking technology with the wafer fab process for the 4Mb through 256Mb DRAM generations (see Table 1).

For example, one of the important issues to the semiconductor device manufacturer is the ability to print different mask layers using different stepper tools in production. But there is a difficult problem of matching one stepper to another in terms of overlay. He noted that one possible solution being examined by a number of companies is to distort the reticle to compensate for the distortion in each stepper lens. As shown in Table 1, Dr. Berglund expects compensation of stepper

TABLE 1

Integration of Maskmaking Technology with Wafer Fab Process Forecast

Year	1987	1990	1993	1996
DRAM Generation	4Mb	16Mb	64Mb	256Mb
Compensate Stepper Distortion	No	Maybe	Yes	Yes
Localized Sizing	No	Maybe	Yes	Yes
Phase-Shift Masks	No	Maybe	Yes	Yes
Proximity Effect Correction	No	No	Maybe	Yes

Source: Etec Systems, Dataquest (December 1990)

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distortion to be required in the 64Mb DRAM generation and beyond.

Another factor being addressed today in the R&D environment is the issue of localized sizing. Certain problems, such as resist thinning, lead to different critical dimensions (CDs) across the fabricated device. Dr. Berglund believes that this problem can be compensated for by varying CDs within a design. He expects localized sizing to become commonplace in future technologies and, like stepper distortion compensation, to be used in the 64Mb DRAM generation and beyond.

In his concluding remarks on maskmaking, Dr. Berglund noted that the e-beam technology of today is approaching its limits for making 5X reticles. He believes that significant problems will need to be overcome in order to manufacture quality 1X masks for optical and X-ray applications in the future.

E-BEAM SYSTEMS: VECTOR SCAN VERSUS RASTER SCAN

There are two basic types of e-beam lithography systems: vector scan and raster scan systems. On a historical note, Dr. Berglund reminded the audience that back in the 1970s, Bell Labs developed a raster scan system called EBES, which was then commercialized by Perkin-Elmer (now Etec) and by Varian. The EBES system became the standard for the maskmaking community, and that is the primary reason it dominated such a large share of the market early on.

One of the important trends driving the industry more and more toward vector scan systems is economics. In a raster scan system, every pixel is printed whether there is an exposure there or not. In contrast, a vector scan system exposes only those areas that need to be exposed. Thus, the throughput of a vector scan system has the advantage—or disadvantage—of being highly dependent on the percent coverage of each layer. Data file size is also an important reason for using a vector scan machine because the inherent hierarchy of the system architecture allows the data files to be greatly simplified for any design. Raster scan machines to date have been the dominant choice for maskmaking applications while direct-write machines have been vector scan systems. Dr. Berglund believes that vector scan machines will dominate the e-beam lithography market overall by the end of the 1990s.

DIRECT WRITE

Three major applications for direct-write e-beam lithography were identified: research and development (R&D), low-volume production, and high-volume production.

Very high resolution, very low volume device fabrication has been the traditional area of direct-write lithography for many years in the R&D environment. A relatively new application, however, is advanced prototyping. In order to develop new DRAM technologies, a semiconductor manufacturer needs to work on not only lithographic processing, but also the supporting etch and deposition technologies. It is key that the semiconductor manufacturer understand these processes well in advance of when they will be used in production. Dr. Berglund pointed out that because the availability of advanced optical lithography tools is occurring later in the R&D cycle, an increasing number of companies are turning to direct-write e-beam machines for prototyping advanced DRAMs. This strategy allows the manufacturer to get started on the development of related aspects of processing at an early stage.

In the low-volume production environment, direct-write applications have been targeted primarily at ASICs, gate arrays, and gallium arsenide (GaAs) chips requiring medium to high resolution. Dr. Berglund noted that an interesting application for direct write in high-volume production is just starting to be explored at this time: high-resolution mix-and-match in DRAM manufacturing. As mentioned previously, vector scan systems have a throughput that is dependent on the percent coverage of each layer. Thus, a direct-write vector scan machine could be dedicated to specific layers in a mix-and-match mode. As an example, he pointed out that a direct-write system could be stripped down and modified so that it would be optimized to print low-coverage contacts at one-half the size that could be printed optically at any given DRAM generation. He believes that, even with today's equipment, a strong argument could be made that the return on investment for such a machine is very positive.

Dr. Berglund mentioned that Hitachi has taken a further step in direct-write e-beam lithography by using custom apertures with defined shapes. By specifying given shapes to the device designer, significant throughput in the direct-write machine can be achieved because the time spent shaping the beam is now eliminated. This approach supports Dr. Berglund's view that the semiconductor manufacturer needs to work back from what is wanted on the wafer—back to the designer through the lithography tool.

SUMMARY

Dr. Berglund summarized his presentation by noting that e-beam is a key technology in semiconductor device manufacturing because of its use in both maskmaking and direct-write applications. He expects vector scan systems to dominate the market in the long term. Direct write is economical for low-volume device production today, particularly for ASICs. However, he believes that direct write will be cost-competitive against any of the other techniques for selected production layers by the mid-1990s.

Peggy Marie Wood

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the newsletters. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Research *Newsletter*

LITHOGRAPHY STRATEGIES: PUSHING THE LIMITS—MASKMAKING

INTRODUCTION

On October 8, 1990, a panel session on lithography strategies in the 1990s was held as part of Dataquest's Semiconductor Industry Conference in Monterey, California. This newsletter highlights several of the significant points discussed by Dr. John Skinner, Director of Advanced Photomask Technology at DuPont Photomask, Incorporated (Gladstone, New Jersey), as part of his presentation on maskmaking issues.

MASKMAKING/LITHOGRAPHY TIME SCHEDULE

The advent of the commercial e-beam system in the early 1970s allowed high-precision masks to be made with relative ease by both the merchant and captive mask houses. Dr. Skinner noted, however, that the time when the ease of maskmaking could be taken for granted is coming to an end. Dr. Skinner believes that maskmakers will face a substantial capital investment for retooling their facilities in the next several years in order to meet the mask requirements for advanced lithographic processing.

Table 1 presents Dr. Skinner's perspective on the lithography time schedule for the 16Mb, 64Mb, and 256Mb DRAM device generations. Processing of 0.5-micron geometries is beginning now. By 1991, semiconductor manufacturers will be approaching the end of the R&D phase and beginning the qualification procedure for 0.5-micron device production. Dr. Skinner estimated that the R&D period represents about 3 percent of the masks required and that the qualification of production devices represents an additional 10 to 14 percent. Dr. Skinner believes that the 0.5-micron geometries will be produced using i-line lithography and conventional masks.

Qualified production of 64Mb devices with 0.35-micron geometries will begin in the 1992/1993 time frame. Dr. Skinner believes that i-line lithography with phase shift masks and possibly deep-UV—krpyton fluoride (KrF) excimer laser—lithography will be used. Dr. Skinner noted that by the 1994/1995 time period, it is expected that X-ray lithography will be used for the 64Mb DRAM at approximately 0.25-micron geometries. Optical lithography is projected to go down to 0.20 micron, or possibly even lower by 1996/1997. Dr. Skinner

TABLE 1
Lithography Time Schedule

Minimum Feature	Time Schedule	Lithography/Maskmaking Technology	DRAM Device Generation
0.50um	1990/1991	I-line/conventional masks	16Mb
0.35um	1992/1993	I-line/phase shift masks KrF	64Mb
0.25um	1994/1995	KrF/phase shift masks X-ray	64Mb
0.20um	1996/1997	KrF/phase shift masks X-ray	256Mb

Source: DuPont Photomask, Dataquest (November 1990)

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believes that such devices will be manufactured with deep-UV lithography using phase shift masks or with X-ray lithography.

5X RETICLE SPECIFICATIONS

Dr. Skinner identified a number of mask parameters that will need to be manufactured to much tighter specifications as minimum features decrease from 0.5 micron (16Mb DRAM) to 0.2 micron (256Mb DRAM). These mask parameters include registration, CD to target (variation between average CD and the specified value), CD range (variation across the 5X reticle), defect size, and minimum mask feature. Table 2 summarizes Dr. Skinner's expectations for these specifications. He noted that the actual values of the mask parameters requested by the mask users are approximately 30 percent less than the values presented in Table 2. Dr. Skinner believes that a balance will be achieved between what is being requested by users and what will be available from the maskmaking community.

IMPROVEMENTS NEEDED IN MASKMAKING, 1991-1996

To meet the specifications in mask parameters required to manufacture the 16Mb DRAM through the 256Mb DRAM, Dr. Skinner believes that the maskmaking industry will face significant retooling of its facilities. For example, to achieve the specifications required in registration, maskmakers must upgrade their existing MEBES machines or pattern generators, or be forced to purchase new systems. According to Dr. Skinner, nothing was purchased in the 1980s that meets any of the specifications that will be needed in the 1990s.

CD control can be achieved by improving the present process, but new materials and new processing techniques will be required by 1992. Dr. Skinner pointed out that more automation will be key to achieving this result because much of the current maskmaking process is performed manually.

Defect detection is available now. In a die-to-die inspection mode, defect inspection tools today can detect defects down to 0.25 micron, with 95 to 99 percent probability of detection. However, Dr. Skinner pointed out that it still is not 100 percent. When maskmakers go to a single die per reticle and have to use die-to-database inspection, the inspection procedure will become much more complex. In addition, Dr. Skinner noted that significant development (at significant cost) will be required to achieve 0.10-micron defect detection with 99 percent probability.

Dr. Skinner commented that this is the year that phase shift mask technology is beginning significant development. He believes that phase shift masks have the ability to extend the life of millions of dollars worth of existing wafer exposure tools, but he noted that phase shift masks do not come without a price. The price is that semiconductor manufacturers must use their wafer exposure tools at their limit in order to take advantage of the increased resolution provided by phase shift masks.

SUMMARY

Dr. Skinner concluded his presentation by noting the capital-intensive nature of both the maskmaking and semiconductor device manufacturing industries. As he stated earlier, none

TABLE 2
5X Reticle Specifications

		1990/1991	1992/1993	1994/1995	1996/1997
Minimum Device Feature (MDF)		0.50um	0.35um	0.25um	0.20um
Mask Parameter	**% of MDF**				
Registration	20	0.10um	0.07um	0.20um	0.04um
CD to Target	10	0.05um	0.035um	0.025um	0.02um
CD Range (3 sigma)	8	0.04um	0.028um	0.020um	0.016um
Defect Size	50	0.25um	0.18um	0.13um	0.10um
Minimum Mask Feature	400 (4x)	2.0um	1.4um	1.0um	0.8um

Source: DuPont Photomask, Dataquest (November 1990) of the equipment purchased in the 1980s is suitable to meet the needs of maskmaking in the 1990s. Semiconductor manufacturers gauge productivity by measuring throughput on a given machine in terms of wafers per hour. The maskmaker, however, is concerned with hours per mask. Dr. Skinner reminded the audience that as we approach the mid-1990s, the cost of the mask has to go up. This cost increase will reflect not only the longer writing time due to smaller design rules, multiple writes, and larger pattern densities, but also the higher precision and tighter specifications that will be required on the mask. The high cost of capital required for leading-edge technology will necessitate the formation of partnerships between the maskmakers and users. On a final note, Dr. Skinner reassured the audience that although significant retooling of the industry will be required, maskmaking in the 1990s will be a continuation of an already well-established process.

Peggy Marie Wood

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Research *Newsletter*

LITHOGRAPHY STRATEGIES: PUSHING THE LIMITS—OPTICAL LITHOGRAPHY

INTRODUCTION

On October 8, 1990, a panel session on lithography strategies in the 1990s was held as part of Dataquest's Semiconductor Industry Conference in Monterey, California. This newsletter highlights several of the significant points discussed by Dr. Gene Fuller, Manager of Stepper Programs at SEMATECH (Austin, Texas), as part of his presentation on optical lithography strategies.

WHY NEW TECHNOLOGIES DID NOT TAKE OVER OPTICAL LITHOGRAPHY

Every few years, over the past 15 to 20 years, someone in the semiconductor industry has forecast the demise of optical lithography and claimed that e-beam, X-ray, ion beam, or some other technology would become dominant. According to Dr. Fuller, the expected demise of optical lithography teaches us a valuable lesson for the future. Optical lithography has not died away for several reasons.

First, optical lithography has not been pushed to its limit. It only has been at the limit of what semiconductor manufacturers were willing to pay for and knew how to do at that particular time.

Second, the projections for new technologies such as e-beam, X-ray, or even new optical technologies were more optimistic than realistic. These new technologies have encountered various delays and technical difficulties in their development cycles.

Finally, the technical and manufacturing environment has continued to change. Semiconductor device and equipment manufacturers have been able to continue to use existing technology and know-how to generate, or "bootstrap," next-generation tools and processes. Dr. Fuller noted several technical enhancements in the manufacture of new lenses, including the availability of better quality glasses and significantly improved computing resources for lens design. Lens designs that were not possible even five years ago are easily done with today's workstations.

G-LINE/I-LINE/DEEP-UV DEBATE

There is significant discussion in the industry regarding g-line, i-line, and, to some extent, deep-UV lithography. Dr. Fuller commented that the g-line/i-line debate (if it is a debate) is overblown. In fact, he concludes, what the semiconductor industry needs are good quality lenses of both varieties. Although i-line is expected to rapidly displace g-line for new system shipments, no one is going to rip out an installed base of g-line steppers and throw them away in order to use i-line lithography. Deep-UV lithography still faces several development problems including the source (especially the laser-based systems), resists that are not exactly mature, and issues regarding the protection of the mask with pellicles. Dr. Fuller did note that the lens design and manufacture for the rest of a deep-UV system is really no more complex than for g-line or i-line.

KEY ENABLERS AND POTENTIAL PITFALLS

Two of the key enablers for future optical lithography are phase shift masks and surface-imaging resists. Dr. Fuller pointed out that although the technology for phase shift masks has been known for a decade, they are not easy to manufacture. He noted that if the industry can, in fact, build the masks, they will provide virtually "free" resolution to the fab engineer, meaning that the engineer

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will have to give up little in order to obtain additional resolution. In addition, the mask user will not need to know how the masks were made in order to use them.

Surface-imaging resists are particularly attractive as device topographies become more extreme. Dr. Fuller discussed the necessity for separating the imaging function of the resist from the use of such a resist to block an etch or implant. Surface-imaging resists are well suited to dry processing. This is particularly attractive to semiconductor manufacturers because dry processing minimizes the disposal of used chemicals. A large cost difference exists between dry and wet processing, but Dr. Fuller believes that this difference has narrowed during the past several years. Surface-imaging resists have been proven technologically, but they are still commercially immature at this point.

Some of the pitfalls facing optical lithography include field size and depth of focus. Larger field sizes are needed to accommodate ever-increasing chip dimensions. Currently, SVG Lithography's Micrascan tool has the largest field size for a stepper system today at 20mm x 32.5mm. Dr. Fuller noted that, in addition, people are talking about and even experimenting with subfield stitching.

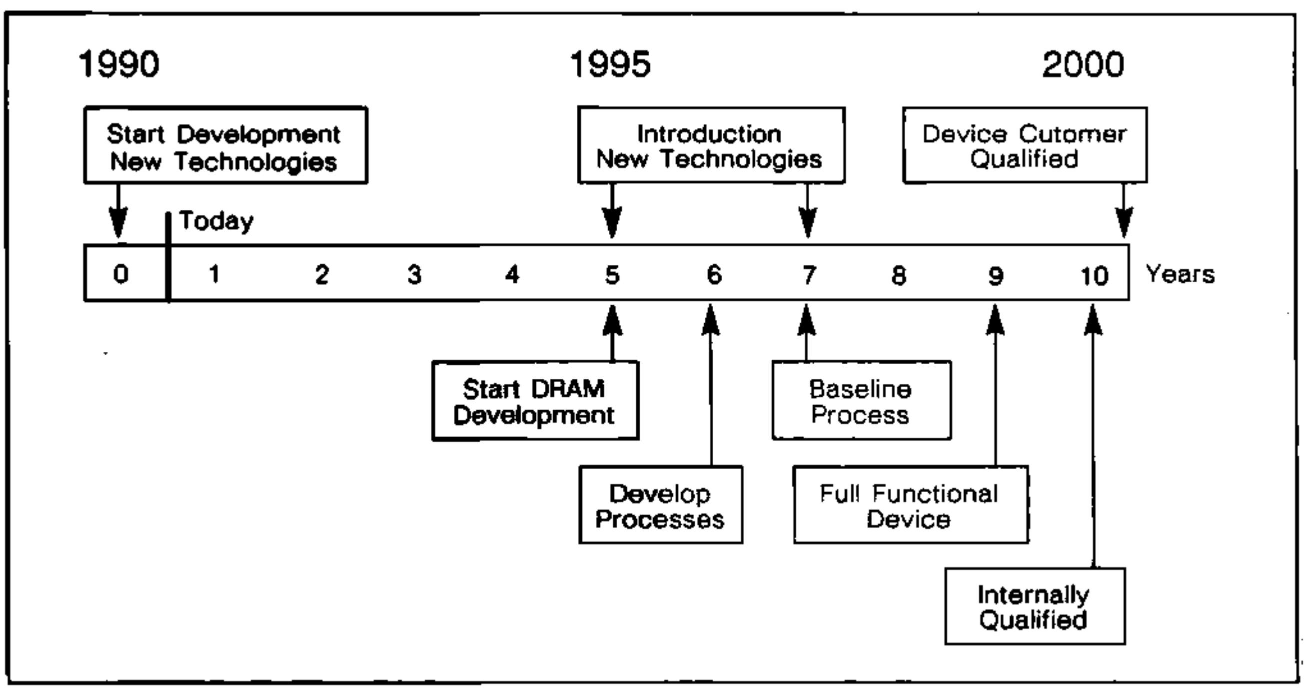
Depth of focus will also be an ongoing problem. As manufacturers utilize lenses with higher numerical apertures (NA) to achieve smaller resolution, the depth of field decreases proportionally to the square of the NA. Dr. Fuller pointed out that this decrease in NA will require semiconductor manufacturers to tightly control circuit topography. As he stated earlier, some semiconductor manufacturers favor surface-imaging resist to address this problem. He further noted that depth of focus also will drive wafer flatness requirements.

CHALLENGES IN THE 1990s

Historically, the average time from development of a new process or equipment technology to its implementation in production has been six to seven years. With the aid of a development road map for the 1Gb DRAM (see Figure 1), Dr. Fuller extended this concept by concluding that we must begin on lithography technology development now, in 1990, in order to be able to produce customer-qualified devices for the year 2000.

This conclusion translates into two important factors in lithography. First, optical lithography will continue to be the dominant technology for a number of years because of the time lag associated

FIGURE 1
Next-Generation Device Development
(0.2- to 0.15-Micron Minimum Geometries—1Gb)



Source: Graydon Larrabee, Texas Instruments, Dataquest (October 1990) with developing new technologies. Second, Dr. Fuller stressed that if manufacturers expect optical lithography to be replaced by direct-write e-beam, X-ray, ion beam, or some other lithography technology five to ten years down the road, it is not too early to put full effort into such programs now.

Dr. Fuller emphasized his belief that the semiconductor industry historically has had difficulty understanding just how long it takes to develop new technologies from the point of a lab demonstration, to writing papers and making presentations at technical seminars, to actually shipping high-volume product. Although optical lithography is here today and must be the tool of choice for some time to come, the industry needs to have major activities ongoing right now in other advanced lithography programs or these technologies will not be ready when they are needed.

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Research Newsletter

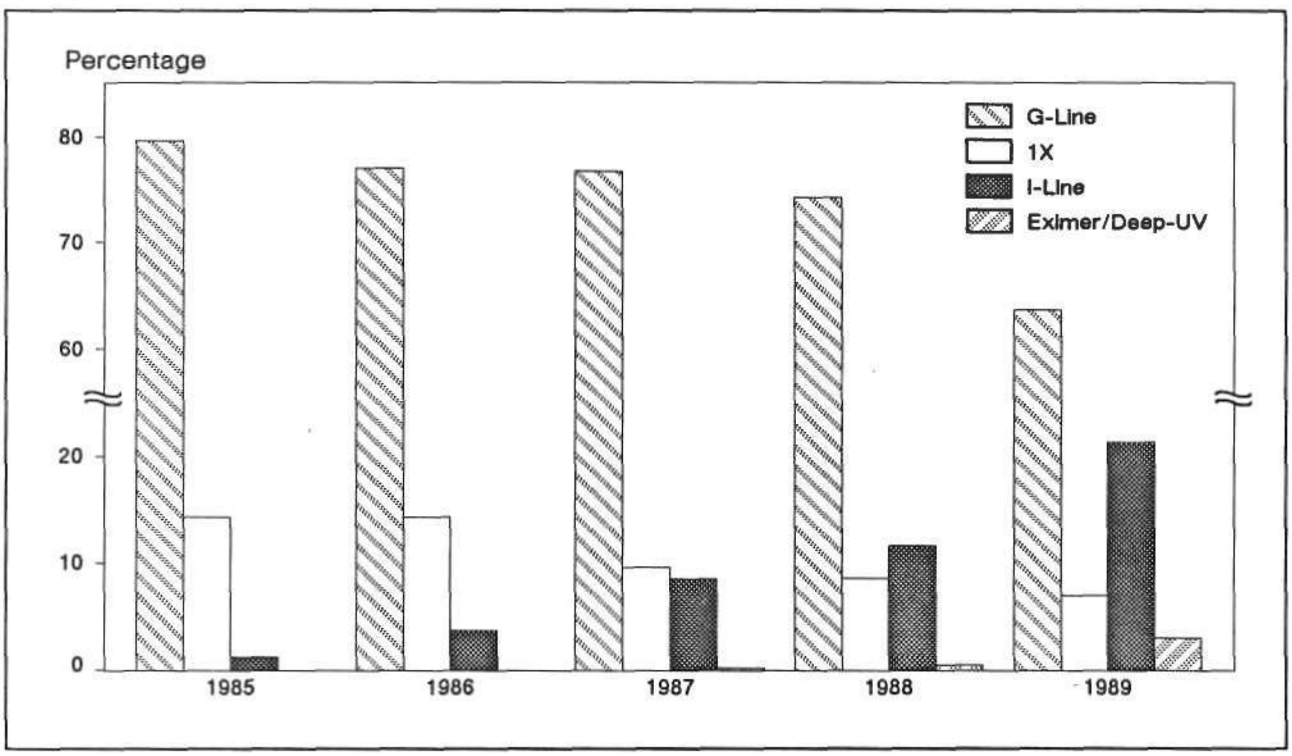
THE AYES HAVE IT: I-LINE LITHOGRAPHY IN THE 1990s

G-line steppers, historically, have been the workhorses of the industry for producing the fine lines required for advanced semiconductor devices. In the last several years, however, other optical alternatives have been gaining market acceptance. In particular, i-line steppers became a significant percentage of the lithography product mix in the late 1980s, accounting for more than 20 percent of stepper shipments in 1989 alone. (See Figure 1; please note change in y-axis scale.) This newsletter discusses the role of i-line lithography in the 1990s.

LITHOGRAPHY STRATEGIES

In the 1980s, one of the submicron lithography strategies being considered by many semiconductor manufacturers was to push g-line steppers to

FIGURE 1
Worldwide Stepper Shipments by Technology
Percent Unit Shipments



Source: Dataquest (September 1990)

SEMS Newsletters Lithography

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their limit, make a transition to excimer laser or deep-UV steppers for processing in the 0.5-micron to 0.35-micron range, and then make the next processing transition to X-ray lithography. The prevailing wisdom was that i-line steppers would represent only an interim technology. Semiconductor manufacturers were reluctant to invest the time, dollars, and resources to characterize a whole new lithography system (tool, materials, and process) if its expected usage were to be limited.

Now, however, the options for i-line are considered to be significant. For example, Table 1 presents a sampling of the DRAM lithography strategies implemented or under consideration by semiconductor manufacturers. DRAM lithography strategies are the leading-edge indicator of lithography tools that will be adopted for the manufacture of other types of integrated circuits. (Please note that the sample-year column in Table 1 reflects the first year of serious sampling of a given DRAM generation, not the first year in which samples of limited quantity are made available.)

The i-line lithography strategies presented in Table 1 include dedicated i-line fab lines, a variety of mix-and-match strategies (i-line/projection, i-line/g-line, i-line/e-beam), and i-line steppers incorporating phase shift masks. Although phase shift mask technology is still in the early stages of development, some researchers believe that with such mask sets, it may be possible to extend i-line to the 0.3-micron processing regime required for the 64Mb DRAM and possibly even utilize this

Table 1
A Sampling of Lithography Strategies for DRAM Manufacturing

DRAM Density	Sample Year	>10 Million Units/ Month	Peak Prod. Year	Linewidth, Sample to Full Shrink	Lithography Strategies
1Mb	1985	1988	1991	1.2-0.8um	G-line 1x
4Mb	1988	1991	1994	0.8-0.6um	G-line G-line mix-and-match With 1x I-line I-line mix-and-match With G-line With projection
16Mb	1991	1994	1997	0.6-0.4um	I-line I-line mix-and-match With G-line 1x mix-and-match
64Mb	1994	1996	2000	0.4-0.3um	Excimer/deep-UV I-line mix-and-match With excimer/deep-UV With e-beam I-line (phase shift masks) Point-source X-ray
256Mb	1997	2000	2004	0.3-0.2um	Excimer/deep-UV Excimer/deep-UV (phase shift masks) I-line (phase shift masks) E-beam Point-source X-ray SOR X-ray

Source: Dataquest (September 1990)

technology for the 256Mb DRAM. Dataquest believes that i-line lithography will be an important portion of the lithography product mix for the 4Mb, 16Mb, and 64Mb DRAM generations. Note that the overall advances in optical lithography are expected to push widespread use of X-ray lithography out well beyond the 64Mb DRAM generation.

WHAT IS A PHASE SHIFT MASK?

One of the hottest topics of interest today in advanced optical lithography is phase shift masks. A phase shift mask consists of a normal mask that has been coated with a transparent layer of material. The transparent material is patterned in such a way that destructive interference patterns are created that cancel some diffraction effects and increase the spatial resolution. Theory indicates that the increase in resolution is accompanied by a minimal decrease in depth of focus. Thus, phase shift masks appear to be a desirable technique to enhance optical lithography resolution.

NEW LENSES

A variety of lenses for 5x reduction i-line steppers are available on the market today. A sampling of such lenses with the manufacturers' specifications is presented in Table 2. Several manufacturers offer wide-field lenses with a field size larger than the standard 15mm x 15mm. Wide-field lenses accommodate more devices in the image field than the standard 15mm x 15mm field and thus have a significant impact on system throughput.

One of the challenges facing i-line stepper manufacturers is that the conventional material that has been used to build some i-line lenses absorbs energy at the 365nm exposure radiation of i-line. The temperature fluctuations in the lens material cause a change in refractive index that translates to a shift in lens focus on the order of several microns. Some companies have addressed this issue by allowing sufficient time for the lens to cool down or by applying sophisticated monitoring and corrections to the lens system to compensate for the fluctuations. Other i-line stepper manufacturers have used fundamentally different materials than conventional stepper lens glass in their lens designs. These new materials do not absorb energy at 365nm, and thus lens heating is not an issue.

NEW PLAYERS, NEW REGIONAL MARKETS

Five companies currently are marketing i-line steppers today: ASM Lithography, Canon, GCA, Hitachi, and Nikon. GCA has been active the longest in supplying i-line steppers, although ASM Lithography was the largest supplier of systems in 1989. Nikon and Canon, the two largest suppliers of steppers in the world, have only just recently entered this lithography market segment. Nikon's first year of significant shipment levels of i-line steppers was in 1989, and Canon announced its entry into the i-line stepper market in July of this year.

Historically, activity in i-line lithography has been focused in the United States and Europe and, to some extent, in the Asia/Pacific region. In Japan, many semiconductor manufacturers had been considering a different lithography strategy for

TABLE 2
A Sampling of 5x I-Line Lens Offerings

Company	Stepper Model	Resolution	Numerical Aperture	Field Size
ASM Lithography	PAS 5000/50	0.50um	0.48	15mm x 15mm
Canon	FPA-2000i1	0.50um	0.52	20mm x 20mm
GCA	Autostep 200	0.65um	0.45	15mm x 15mm
Hitachi	5011i	0.55um	0.43	15mm x 15mm
Nikon	NSR-1755i7A	0.58um	>0.45	17.5mm x 17.5mm

Source: Dataquest (September 1990)

advanced device manufacturing: high numerical aperture (NA) g-line to excimer/deep-UV to X-ray. The outlook on i-line in Japan, however, has changed considerably over the last several years, and today there are growing expectations of extending i-line lithography through the 64Mb DRAM and possibly beyond to the 256Mb DRAM. Dataquest views the recent entry by Canon and Nikon into the i-line market as a strategy on the part of both companies to take advantage of growing market opportunities throughout the world, including their home market of Japan.

COMPETITIVE TECHNOLOGIES

I-line lithography faces a number of competitive technologies in the 1990s including high NA g-line, excimer/deep-UV steppers, holographic lithography, direct-write e-beam, and X-ray:

- High NA g-line lithography with, for example, an NA of 0.42 is capable of handling 0.8um design rules (4Mb DRAM), even though the depth of focus is shallow. The i-line lens is expected to overcome the shallower depth of focus of the g-line lens because it has about 20 percent wider depth of focus when the same resolution is required.
- One of i-line's important advantages over excimer/deep-UV lithography is that a broad selection of i-line photoresists is available from a number of suppliers on the market today, while excimer/deep-UV resist technology still is in its infancy.
- Holographic lithography does not pose any significant challenge at this time, as it is still in its early development stage.
- Although direct-write e-beam systems can achieve finer resolutions than i-line steppers, the significantly lower e-beam throughput puts it at a disadvantage when compared with optical steppers.
- X-ray mask technology still requires significant work before X-ray lithography can become a mainstream lithography option.

DATAQUEST CONCLUSIONS

Lithography equipment constitutes the largest segment of the worldwide wafer fab equipment market. From a technology perspective, lithography equipment represents the engine driving wafer fabrication in the submicron era. A variety of advanced DRAM manufacturing strategies are being developed that incorporate i-line lithography, from the 4Mb through the 64Mb and possibly extending to the 256Mb DRAM. While it is not yet time to put the g-line workhorse out to pasture, i-line lithography may well overtake a declining g-line stepper market and become the dominant lithography technology of the 1990s.

Peggy Marie Wood

Research *Newsletter*

NEW TRACK PLAYERS AND TECHNOLOGIES AT SEMICON/WEST

INTRODUCTION

Automatic photoresist processing equipment, also known as track equipment, was a lively and interesting industry segment at the recent SEMICON/West equipment show in San Mateo, California. It was interesting and lively from both business and technology perspectives.

First, there are several new players and some old players dressed up in new clothes. The relationship between FSI and Convac, under which FSI marketed Convac's track equipment in the United States, was terminated on January 19, 1990. FSI now manufactures and markets the Polaris track system, which was designed by the Texas Instruments Process Automation Center (TIPAC). Meanwhile, Convac has acquired Applied Process Technology of Fremont, California, a manufacturer of spray etching and mask processing equipment. Because of this acquisition, Convac now is able to market its track system through its own organization in the United States.

Another new player bears watching in the US market—Varian/TEL. Varian/TEL, a joint venture between Varian and Tokyo Electron Ltd., is responsible for sales and service support of TEL's track, diffusion, and etch systems in the United States and Europe. Varian/TEL showed TEL's Mark V track system at SEMICON/West. Although other Japanese track companies (e.g., Dainippon Screen and Semix), have shown track systems previously at SEMICON/West, TEL, through its joint venture with Varian, is the first Japanese track system to have the major distribution and service strength that a large US company such as Varian offers.

Technologically, the show was interesting because several track vendors showed equipment designed specifically for flexible manufacturing in a submicron environment. This new equipment not only featured improved performance parameters (better cleanliness, throughput, and reliability), but it also looked different. Robotic transfer arms have replaced the linear moving belts (or the tracks from which the equipment gets its colloquial name). And environmental chambers that enclose the equipment are also being offered by several vendors.

The use of robotic transfer arms to move the wafers from station to station is in response to the concern that belts can be a source of particulates in submicron processing. Robotic transfer arms have another advantage over belts: They allow the wafer to be moved from any process station to any other process station within the track system. This function allows more flexibility in the manufacturing process and allows equipment engineers to configure the track system directly.

The use of environmental chambers also reduces contaminants in the system by isolating the track system from the clean room and operators and by allowing for a full Class I laminar flow over the area where the wafer resides.

INTRODUCTIONS AT SEMICON/WEST

FSI International

FSI displayed the Polaris Photoresist Processing Work Cell, which is a customer-configurable photoresist processing system. The Polaris integrates the stepper into the photoresist processing system without the need for a stepper interface module. It is able to do this because it uses a high-speed robot arm (a modified PUMA 562 with 6-axis movement) to transfer the wafer from the stepper to the Polaris' I/O port. This same robot moves the wafers from the I/O port to process stations and between process stations.

Each process station is randomly accessed by the robotic arms. Random access allows the system to be configured by the customer and allows the

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process recipe to be varied for optimization of throughput, user application, and optimum cycle time. FSI claims that random access has the additional advantage of eliminating queuing. The elimination of queuing means that wait time for the next process is eliminated, thereby enhancing wafer-to-wafer uniformity, repeatability, and throughput.

The entire system is self-contained, operator isolated, and capable of running at Class 1 levels although the outside environment may be as much as Class 10,000. The Polaris has been designed so that the majority of service work can be performed from outside the cell.

Silicon Valley Group (SVG)

SVG introduced the 90 Series system. In order to ensure the system's reliability before its introduction at the show, SVG built and tested four prototype models of the 90 Series. SVG notes that the improved reliability of the 90 Series is partly due to SVG's relationship with Sematech. SVG plans to use the 90 Series as a platform from which to launch several generations of photoresist processing systems.

The 90 Series was designed for both productivity and flexibility and is capable of processing 200mm wafers. SVG claims a cleanliness level of less than 1 particle of 0.3 micron per wafer pass.

The 90 Series is capable of transferring wafers through either serial or random access, or by a combination of the two that the company calls "MultiPath." SVG claims a possible 30 percent throughput gain from using the MultiPath technique. In addition to throughput gains, SVG also claims that the 90 Series has superior process control because the use of serial transfer arms provides shorter and more consistent transfer times between stations.

Other features of the 90 Series include precise control of photoresist and developer temperatures, ambient temperature, relative humidity, bake temperature, exhaust flow, and spin speed.

Varian/TEL

Varian/TEL exhibited the Mark V at SEMICON/West. The Mark V had been introduced in Japan in October 1989. It features robotic transfer with minimum backside contact. The use of robotics with a building-block-type architecture allows the Mark V to be configured and reconfigured according to the needs of the process flow.

In addition to flexible configurability, the Mark V also features process flexibility. This is achieved by the ability to program process parameters, fluid temperatures, and wafer routing.

The Mark V can be interfaced with exposure tools and thus be operated as an integrated coat/expose/develop system. The Mark V has an optional environment chamber for controlling humidity and temperature.

Convac

The Convac 6000 was also at the show. The 6000 was one of the first track systems to feature random wafer transfer with user-configurable systems. The 6000 was introduced at SEMICON/Europa in 1988.

Eaton Corporation

Eaton Corporation's Semiconductor Equipment Division displayed the System 10. The System 10 is Eaton's tenth generation of photoresist processing equipment and Eaton's first new generation since the System 6000XL in 1986. The System 10 is designed specifically for flexible manufacturing in the submicron era. Key features include pick-and-place wafer handling, a small footprint, and advanced controls.

The System 10 has been designed to maximize flexibility. Each basic photoresist function (coat, prime, develop, and bake) can be expanded and enhanced by a variety of options. Four basic cabinet sizes can accommodate from 10 to 21 process positions, and the control system's fiber-optic links can accommodate configurations ranging from five process modules in a single cabinet to larger arrays and multiple cabinets. The System 10 also can interface directly to exposure and inspection tools, host computer systems, and process monitors.

The System 10 has been designed to maximize reliability also. This product has evolved from previous generations of Eaton track equipment; therefore, because it is an evolutionary rather than a revolutionary product, many of its systems have been thoroughly debugged. The System 10, however, does break ground in ways that are designed to improve reliability. For example, the control system features fiber-optic control links rather than the bulky, complex wiring harnesses that usually typify automatic processing equipment.

DATAQUEST CONCLUSIONS

The technology for submicron automatic photoresist processing is here. It features low-particulate transfer mechanisms, automated and programmable processing, and designed-in flexibility. This new technology is taking place within a very fluid business environment. This environment features joint ventures and partnerships in which technology is just one element of the mix. Manufacturing ability, marketing ability, and the ability to provide service on a worldwide basis are equal elements in the mix. It is also noteworthy that the new business environment in the United States features an international cast: Varian/TEL and Convac. Dataquest has long noted that semiconductor manufacturing is global in nature. The semiconductor capital equipment market in the United States is no exception to this trend.

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Research *Bulletin*

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Research Newsletter

GCA AND ULTRATECH MERGE: CAN OIL AND WATER MIX?

CONSOLIDATION AT GENERAL SIGNAL

It has been two years since General Signal acquired GCA. This week, General Signal announced plans to consolidate its regionally dispersed stepper businesses: they are GCA, located in Andover, Massachusetts, and Ultratech Stepper, located in San Jose, California. Essentially, General Signal has been running two separate stepper operations at opposite sides of the continent; it therefore comes as no surprise that the company has finally decided to consolidate the two business activities into a single company. The obvious course of action is to merge the smaller operation into the larger one, which is what will happen. GCA, which has a work force that numbers approximately twice that of Ultratech Stepper's 350 employees, will assimilate the operations of Ultratech Stepper. Moreover, while Ultratech Stepper is occupying leased premises, GCA owns its facilities, and approximately 50 percent of its 350,000-square-foot manufacturing facility is currently unused.

General Signal is bound to reap savings by using the excess capacity at GCA's production facility. It is estimated that between 15 and 25 percent of Ultratech Stepper employees will be asked to relocate to Andover. Only a regional office providing sales and field service and support will be left in San Jose. The new unit, headquartered in Andover, will be called GCA/Ultratech and will be operated under current GCA president, Peter Simone. Resistance to the proposed merger appears to have dissipated since the exit last month of General Signal's senior vice president, John Halter. General Signal hopes that the reasonably generous severance package offered to the affected employees will help alleviate the human distress factors this consolidation can be expected to evoke. The company expects to complete the formation of the new unit by the October/November time frame.

MARKET IMPACT

Although this merger may be a rocky one because of the opposing marketing strategies for reduction and 1:1 lithography, Dataquest believes that it makes good business sense. The synergy of the companies' respective product lines will allow a single sales organization to sell mix-and-match solutions to its customers. Somewhat of a maverick in the industry, Ultratech Stepper has pursued 1X lithography technology, while GCA has been at the forefront of promoting 5X i-line stepper technology. A single salesperson offering the powerful combination of a low-cost solution based on Ultratech Stepper's 1X product line, which is very cost-effective at the less critical layers, in conjunction with a GCA 5X stepper for critical mask layers will enhance GCA/Ultratech's market competitiveness. To use the 16Mb DRAM as an example, approximately 12 to 14 of its 20 layers are noncritical, and about 6 layers are at the critical submicron level. Ultratech Stepper has pursued an open architecture approach of mixing and matching its equipment with other vendors' equipment. This places GCA/Ultratech in a prime position to combine both equipment types to deliver an integrated solution to the customer.

GCA pioneered the direct step-on-wafer approach to lithography in 1979; Ultratech Stepper later brought the 1X stepper to the market. By 1984, GCA and Ultratech had their best year ever when the combined market share of the companies stood at 51 percent in terms of stepper units. Since then, however, GCA and Ultratech's market shares have declined in the face of formidable Japanese competition from Nikon and Canon. Dataquest estimates that GCA/Ultratech's combined market share represented only 13 percent of the total stepper unit shipments in 1989. Although unit shipments are split almost evenly between the two companies, GCA's revenue is significantly higher than Ultratech's because of GCA's higher ASPs.

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TECHNOLOGY FACTORS

Ultratech Stepper is the only major supplier of 1X stepper technology. Its share of the market, stated in units, has declined from a peak of 17 percent in 1984 to 7 percent in 1989. The market, however, favors 5X stepper technology for submicron wafer fabrication. GCA is well regarded for its state-of-the-art technology and has been a pioneer in i-line steppers. In the early 1990s, Dataquest expects i-line stepper technology to serve as one of the mainstream submicron lithography tools down to the 0.5-micron feature size. In addition to its expertise in i-line steppers, GCA offers impressive lens technology through its Tropel division. Moreover, the company is involved with Sematech on two stepper programs. A joint development contract focuses on optical stepper technology, and an equipment improvement project focuses on i-line steppers. For its part, Ultratech possesses excellent stage technology, as well as mask and reticle technology.

Considerable synergy can be derived by combining the R&D activities of the two companies. In addition to pioneering i-line stepper technology, GCA has been active in excimer laser steppers and continues to pursue advanced lens technology through the efforts of its Tropel operations. For its part, Ultratech Stepper has been investing in a revolutionary new tool, a 1X deep UV optical stepper, which is a large field stepper that the company claims will be capable of 0.25-micron optical lithography. Ultratech is pursuing this fundamental R&D program at UC Berkeley and Stanford University in collaboration with SRC and Sematech. This technology is based on Ultratech's proprietary reflection mask concept as opposed to conventional transparent masks. The collection of these various R&D activities under one organization will provide considerable momentum to GCA/Ultratech's future strategic development plans.

DATAQUEST CONCLUSIONS

Dataquest believes that this consolidation represents a positive strategic move for General Signal's fragmented semiconductor equipment operations. The combined entity will allow for better economies of scale, enhanced technology synergies, and better utilization of GCA's excess production capacity. GCA/Ultratech will be the first stepper equipment company to offer both reduction and 1X steppers as an integrated solution, which may lend momentum to the industry in its move toward adopting mix-and-match lithography strategies.

However, the new company still faces some tough challenges. The company will have to place increasing emphasis on global customer support and service in an industry environment that favors closer user/vendor relationships. One major challenge will be to increase market penetration in Japan. In 1981, GCA occupied the number one position in the worldwide stepper market, with more than one-half of the Japanese market to its credit. However, GCA has experienced a severe erosion of market share in Japan in recent years. Today, it has virtually no business in that region. Ultratech Stepper also is not a significant player in Japan, although it has been very successful in gaining market share in the Asia/Pacific countries.

Companies such as Nikon of Japan and ASM Lithography of Europe, dominant suppliers in their own domestic markets, also have made significant inroads into GCA's domestic market share. Thus, a major challenge for GCA/Ultratech will be to recapture lost business among major U.S. accounts. Dataquest expects GCA's involvement in a number of Sematech programs to aid the company in terms of equipment improvement and access to incremental market share through the Sematech member companies.

Dataquest believes that GCA/Ultratech's major new strength will be its ability to offer a integrated mix-and-match strategy to submicron device manufacturers. Such a mix-and-match strategy is being increasingly examined by semiconductor companies as a method to control the skyrocketing costs of advanced wafer fabrication.

This merger will have implications for other fragmented business units within General Signal's semiconductor equipment operations. It can be assumed that the company is carefully evaluating its options in this regard.

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Research Newsletter

PERKIN-ELMER SELLS ITS E-BEAM OPERATION: A STRONGER ENTITY WILL EMERGE

SUMMARY

Perkin-Elmer (PE) announced on March 19 that it had sold its Electron Beam Technology (EBT) Division to a group of investors headed by former and current staff members of EBT, along with equity participation from IBM, Du Pont, Grumman, Micron Technology, and Zitel. Perkin-Elmer also will be an equity partner in the new company, which is named ETEC.

This announcement is very significant because the new company, ETEC, will emerge as a stronger entity than PE's former EBT division; and it should significantly enhance lagging U.S. efforts in e-beam lithography, thus making the United States more competitive in the world e-beam market.

BACKGROUND

It was almost a year ago that Perkin-Elmer announced its intent to sell its Semiconductor Equipment Group, which consists of the EBT division and the Optical Lithography Operations (OLO). As recently as 1985, PE was the world's leading wafer fab equipment and lithography equipment supplier. Since 1985, PE's fortunes in semiconductor equipment have steadily declined, and the sale of the EBT division is the first step in the company's complete exit from the industry. (The sale of OLO to another group of investors is still in the making.)

As a note of historical interest, ETEC was also the name of the original e-beam company founded in 1970 to manufacture laboratory e-beam systems. In 1975, ETEC obtained a license to use AT&T's Bell Laboratories' technology to manufacture commercial e-beam systems that eventually became known as the MEBES series. In 1979, PE acquired ETEC; actually, therefore, this operation always has been the stronghold of U.S. commercial e-beam technology and activity.

AN INTERESTING GROUP OF INVESTORS

Although financial details of the deal have not been released, Dataquest estimates that the division sold for between $20 million and $30 million. It is rumored that the ETEC management team—headed by Charles E. Minihan, chairman of the board and CEO, and Thomas Halloran, president and COO—will hold the largest share of ETEC, with the remaining portion being equally held by the other investors. But why this seemingly diverse group?

The deal is described as a synergistic investment made in the interest of national policy to keep U.S. efforts alive in e-beam lithography. It is also being touted as an example of U.S. companies putting together consortiums. For one thing, this is not a consortium at all, but really a venture capital deal. Secondly, U.S. e-beam technology will certainly get a boost from this deal, but Dataquest believes that strict business interests were the prime motives, although not all the participants' motives are clearly understood. Let's take a look at the individual investors.

IBM

As part of the deal, IBM will provide its own e-beam technology to ETEC. IBM has been building e-beam systems for its own use for more than 20 years and probably has more experience in the use of e-beam systems in lithography applications than all other companies combined. For instance, Dataquest estimated a few years ago that IBM had at least 40 e-beam systems in operation. IBM will

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transfer to ETEC the technology for the EL-4 e-beam system, an advanced machine that is still under development by IBM. This technology will augment and significantly boost the competitiveness of ETEC in the world lithography market. This technology transfer is the main reason that ETEC will emerge as a stronger entity to help revitalize the U.S. lithography activity.

IBM's technology contribution to ETEC also should be seen in the broader light of IBM's objective both to strengthen the U.S. industry and to improve the balance of technology in areas in which IBM relies on local vendors. Examples of IBM's objectives in the United States are its activity in Sematech and U.S. Memories, its 4Mb DRAM agreement with Micron Technology, and its X-ray program with Motorola. Examples in Europe are IBM's participation in JESSI and the 64Mb DRAM joint development agreement with Siemens. The conclusion here is that we will likely see more industry involvement by IBM in the future.

Another idea is that IBM may want to establish a potential alternate supplier for its EL series machines.

Du Pont

Du Pont has become the largest non-Japanese supplier of photomasks with operations in the United States and Europe. It entered the photomask business in 1986 and has invested more than $150 million since that time. Du Pont sees maskmaking as strategically important both to its own total electronics business and to the U.S. semiconductor industry; therefore, Dataquest expects more investments to be made in this area. The technical performance of e-beam maskmaking machines must improve continually to meet the demands of ever more complex ICs. Clearly, Du Pont, a large customer of e-beam systems, wishes to ensure a domestic supply of state-of-art maskmaking machines.

Grumman

Grumman's Electronic Systems Division has been manufacturing e-beam systems for IBM for some time; currently, it is manufacturing the EL-3 system for IBM. It is not yet manufacturing the EL-4 system, the technology of which is being made available to ETEC. Grumman's investment motives are not clear, as the company is investing in a potential competitor to its IBM business. Incidentally, Grumman also has other activities under way in lithography, namely in X-ray synchrotron orbital radiation (SOR).

Micron Technology

At this time, we do not understand the reason for Micron's involvement. Micron has i-line steppers, and its position possibly could be construed as a view toward future mix-and-match lithography with i-line and e-beam. However, Dataquest does not consider this to be Micron's motivation. Micron has near-term financial problems, and we do not think that such a long-term view is in its immediate interest. We believe that Micron's involvement may be simply an investment position.

Zitel

Zitel, a $32 million company (in fiscal year 1989), designs and manufactures high-speed memory subsystems for use in various OEM applications, including e-beam lithography systems. Zitel is an OEM supplier to ETEC and provides the entire memory/control subsystem for ETEC's e-beam systems. Dataquest believes that Zitel also provides the memory subsystems to Grumman/IBM for the EL e-beam series.

DATAQUEST CONCLUSIONS

It is clear to us that ETEC will emerge as a stronger entity than the former EBT division of Perkin-Elmer. ETEC will be stronger technically with the EL-4 technology, and it should also be stronger financially. Dataquest believes that the EBT division was starved for R&D funding while PE was pouring resources into the Micrascan project and that this lack of funding was reflected in the lack of significant e-beam advances made by the EBT Division. ETEC should benefit from better funding, and, of course, the U.S. e-beam lithography effort will benefit also.

Although the motives of all investors are not yet clear, the diversity of investors is interesting; they include both suppliers to and customers of ETEC. Very possibly, this new venture may serve as an example of U.S. companies learning to work together.

Joseph Grenier

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Research Newsletter

US COMPANIES DOMINATE THE DRY ETCH MARKET, BUT FACE NEW CHALLENGES IN THE 1990s

SUMMARY

US-based companies have dominated the dry etch equipment market for the past two decades. Dataquest estimates that US-based equipment companies owned 60 percent of the 1989 worldwide $636 million dry etch market. US-based companies are in the forefront of new dry etch technologies such as magnetically enhanced reactive ion etch (MERIE) and single-wafer, cluster-tool-based equipment architectures. US-based companies are mounting aggressive efforts to pursue the fast-expanding international dry etch equipment market as the semiconductor industry's globalization continues in the 1990s.

Japan-based companies are poised to offer a significant challenge to US-based companies in the quest for worldwide dry etch market leadership in the 1990s. Japanese dry etch companies gained dry etch equipment market share on a worldwide basis between 1985 and 1989. Their ownership of the worldwide dry etch market increased from 26 percent of the 1985 dry etch market of $300 million to 36 percent of the 1989 dry etch market of $636 million. Japan-based companies lead in the development of microwave-based/electron cyclotron resonance (ECR) dry etch technology. Dataquest expects microwave-based/ECR dry etch technology to significantly penetrate the submicron polycide and metal etch markets in the 1990s.

Although US-based companies continue to be the dry etch market leader, their lead over the competition has slimmed during the past five years. US-based companies have lost worldwide market share over the past five years: Their ownership of the dry etch market has shrunk from 68 percent in 1985 to 60 percent in 1989.

Japan continued to be the largest dry etch equipment market, making up 48 percent of the worldwide 1989 market of $636 million. Japan-based companies had a home-field advantage in the Japanese market, the largest and most technology-intensive market in the world. US-based companies, meanwhile, had to intensify their international marketing efforts as the US market shrank from 49 percent of the worldwide 1985 dry etch market to only 30 percent of the 1989 dry etch market. The exit of most US semiconductor companies from the high-volume DRAM business has been a dominant factor in decreasing the US percentage share of the total worldwide dry etch market.

The Asia/Pacific dry etch market, led by South Korea and Taiwan, has grown dramatically, going from 6 percent of the 1985 market to 11 percent of the 1989 market. South Korea's emergence as a leading DRAM producer, together with Taiwan's emergence as a leading ASIC, DRAM, and PC chip set producer, has fueled the rapid growth of the Asia/Pacific region's dry etch market. The combined Japan-Asia/Pacific dry etch equipment market constitutes almost 60 percent of the worldwide 1989 dry etch market. Any dry etch equipment company that aspires to market leadership in the 1990s has to stake out a dominant presence in the Pacific Rim, which has become the new frontier for leading-edge, high-volume device manufacturing.

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RAPID GROWTH OF THE DRY ETCH EQUIPMENT MARKET

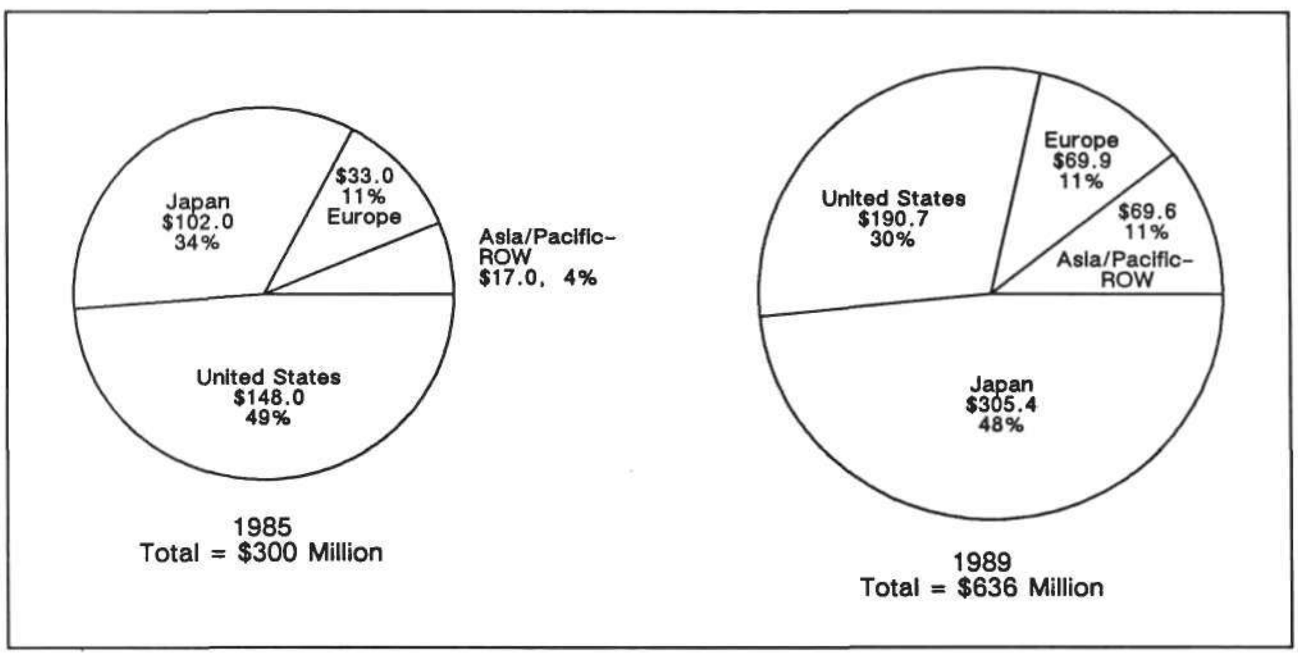
Figure 1 illustrates the regional growth trends of the worldwide dry etch equipment market between 1985 and 1989. The dry etch equipment market's compound annual growth rate (CAGR) of 20.7 percent between 1985 and 1989 has significantly outpaced the overall wafer fabrication equipment market CAGR of 15.1 percent between 1985 and 1989. Factors that have been responsible for the rapid growth of the dry etch equipment market include the increasing shift from wet to dry processes, the increasing number of mask/etch levels in leading-edge processes, and increasing dry etch equipment average selling prices (ASPs) due to submicron process complexity and defect sensitivity.

Why Is Japan the World's Largest Dry Etch Equipment Market?

Japan's sustained level of capital spending in 1988 and 1989 in order to add state-of-the-art 1Mb/4Mb DRAM capacity has resulted in its emergence as the largest dry etch equipment market. The number of mask levels in DRAM processes has increased dramatically with each succeeding device generation. For example, the typical 4Mb DRAM process uses 20 mask/etch levels, and the 16Mb DRAM process may use 24 to 28 mask/etch levels. Many of these levels are critical levels with submicron design rules. It is natural that the Japanese dry etch market should expand enormously in order to meet these high-volume production requirements.

Many Japanese semiconductor manufacturers have adopted a modular approach to process design for different device families such as DRAMs, SRAMs, EPROMS, microprocessors, and ASICs. Such a modular approach to process design increases the total available Japanese dry etch equipment market as Japan-based semiconductor manufacturers leverage off their DRAM process expertise to penetrate other high-volume commodity-type products such as SRAMs, EPROMs, and gate arrays.

FIGURE 1
Regional Dry Etch Equipment Market
(Millions of Dollars)



Source: Dataquest (September 1990)

Why Is the US Dry Etch Equipment Market Growing More Slowly?

The US dry etch equipment market has grown more slowly relative to the Japan-Asia/Pacific market as US semiconductor manufacturers adopt a strategy of retreating from high-volume standard products such as memories and gate arrays to low-volume, niche-oriented proprietary devices. Dataquest believes that such a strategy may not be effective because of the increasing trend toward common core processes for products such as memories, ASICs, and programmable logic devices. In effect, the decline of US leadership in DRAM production may eventually lead to the decline of US leadership in other high-end, standardized device production arenas. Niche-oriented device production strategies will not sustain healthy growth of technology-driven equipment markets such as the dry etch equipment market.

Asia-Pacific Dry Etch Market Grows Dramatically

The Asia/Pacific-Rest of World (ROW) dry etch market has grown dramatically between 1985 and 1989 in contrast to the stagnant European dry etch equipment market. Factors such as South Korea's meteoric rise to fame in the DRAM business, together with Taiwan's recent thrust toward submicron manufacturing capability, are responsible for the rapid growth of the Asia/Pacific-ROW dry etch equipment market.

The European dry etch equipment market has maintained an 11 percent share of the worldwide market between 1985 and 1989. Dataquest believes that this market is poised for healthy growth in the next few years as many new European fabs come on-line to meet the 1992 doctrine of domestically diffused chips.

Technology-License Chain Opens Up Global Dry Etch Market

Dataquest believes that the continuing proliferation of technology licenses and offshore fabs will profoundly affect the development of the regional dry etch equipment markets. As an example, global semiconductor manufacturers such as Hitachi, NEC, and Texas Instruments (TI) may equip their US, European, and Asia/Pacific DRAM fabs with dry etch equipment identical to that used at their DRAM fabs in Japan. Technology agreements between Toshiba and Motorola, IBM and Siemens, and TI and Hitachi may result in sole-sourcing of dry etch equipment from a single vendor with a global presence. Effectively, portions of the regional dry etch markets cannot be accessed openly by all possible equipment vendors.

WHY HAVE US-BASED COMPANIES DOMINATED THE DRY ETCH MARKET?

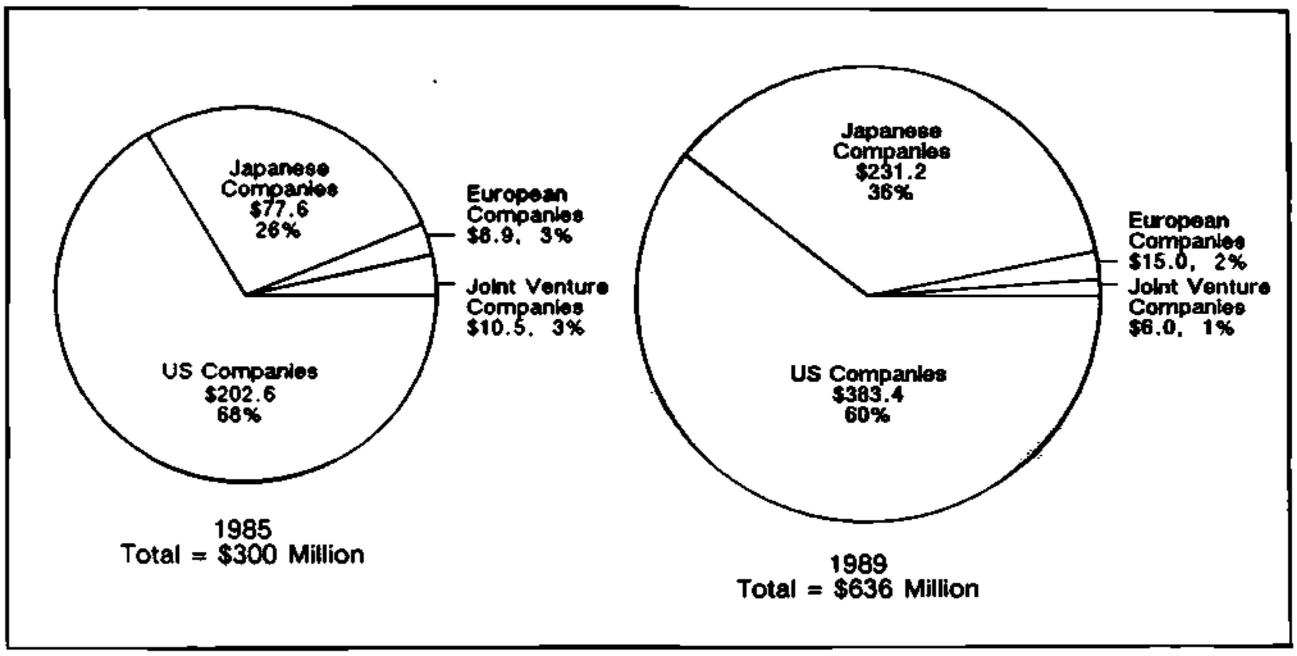
Figure 2 illustrates the regional ownership of the worldwide dry etch market. It is apparent that US-based companies have consistently dominated the market. US-based equipment companies essentially invented the dry etch market in the 1970s. They have been very successful in converting the market potential of RF-plasma technologies into effective dry etch reactor solutions for their customers. In any new market, the companies with first-to-market products usually reap windfall market shares and profits in the initial one- or two-product generations. The dry etch equipment market has been no exception to this rule.

US-based companies have led reactor innovations in batch (hexode and planar) systems as well as single-wafer dry etch systems. They have thus far successfully blended their research efforts in plasma physics, chemistry, reactor fluid dynamics, and system software/control into production-worthy dry etch systems. Dataquest believes that certain segments of the dry etch market such as the single-wafer plasma-assisted RIE market are approaching maturity. Maturing technologies lead to intensified competition from new global competitors.

JAPAN-BASED COMPANIES CHALLENGE US-BASED COMPANIES IN THE GLOBAL DRY ETCH MARKET OF THE 1990s

Japan-based dry etch equipment companies gained 10 percentage points of worldwide market share between 1985 and 1989. TEL, the leading Japan-based dry etch company, has leveraged off its joint-venture-based technology with US-based Lam Research to develop its own proprietary systems. Other leading Japan-based dry etch companies such as Anelva and Hitachi Semiconductor Equipment have benefited from close development partnerships with their large semiconductor parent companies such as NEC and Hitachi, respectively. Such cooperative development partnerships have helped Japan-based companies take the lead in

Figure 2
World Dry Etch Market Ownership
(Millions of Dollars)



Source: Dataquest (September 1990)

advanced technologies such as microwave/ECR dry etch for submicron metal and polycide etch applications.

Japan-based dry etch equipment companies also have the advantage of selling into a domestic market that is the largest and most technology-intensive wafer fabrication equipment market in the world. Japan is the world's largest producer of DRAMs. Advanced submicron 4Mb/16Mb DRAMs drive dry etch equipment requirements. Japanese semiconductor companies also are rapidly expanding to offshore fabs in the United States and Europe in order to maintain a global presence. Process and equipment selection in the offshore Japanese fabs tends to duplicate the parent fab back in Japan. Is it any wonder, then, that Japan-based dry etch equipment companies gained market share between 1985 and 1989?

Dry Etch Technology Is at the Crossroads of Change

Conventional plasma etch and plasma-assisted RIE technology has matured over the last decade. Maturing RF plasma technologies have allowed Japan-based companies to catch up with US-based companies in their understanding and applications of plasma etch technologies. Meanwhile, Japan-based companies are first to jump onto the ECR etch bandwagon for metal and polycide applications. US-based companies are betting on MERIE systems as a solution to submicron etch requirements. The dry etch market is poised at the crossroads, confronting a wide range of technologies such as ECR, MERIE, improved RF plasma-assisted RIE, combination microwave/RF plasma, and low-temperature etch. Dry etch equipment companies that hitch themselves to the right technology bandwagon can expect to ride to market success in the 1990s.

Worldwide Dry Etch Equipment Company Rankings

Table 1 lists the worldwide dry etch equipment company rankings based on calendar year 1989 revenue. Dataquest's equipment company rankings are based on prime system revenue only and do not include spares and service contributions.

TABLE 1
Worldwide 1989 Dry Etch Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Percent Share
Applied Materials (United States)	208.0	32.7%
Lam Research (United States)	85.6	13.5
Tokyo Electron (Japan)	80.0	12.6
Hitachi (Japan)	47.3	7.4
Anelva (Japan)	44.2	7.0
Tegal (United States)	42.0	6.6
Drytek (United States)	22.0	3.5
Tokyo Ohka Kogyo (Japan)	21.7	3.4
Plasma-Therm (United States)	15.2	2.4
Electrotech (Europe)	15.0	2.4
Sumitomo Metals (Japan)	12.0	1.9
Tokuda (Japan)	10.5	1.7
Ulvac (Japan)	8.7	1.4
Materials Research Corporation (Japan)	7.4	1.2
Varian/TEL (joint venture)	6.0	0.9
Others	10.0	1.6
Total	635.6	100.0%

Notes: Calendar year prime systems revenue only. Spares and service are not included. Regions in parentheses denote company regional ownership.
Source: Dataquest (September 1990)

Applied Materials is by far the worldwide dry etch market leader. Its 1989 dry etch revenue of $208 million made up 33 percent of the $636 million market. This total represents more than twice the revenue of the second-ranked dry etch company, Lam Research Corporation (LRC). Competition is, however, intensifying in the dry etch market. Applied's 1989 dry etch revenue only increased 5 percent over its 1988 level although the market increased by 17 percent between 1988 and 1989. Dataquest believes that Applied is encountering strong competition in Japan from Japan-based companies. Applied was relatively late in jumping onto the single-wafer dry etch technology bandwagon. Through much of the 1980s, Applied pursued a strategy of incremental improvement in its highly successful hexode batch technology while the rest of the competition made an early move to single-wafer plasma-assisted RIE, microwave ECR, and MERIE technology.

Dataquest believes that single-wafer dry etch technology will continue its market share gain in the 1990s because of advantages such as 200mm wafer uniformity, process versatility, and compatibility with cluster-tool architecture. Applied's growing portfolio of PE5000-based single-wafer MERIE applications, together with its recent decision to merge its dielectric CVD and etch divisions into a single synergistic operation, supports its strategy to penetrate the single-wafer dry etch market. Dataquest believes that 1990 and 1991 will be watershed years for Applied's dry etch market leadership as it makes the transition from the hexode-based batch RIE system to MERIE-based single-wafer PE5000 systems.

LRC and TEL essentially tie for second place in dry etch company rankings if we attribute Varian/TEL's $6 million dry etch revenue to TEL products. Each company owned approximately 14 percent of the 1989 dry etch market. LRC continues its leading single-wafer plasma-assisted RIE market position with its highly successful Rainbow product family. LRC, which traditionally had dominated the polygate etch market, recently has increased its efforts to penetrate the oxide and metal dry etch markets. Its dry etch development programs with Sematech and Du Pont should prove to be valuable in its market strategies. LRC has also been extremely successful in penetrating the fast-growing Asia/Pacific market for 1Mb/4Mb DRAM applications. Dataquest believes that the success of LRC's Japan-market efforts through its Japanese partner, Sumitomo Metals, will be crucial to the company's quest for dry etch market leadership in the 1990s.

TEL has made spectacular market share gains in the last two years. It has almost doubled its dry etch revenue between 1988 and 1989. The company has successfully absorbed LRC's AutoEtch technology through its prior TEL/LAM Japan-based joint venture. Subsequently, TEL has developed its own proprietary plasma-assisted RIE product line. TEL's new products have suuccessfully penetrated poly/polycide, nitride, and oxide dry etch applications for 1Mb/4Mb DRAM production.

TEL's emphasis on worldwide customer support, service, and product reliability has rewarded the company with significant market share gains. TEL has been able to quickly adopt a global-supplier posture through its Varian/TEL joint venture for the US and European equipment markets. Dataquest predicts that TEL and Varian/TEL will pose a formidable challenge to Applied Materials and Lam Research in the 1990s race for global market leadership. We believe that TEL's future challenge is to quickly expand its technology portfolio to include the high-growth areas of ECR and MERIE applications in a cluster-tool market environment.

Hitachi, with revenue of $47 million, had 7 percent of the 1989 dry etch market. It has been very successful with its ECR-based plasma etchers for polycide and metal applications. Hitachi is in the vanguard of the Japanese market movement toward low-damage, high-selectivity dry etch technology for submicron processes. Hitachi's shipments were mainly confined to the Japan-based market. However, Dataquest expects more Hitachi dry etch systems to be shipped outside Japan as Japanese semiconductor companies expand their US and European operations.

Anelva, which occupied the fifth-ranked spot, owns 7 percent of the dry etch market, with 1989 revenue of $44 million. Anelva is making the transition from its earlier batch RIE systems to single-wafer systems with cluster-tool architecture. The company is using its ILC-1551 series cluster tool as a platform to develop new single-wafer dry etch processes.

Tegal, the sixth-ranked dry etch company, is redefining its identity after emerging from its management/venture-capital-led buyout from Motorola New Enterprises. The company is attempting to leverage off its extensive process knowledge by offering its field-proven plasma, RIE, triode, and MERIE reactors as modules to its Series 6000 cluster-tool architecture. Tegal's strategy is to gain clout quickly as a global equipment company through internal growth as well as synergistic acquisitions of other related equipment companies. Tegal's challenge in the 1990s is to successfully turn its extensive technological expertise into value-added customer solutions on a global basis.

DATAQUEST CONCLUSIONS

Dataquest predicts intense dry etch market competition in the 1990s as Japanese and European equipment companies challenge US companies' market leadership. The dry etch market is at the crossroads of technological change as a host of solutions such as enhanced plasma-assisted RIE, MERIE, ECR, and combination microwave/RF plasma systems enter the marketplace. US-based dry etch companies are betting on enhanced plasma-assisted RIE and MERIE systems as the 1990s solution; Japanese and European companies are pursuing ECR-type reactor designs. US dry etch companies will have to increasingly globalize their operations as a response to the increasing globalization of the semiconductor business. Japan-based dry etch equipment companies will have a competitive advantage in terms of operating on their home turf, which is the largest and most technologically demanding dry etch market in the world.

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DRY ETCH/DRY STRIP EQUIPMENT TRENDS IN JAPAN

OVERVIEW

Japanese dry etch equipment companies are challenging the worldwide market leadership position of U.S. dry etch equipment companies. Recently, Japan has witnessed a tremendous burst of advanced dry etch equipment introductions. Japan leads the world in production implementation of electron cyclotron resonance (ECR) dry etch technology. Companies such as Anelva, Hitachi, and Sumitomo Metals continue to market ECR dry etch equipment for advanced 4Mb/16Mb DRAM applications involving 0.5- to 0.8-micron polycide and metal linewidths. Meanwhile, companies such as Tokyo Electron Limited (TEL) and Tokyo Ohka Kogyo (TOK) continue to gain market share with incrementally improved single-wafer plasma etch systems. Table 1 summarizes recent dry etch equipment introductions in Japan.

COMPANIES

Anelva

Anelva has introduced its ECR-6011 etch system for 16Mb DRAM production applications. The system is 200mm-compatible and is capable of

TABLE 1
Recent Dry Etch Equipment Introductions in Japan

Company	Model	Technology	Application	ASP (Millions)	Comments
Anelva	ECR-6011	ECR	0.5-micron polycide lines	¥160 ($1.2)	200mm capability
Hitachi	M-318EX	ECR	0.5-micron polycide lines	¥170 ($1.2)	Upgrade to M-206 system
Kokusai Electric	Nebula	Plasma	0.8-micron oxide etch	¥150 ($1.1)	MERIE system
Sumitomo Metals	ECR-5500	ECR	0.5-micron metal lines	¥200 ($1.5)	In-situ dry strip and wet clean
TEL	K-Series	Plasma	0.8-micron poly, oxide, metal	¥105 ($0.8)	200mm capability
TOK	TSS-1101	Microwave	0.8-micron polycide lines	¥120 ($0.9)	Low-damage etch
	TUE-1111	Plasma	0.8-micron oxide etch	¥80 ($0.6)	400-kHz frequency
Ulvac	CSE-1000	RIE	0.8-micron polycide lines	¥60 ($0.5)	Single-wafer RIE

ASP = Average Selling Prices

Source: Dataquest
March 1990

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etching 0.5-micron polycide gate geometries. The average selling price (ASP) for the system is ¥160 million ($1.2 million). Anelva expects to commence shipments of the system in the second half of 1990 and to offer metal and oxide etch processes for this system in the future. The company also markets its ECR-510E dry etch tool for research applications. Anelva distributes Branson's L-3200 dry strip system in Japan.

Hitachi

Hitachi is marketing its new M-318EX ECR dry etch system, which will have an ASP of ¥170 million ($1.2 million). This system is an upgrade to the Hitachi M-206 ECR etch system that was introduced in 1985. The main application for the M-318EX system is poly/polycide gate patterning. Hitachi continues to offer the M-308 ECR system for metal etch applications and also has introduced an integrated UV/ozone dry strip system combined with a wet clean station. Dataquest believes that this type of combination dry strip/wet clean system may find applications in polycide gate etch and metallization etch processes.

Kokusai Electric

Kokusai Electric is marketing its new Nebula Series magnetically enhanced reactive ion etch (MERIE) system for oxide etch applications. The system is configured as a cluster tool with three process chambers. A two-chamber version of this system is priced at ¥150 million ($1.1 million). Dataquest believes that Kokusai Electric has a CVD module development effort under way using the same cluster platform.

Sumitomo Metals

Sumitomo Metals is now offering a new product in its extensive portfolio of ECR systems. The ECR-5500 system is targeted at the metal etch market for devices such as the 16Mb DRAM. The system is unique in its use of a sequential dry etch, dry strip, and wet clean in-situ in an integrated processing system. This system enables removal of etch residues before exposing the wafer to the environment. The ASP for the system is ¥200 million ($1.5 million). The system is 200mm-compatible and uses a 13.56-MhZ RF substrate bias together with an electrostatically clamped wafer chuck to improve the etching characteristics. Sumitomo Metals will market the product in the United States and Europe through its trading partner Lam Research.

Tokyo Electron Limited (TEL)

TEL continues to ship its successful K-series single-wafer plasma etchers targeted toward production 1Mb/4Mb DRAM applications for polycide, oxide, and metal etching. The K-series systems were introduced at SEMICON/Japan in December 1988. The Varian/TEL joint venture markets and services the K-series systems in the United States and Europe. The ASP for the system is approximately ¥105 million ($760,000).

Tokyo Ohka Kogyo (TOK)

TOK offers dry etch products based on single-wafer, plasma etch technology. By emphasizing process chemistry and chamber design, TOK claims that it can avoid the high costs associated with submicron reactive ion etchers (RIE). TOK has introduced the TUE series etch systems, which are the latest in TOK's line of plasma etch equipment. The TUE-1111 system, which is a low-frequency (400 kHz) system, is targeted toward oxide etch applications, and the TUE-1101 system is intended for poly and nitride etch applications. The ASP for the TUE series is between ¥70 million and ¥80 million ($500,000 to $600,000).

TOK also is marketing its new TSS series of low-damage "ECR"-like etchers. These systems are characterized by microwave discharge and plasma generation inside the reactor, as opposed to the more traditional ECR systems, which are downstream microwave etchers. The TSS-1101 system, with an ASP of ¥120 million ($900,000), is targeted toward submicron 4Mb DRAM poly or polycide gate etch applications.

TOK has also introduced two dry strip systems. The OPM-2001C is a refined, barrel-type batch system with an ASP of ¥30 million ($217,000); and the TCA-2400 is a single-wafer, downstream RF system with an ASP of ¥27 million ($196,000).

Ulvac

Ulvac is targeting its new CSE-1000 single-wafer RIE system toward polycide and nitride etch applications, at a system ASP of ¥60 million ($435,000). Earlier, the company had marketed only batch RIE systems, such as the CSE-3000 series at an ASP of ¥100 million ($725,000). Meanwhile, Ulvac is shipping its UNA-2000 microwave, downstream dry strip system. This system has an ASP of ¥29 million ($210,000) in production quantities.

DATAQUEST CONCLUSIONS

The recent plethora of dry etch/dry strip equipment introductions by Japanese companies challenges the market leadership position of U.S. companies. Japan leads the world in production implementation of advanced ECR dry etch equipment for submicron polycide and metal patterning applications. Significant efforts are under way in Japan to integrate dry etch, dry strip, and wet clean processes in integrated equipment configurations to minimize defects while maximizing productivity. Dataquest believes that worldwide competition in the etch/clean equipment market will intensify in the near future.

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Research Newsletter

REPROCESSING: A TECHNOLOGY ON THE CUSP

INTRODUCTION

The technology to reprocess acids used in wafer and quartzware cleaning is at a critical junction in its commercialization. Since 1987, Dataquest estimates that semiconductor manufacturers have installed 20 reprocessing systems worldwide. This installed base consists of 18 sulfuric acid reprocessors and 2 hydrofluoric (HF) acid reprocessors.

Over the next few years, the performance of these installed systems will enable engineering staffs to decide to what extent this technology will be used in their fabs. Their evaluation of the technology will determine whether acid reprocessing grows into a $200 million equipment area within the next five years, or lurches along as a niche technology, or simply disappears all together.

The financial community, attracted by the technology's environmental angle, continues to fund the two companies that are developing these systems. Athens Corporation, based in Oceanside, California, has received several rounds of financing from the venture capital community and Air Products and recently sold an equity stake to Sumitomo Corporation. In addition, Hambrecht & Quist has provided $3.5 million worth of financing to Alameda Instruments, a start-up operation located in Pleasanton, California.

TECHNOLOGY ADVANTAGES

In evaluating the technology, three advantages to acid reprocessing stand out. First, the systems consistently deliver a very pure acid at the point of use. It is reported that the acid produced can be guaranteed in the 100- to 200-ppb range, and typical counts run at one-half this level. This purity is difficult to match using current technology designed around bottled acids or bulk acid delivery systems.

The second advantage is that reprocessing systems reduce acid consumption by 90 percent or more. The average selling price of bottled sulfuric and HF acid is $7 to $10 per gallon; moreover, high-purity material costs $15 to $27 per gallon. The payback on an acid reprocessing system that costs $600,000 per unit and produces 100,000 gallons of acid a year is 12 to 24 months.

A third advantage of reprocessing systems is that they produce much smaller waste streams than other systems. This factor lowers the cost of disposal. The disposal cost for sulfuric acid is estimated to be $1.00 for each gallon of acid. The sulfuric waste stream is neutralized and put down the drain. HF disposal cost is estimated to be $1.95 per gallon of acid; fluoride is precipitated out and buried.

Although acid reprocessing systems are marketed as a solution to the environmental hurdles facing semiconductor manufacturers today, Dataquest believes that regulatory issues are not a factor in the purchase of this equipment. The disposal of sulfuric and HF acid is well defined. Both are innocuous after treatment, and there are only minor liability concerns associated with the treatment and disposal of these waste streams.

THE MARKET

Based on the technical advantages discussed above, Dataquest believes acid reprocessing equipment will fit two segments of the semiconductor manufacturing market. The first area is the leading-edge manufacturers that require high-purity process materials for submicron device fabrication. Their primary concern is yield, and they traditionally have viewed wet chemicals as a major source of particulate contamination. The second market segment is semiconductor manufacturers that are using large volumes of acids.

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DRAM manufacturers fit both of these profiles. Microcontamination control is a top priority because the DRAM companies are leading the rest of the industry in submicron device design. The need for controlling acid costs is further compounded by the increasing number of process steps that each new generation of memory technology requires (see Figure 1). The increase in process steps results in higher acid volumes.

Acid reprocessing will most certainly find applications outside of the two segments discussed above. Perhaps the other area that provides the most potential is in new facilities, where it is easier to financially justify the acid reprocessor and design it into the facility layout. Long-term, regulatory pressures may force semiconductor manufacturers to adopt acid reprocessing, but this is not a factor in the current market.

Dataquest's 1990 forecast of the potential market for acid reprocessing equipment is $208 million (see Figure 2). The forecast is based on new facilities beginning production in 1990; retrofits of existing fabs were not considered. Only new fabs producing devices with line geometries of less than 2 microns and having a capacity of 5,000 wafers per week or more were used as the basis for the forecast. Dataquest believes that this is a conservative forecast.

DATAQUEST CONCLUSIONS

Dataquest estimates that actual 1990 sales for acid reprocessing equipment will be in the $5 million to $10 million range. This level of capital spending when compared with the potential market reflects the fact that semiconductor manufacturers are still evaluating the technology. The goal for the equipment vendors over the next few years is to demonstrate that the systems are production worthy and safe.

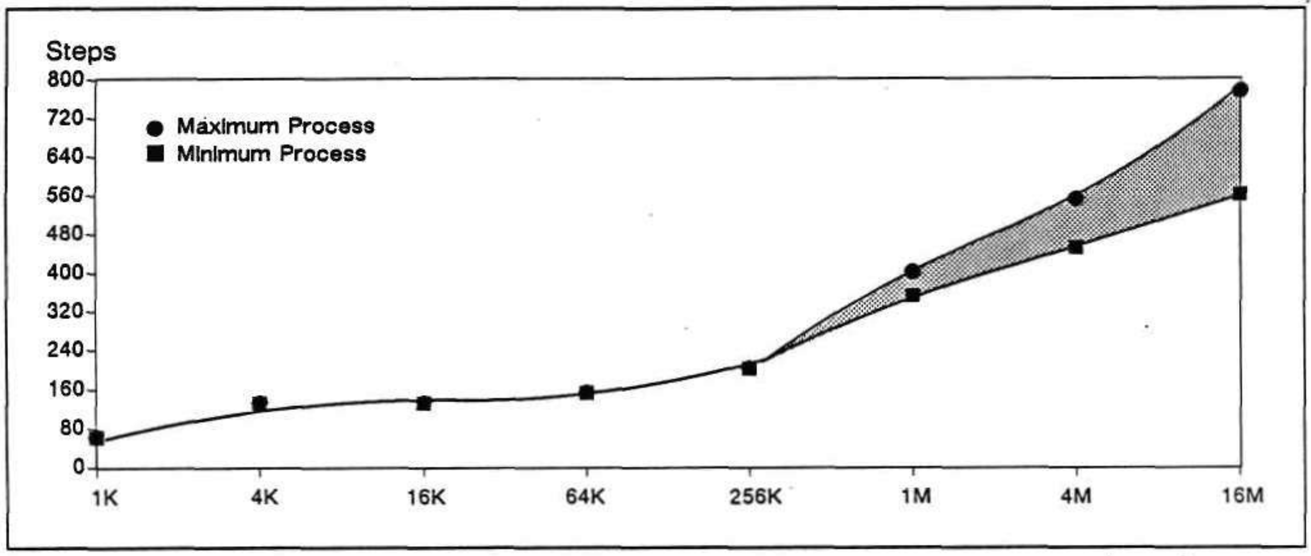
On a regional basis, Dataquest believes that Japan is the largest potential market for acid reprocessing equipment today. Japanese semiconductor manufacturers have focused on the wet processing area in terms of critical yield issues. As a result, they lead the world in the production of automated wet benches, bulk acid delivery systems, and high-purity acid. Reprocessing technology will complement their efforts in this area.

The first acid reprocessor systems have been sold by Sumitomo Corporation, which markets the systems for Athens Corporation. The systems are scheduled to be installed in the facilities of two of Japan's leading DRAM manufacturers this spring. If the technology proves itself, Dataquest believes that the Japanese semiconductor manufacturers will aggressively integrate acid reprocessing into their highly automated wet processing areas.

Reprocessing technology has the potential to revolutionize material management in the fab, and in the process, it could grow into a several-hundred-million-dollar-a-year business. The arguments favoring the technology are persuasive. Yet Dataquest believes the task at hand today is to convert the technology into production-worthy equipment.

Mark FitzGerald
Mark T. Reagan

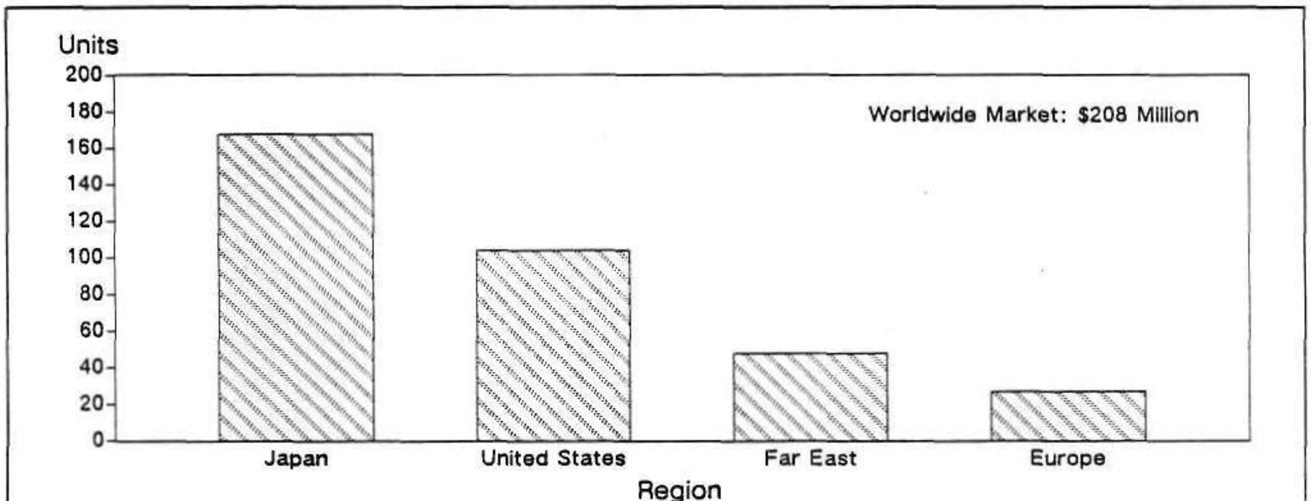
FIGURE 1
Number of Process Steps as a Function of DRAM Technology



0006420-1

Source: Dataquest
February 1990

FIGURE 2
Potential Sulfuric and HF Acid Reprocessor Market Based Only on New Fabs* in 1990



*New fabs with <2-micron geometries and >5,000 wafers per week

0006420-2

Source: Dataquest
February 1990

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Research *Bulletin*

Wet Processing Equipment Trends in Japan

Overview

Japan saw robust demand for wet processing equipment in 1989 due to the increasing number of cleaning processes required in submicron device fabrication. Device manufacturers in Japan continued to automate their wet processing areas using robotic shuttles to sequence wafer lots between work-in-process (WIP) holding stations and various cleaning stations. Japanese wet processing equipment companies appear to have a significant backlog of orders extending through the middle of 1990.

Dataquest believes that Japanese wafer fabrication plants use significantly more advanced and integrated wet processing stations than their counterparts in other regions of the world. Also, wet processing equipment tends to be custom-made in Japan to suit the individual automation needs of different semiconductor manufacturers. Hence, many wet processing equipment vendors do not exhibit all of their products at trade shows such as SEMICON/Japan because they want to protect customer-specific equipment configurations. This research bulletin highlights significant new trends in Japanese wet processing equipment.

A major new trend in Japanese wet processing technology is the emergence of double-sided wafer scrubbers offered by companies such as Dainippon Screen, Sankyo, and Shimada. Double-sided scrubbers are able to remove particles from both the front and back sides of wafers, thus improving focus latitude during photolithographic exposure. Prices for these scrubbers are in the ¥40 million to ¥50 million ($290,000 to $362,000) range.

Companies

Dainippon Screen

Dainippon Screen's WSW-625 wet station series continued to gain acceptance in Japan. ASPs of the WSW-525 family are approximately ¥40 million ($290,000) without robotic shuttle automation and approximately ¥80 million ($580,000) with robotic shuttle automation. The new RSW-612-A model is capable of removing fine particles from wafer surfaces using a water scrubbing technique in combination with a rotating brush.

Kaijo Denki

Kaijo Denki offers automated wet stations equipped with robotic shuttles for completely unmanned operation. The ASP of the system is approximately ¥100 million ($725,000).

Sankyo

This company derives a majority of its revenue from highly automated integrated wet stations. The company continues to market its double-sided scrubber, which was originally introduced in October 1988 and is priced at ¥45 million ($326,000).

Shimada

Shimada is active in the double-sided wafer scrubber market. Its SBJ series has been upgraded with extensive automation features. ASPs range between ¥40 million and ¥60 million ($290,000 to $435,000) depending on the configuration.

Sumitomo Corporation

Sumitomo is manufacturing and marketing sulfuric acid and hydrofluoric acid (HF) reprocessing equipment under a licensing agreement with

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Athens Corporation. Athens Corporation, based in Oceanside, California, focuses on acid reprocessing systems. Athens Corporation claims that its acid reprocessing techniques offer higher purity and lower particulate defect levels than bottled acid currently offered by worldwide wet chemical manufacturers. The ASP for the HF reprocessing system is ¥60 million ($435,000), and the ASP for the sulfuric acid reprocessing system is ¥70 million ($507,000).

Dataquest believes that Japanese manufacturers of submicron devices such as 4Mb and 16Mb DRAMs may use acid reprocessing systems to minimize particle defects added to the wafer during wet processes. We estimate that Sumitomo Corporation has already shipped two wet processing systems to leading Japanese DRAM manufacturers.

Tokyo Electron Limited (TEL)

TEL established a trading arrangement with Sugai in 1987. TEL markets Sugai's automated wet stations, which have prices ranging from ¥50 million to ¥100 million ($362,000 to $725,000) depending on the degree of automation. In addition, TEL also markets Semitool's model 2080S batch wet processing system with wet cleaning, resist strip, and etching capabilities.

DATAQUEST CONCLUSIONS

Dataquest believes that Japan leads the world in the implementation of fully automated, integrated wet processing stations. The move to more complex submicron processes for 4Mb and 16Mb DRAM devices in Japan has catalyzed the development of many new wet processing tools that offer progressive automation while simultaneously minimizing defects. Dataquest urges its clients to view wet processing technology as a crucial yield enhancement tool that rivals the more glamorous equipment technologies of lithography and thin-film equipment in importance.

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Deposition

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Research Newsletter

THE THERMAL CVD MARKET HEATS UP AS LAM RESEARCH UNVEILS ITS INTEGRITY SYSTEM

Lam Research unveiled its Integrity Series chemical vapor deposition (CVD) system at SEMICON/Japan in October 1990. Lam Research claims that the Integrity system delivers two revolutionary advances to the wafer fabrication industry: It is the first system to have adopted a process-oriented ground-up approach to reactor hardware design, and it is also the first example of multiprocess, single-chamber process equipment that integrates sequential processes such as borophosphosilicate glass (BPSG) deposition, flow, and anneal within the same chamber.

HIGHLIGHTS OF THE INTEGRITY SYSTEM

The heart of the Integrity system is a unique, isothermal batch reactor chamber that has been designed to ensure tight control over the reactant gas flow, temperature, gas concentrations, and process pressure. Lam Research claims that the resulting BPSG films, based on a tetraethylorthosilicate (TEOS) source process, can be flowed and stabilized in situ during deposition; this is in contrast to conventional BPSG processes, which use separate equipment for deposition and reflow. Lam claims that the batch architecture and in situ cleaning combined with the clean process (defect densities less than $0.1/cm^2$ for particles greater than 0.3 micron on 150mm wafers) enables throughputs of up to 48 wafers per hour (150mm process) or 36 wafers per hour (200mm process). Dataquest believes that semiconductor manufacturers will carefully assess the Integrity's effective cost of ownership based on its integrated deposition/flow process versus competitive standalone deposition/flow processes.

HOW WILL LAM RESEARCH POSITION THE INTEGRITY IN THE CVD MARKET?

We believe that the success of the Integrity system is crucial to the efforts of Lam Research to position itself as a global thin-film solutions company. The system will enable Lam to target the high-growth CVD film equipment market, which is projected to grow at a compound annual growth rate (CAGR) of 18.8 percent, from $550 million in 1990 to $1.3 billion by 1995. Lam Research is already a leading player in the dry etch equipment market, which is expected to grow at a healthy CAGR of 18.5 percent from $600 million in 1990 to $1.4 billion by 1995. The company is effectively doubling the size of its total available market (TAM) by entering the CVD market. Lam often has stated its goal of becoming a $500 million company in the next few years. The Rainbow dry etch product family, together with the new Integrity CVD product family, positions Lam Research well in aiming for such an ambitious goal.

Short-Term and Long-Term Integrity Market Focus

In the short term, Lam Research hopes to get a slice of the thermal CVD oxide market, which includes undoped glass and doped glass such as BPSG. The thermal CVD oxide film equipment market accounted for approximately $110 million (20 percent) of the anticipated $550 million 1990 CVD market. In the long term, Dataquest predicts that Lam Research will diversify its Integrity applications to target the fast-growing metal CVD and polysilicon/silicon deposition markets. We believe that Lam also will target other high-integrity thermal CVD films such as thermal LPCVD nitride, tantalum oxide DRAM capacitor dielectrics, and LPCVD titanium nitride barrier films.

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DATAQUEST'S THERMAL CVD AND PLASMA CVD EQUIPMENT FORECAST

Lam's Integrity system essentially targets the thermal CVD film market. Figure 1 shows our forecast for the growth of the thermal CVD equipment market between 1990 and 1995. Dataquest defines thermal CVD as including thermal films such as APCVD/LPCVD oxide films (e.g., undoped oxide, PSG, and BPSG), thermal LPCVD silicon nitride films, LPCVD polysilicon, LPCVD tungsten, and titanium nitride. Plasma-enhanced CVD (PECVD) films include low-temperature doped/undoped plasma-enhanced oxide and silicon nitride CVD films. We estimate that thermal CVD film applications accounted for $292 million (53 percent) of the $550 million 1990 CVD equipment market, while plasma CVD films accounted for the remaining $258 million (47 percent).

Thermal CVD Equipment Market Will Grow Rapidly

By 1995, Dataquest projects that thermal CVD films will grow rapidly and account for $755 million (58 percent) of the $1.3 billion total CVD market; plasma CVD films will account for the remaining $545 million (42 percent). The thermal CVD film market comprises a broader range of dielectric, polysilicon, and metal films compared with the more specialized PECVD market, which currently offers only plasma oxide and plasma nitride dielectric solutions. The thermal CVD market CAGR of 20.9 percent between 1990 and 1995 substantially outpaces the PECVD market CAGR of 16.2 percent.

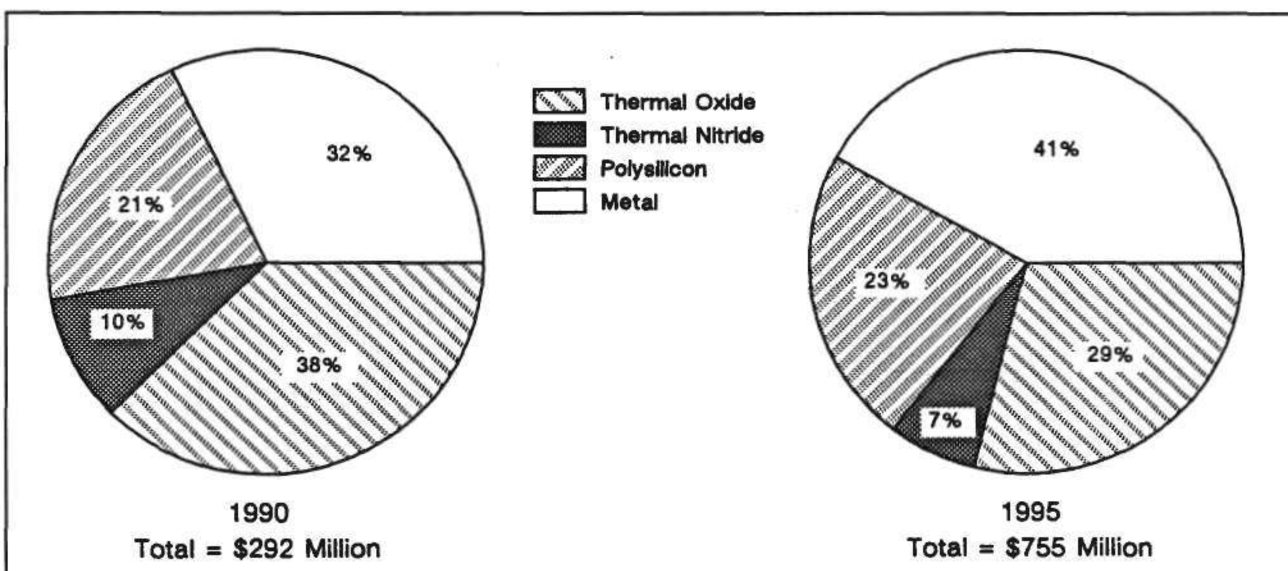
The Highest Growth Segments of Thermal CVD: Polysilicon and Metal CVD

The polysilicon and metal CVD markets will be the fastest-growing segments of the CVD equipment market during the next five years. Traditionally, polysilicon CVD has been implemented in relatively low-cost tube CVD reactors. However, Dataquest believes that there is an emerging need for critical high-quality polysilicon in submicron process applications. Such critical polysilicon films may be better implemented in specialized nontube reactors that offer low defects and high-quality films. Polysilicon or selective silicon deposited in reactor modules, as opposed to traditional tubes, has the advantage of process integration with related processes such as rapid thermal processor (RTP) thin-gate dielectrics and tungsten/tungsten silicide gate CVD.

How Will the Integrity System Target the Polysilicon and Metal CVD Market?

Lam's Integrity system may target critical future needs for high-quality polysilicon/selective silicon in applications such as submicron gate

FIGURE 1
Worldwide Thermal CVD Market by Film (Millions of Dollars)



Source: Dataquest (December 1990)

polycides, stacked DRAM capacitors, poly plugs, and selective silicon deposition for active device fabrication. The combined polysilicon silicon/selective silicon deposition market will almost treble in size, from $60 million in 1990 to $170 million by 1995. The Integrity reactor could also lend itself to more esoteric applications such as tantalum oxide capacitor dielectrics for high-capacitance, small-area 64Mb/256Mb DRAM memory cells. In the longer term, Dataquest believes that Lam Research may focus on the metal CVD market for tungsten, aluminum, and copper interconnect films. Lam may modify the Integrity system architecture in the future in order to address the uniquely different requirements of the metal CVD market for applications such as tungsten, aluminum, titanium nitride, and copper.

LAM RESEARCH'S EVOLUTIONARY PROCESS INTEGRATION STRATEGY

Lam Research always has pursued an evolutionary process/equipment upgrade and integration strategy. For example, the Rainbow Series dry etch system represents an evolutionary next-generation system to Lam's earlier successful AutoEtch dry etch systems. Lam Research claims that it can continue to develop enhancements to the Rainbow's plasma source, reactor chamber, wafer handling, and other subsystems in order to make it compatible with the requirements of the 0.35-micron 64Mb DRAM generation.

Lam has leveraged off its successful Rainbow system architecture by incorporating key wafer-handling subsystems and control module/software from the Rainbow system into the new Integrity system. Such an evolutionary approach minimizes new product development risk by focusing resources on the core reactor development using field-proven wafer-handling platforms, control software, and subsystems. Dataquest predicts that Lam Research will carry its evolutionary development strategy to its logical conclusion by integrating the Integrity CVD platform with the Rainbow dry etch platform for future process-integration applications.

INTENSE COMPETITION IN THE THERMAL CVD EQUIPMENT MARKET

The immediate application for the Integrity system is the BPSG film market, which is a highly mature market, with numerous competitors offering different technology solutions.

Competition in the APCVD/BPSG Market Segment

In the APCVD/BPSG segment, Lam Research will encounter competition from entrenched competitors such as Amaya, Applied Materials, Canon, Hitachi, Toshiba Machine, and Watkins Johnson. Lam will compete with these companies in offering TEOS/Ozone-based BPSG films, which offer better conformality and film characteristics than do traditional silane-based BPSG films. Dataquest believes that Lam will position its Integrity platform as a cost-effective, integrated reflow glass solution compared with the traditional approach of sequential deposition and reflow in multiple, standalone equipment.

Competition in the LPCVD/BPSG Market Segment

In the LPCVD/BPSG segment, Lam Research will compete with the vertical tube reactor (VTR) companies such as ASM International, BTU International, Kokusai Electric, SVG, and TEL. The VTR companies are approaching the BPSG film market from the furnace viewpoint by pursuing special tube designs to accommodate TEOS-source oxides. VTR processes are becoming popular for thin-gate oxides, polysilicon, and thermal nitride applications. VTR companies are feverishly expanding their process portfolios in order to get a slice of the large thermal oxide market. VTR companies also will attempt to offer an integrated BPSG reflow solution by offering two-step deposition/reflow in situ processes within the same tube.

Competition in the PECVD/BPSG Market Segment

In the PECVD/BPSG segment, Lam will compete with companies such as Applied Materials, Electrotech, and Novellus. PECVD reactor companies already offer low-temperature, plasm-enhanced TEOS oxide processes for application as interlayer dielectrics. Such companies now are exploring thermal CVD processes using TEOS/Ozone chemistry at high pressures (close to atmosphere) without plasma enhancement. PECVD reactor companies are actively developing cluster-tool-based integrated process solutions based on multichamber equipment architecture. Dataquest predicts that Applied Materials will introduce an integrated thermal BPSG TEOS/Ozone reflow process on its PE5000 mainframe using an RTP module for reflow. Novellus also is likely to form an RTP alliance and develop a thermal CVD reactor module to interface with its rumored 1991 Concept-Two cluster-tool platform introduction.

Competition in the Polysilicon, Nitride, and Metal CVD Market Segment

In other nonoxide CVD film applications such as polysilicon, nitride, and metal films, Lam Research will encounter competition from the same group of CVD market competitors. VTR tube companies are continually improving the quality of their thermal nitride and polysilicon films. Hence, VTR companies are a viable alternative for submicron polysilicon and thermal nitride applications. Dataquest believes that PECVD companies such as Applied Materials and Novellus will offer thermal CVD-based polysilicon/silicon deposition modules that will interface with their cluster-tool platforms for critical integrated processes. Because of the integrated nature of polysilicon and tungsten CVD applications, we believe that tungsten CVD market players also will eventually enter the polysilicon/silicon deposition market.

LAM'S PROCESS DEVELOPMENT STRATEGY WITH KEY DEVICE COMPANIES

Dataquest believes that Lam Research has worked closely with Texas Instruments, its strategic U.S. partner, for the Integrity system's application in 4Mb/16Mb DRAM processes. In the strategic Japanese CVD equipment market, which is the largest regional market, Lam will have to rely heavily on its strategic partner, Sumitomo Metals, in order to be designed into next-generation 4Mb shrink/16Mb DRAM processes. Sumitomo Metals has invested heavily in applications and customer support facilities in major semiconductor production regions in Japan. Sumitomo Metals' industry network and its deep pockets should greatly benefit Lam's penetration of the Japanese thin-film deposition/etch market.

Lam Research needs to gain field process experience quickly through multiple joint process-development programs with globalized device manufacturers. The company's Integrity high-temperature CVD film solutions are very synergistic with its ECR CVD low-temperature intermetal dielectric solution. Lam Research exclusively markets and supports Sumitomo Metals' ECR deposition/etch systems in the United States and Europe. Lam currently is developing new ECR CVD technology as part of a joint development program contract with Sematech.

If the Sematech ECR CVD development contract and the Integrity CVD platform succeed as cost-effective process solutions, Lam Research could emerge as an integrated, global thin-film company with a broad range of CVD and dry etch process capabilities. Lam also has announced that it will ship an Integrity system to the MCNC research consortium in North Carolina. Such cooperative development projects will allow Lam Research an early design-in window into a diverse group of device development efforts.

DATAQUEST CONCLUSIONS

Competition is heating up in the dynamic thermal CVD market, which will grow at an explosive 20.9 percent CAGR from $292 million in 1990 to $755 million by 1995. Lam Research's new Integrity CVD platform represents Lam's stake in the ground in the burgeoning CVD market. Although the Integrity is immediately targeted at BPSG flow dielectric applications, Dataquest believes that Lam Research will expeditiously offer other thermal CVD solutions aimed at the polysilicon/silicon, silicon nitride, and metal CVD markets. Lam claims to have spent almost $20 million over about four years in order to develop the Integrity platform. This amount illustrates the escalating cost of new product development in the equipment industry.

The Integrity CVD system is in the vanguard of the growing trend among thin-film equipment companies to develop versatile hardware platforms in order to spread development costs, exposure to competition, and market risks over a number of related process segments. Lam Research's global development strategy with key global device customers and research consortia is aimed at quickly proliferating the process capabilities of the Integrity system. The Integrity CVD product is a good example of global joint development between vendors and users in order to achieve next-generation technology requirements.

Krishna Shankar

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Research *Newsletter*

COMPETITION HEATS UP AS NOVELLUS ENTERS THE TUNGSTEN CVD MARKET

SUMMARY

Competition is intensifying in the tungsten chemical vapor deposition (CVD) equipment market. Novellus Systems, which recently announced its Concept One-W system, joins a growing list of equipment companies that offer blanket tungsten interconnect solutions for ultralarge-scale integrated (ULSI) interconnect and contact-plug applications. Many semiconductor manufacturers view tungsten CVD as one of the enabling technologies for sub-0.5-micron devices such as the 16Mb/64Mb DRAM generations. The typical device aspect ratio, which is defined as the depth-to-width ratio of the device feature, continues to increase dramatically with successive semiconductor generations. It is increasingly more difficult for conventional sputtered aluminum films to conformally coat the sidewalls of submicron contacts that have progressively increasing aspect ratios. Dataquest believes that physical vapor deposition (PVD) techniques such as barrier metal/aluminum sputtering processes will be augmented with tungsten CVD techniques in the 1990s in order to meet submicron interconnect reliability and performance requirements.

The tungsten CVD equipment market is expected to almost triple in size between 1990 and 1994. Dataquest predicts that the tungsten CVD market, which includes silicides, blanket tungsten, and selective tungsten, will have a healthy compound annual growth rate (CAGR) of 30 percent, from $90 million in 1990 to $260 million by 1994. Many equipment companies are rushing their tungsten CVD systems to market, hoping to capturing a slice of this lucrative pie. The systems offer a wide range of reactor architectures and process recipes. All the competitors are, predictably, claiming that their system offers the most cost-effective manufacturing solution. Dataquest believes that semiconductor manufacturers will ultimately rank the competing systems with regard to their own development time schedules, process flow, device applications, and cost structure. In the final analysis, standalone equipment productivity indicators pale in comparison with the acid test of complete process integration in order to achieve the lowest cost per yielding chip. Dataquest believes that semiconductor manufacturers will identify the tungsten market leaders in the 1991 to 1992 time frame, commensurate with the preparation for pilot-line production of the 16Mb DRAM generation.

THE HIGH-GROWTH TUNGSTEN CVD EQUIPMENT MARKET

Figure 1 shows our forecast for the worldwide tungsten CVD equipment market between 1990 and 1994. Dataquest divides the tungsten CVD market into three process segments: tungsten silicide, blanket tungsten, and selective tungsten.

Tungsten Silicide: The Relatively Mature Segment

Tungsten silicide CVD films were the earliest tungsten-based CVD films used in production. These films were used as an overcoat on doped polysilicon films in order to improve the gate speeds of devices with design rules below 1.6 microns, such as the 256K/1Mb DRAM generations. Many semiconductor manufacturers may continue to use tungsten silicide films in 4Mb/16Mb DRAM gate applications. However, titanium silicide, which has a lower resistance than tungsten silicide, is emerging as the gate-silicide film of choice for high-speed submicron

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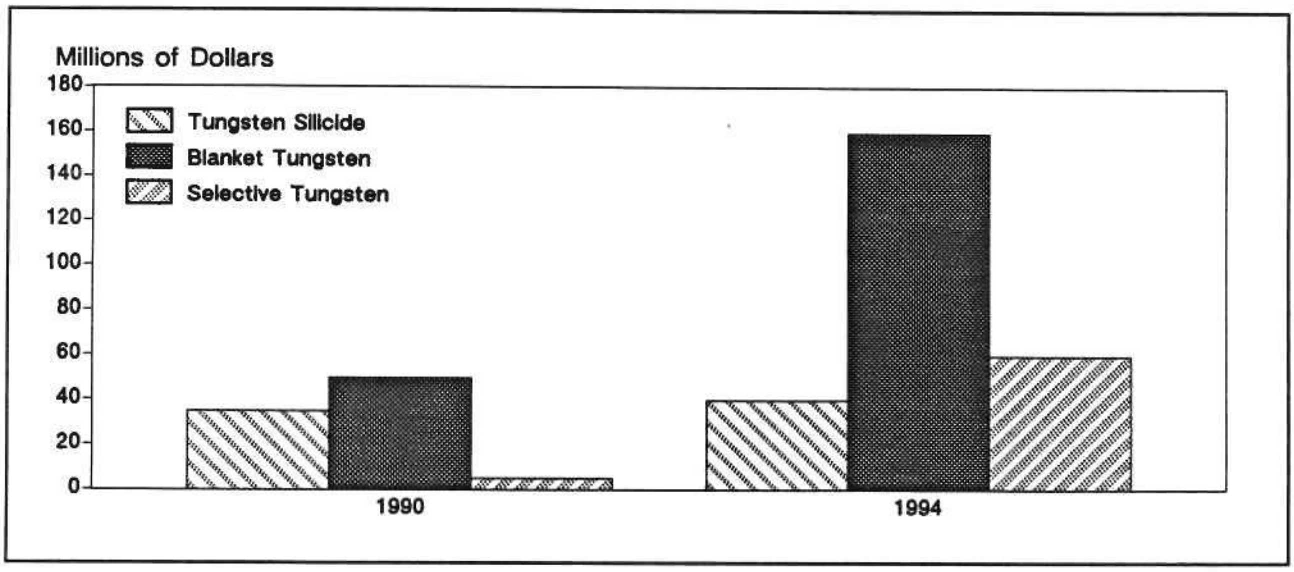
FIGURE 1
Worldwide Growth of the Tungsten CVD Market (Millions of Dollars)



Source: Dataquest (October 1990)

applications. Dataquest expects the silicide market segment to exhibit relatively flat growth between 1990 and 1994 compared with the blanket tungsten market segment.

Blanket Tungsten: The Largest Segment

The blanket tungsten CVD film segment will continue to be the largest tungsten CVD market between 1990 and 1994. Dataquest forecasts this segment to have a healthy CAGR of 34 percent, from $50 million in 1990 to $160 million by 1994. Blanket tungsten CVD will find applications on multiple fronts such as contact/via plug fills, metal interconnects, and gate conductor applications. Dataquest believes that many 16Mb/64Mb DRAM manufacturers may use blanket tungsten CVD extensively in numerous applications. The availability of integrated deposition and etchback technology for plug applications will hasten the acceptance of blanket tungsten technology.

Selective Tungsten: The Wild Card Segment

The selective tungsten CVD market is associated with high risks and high rewards. In principle, the technology offers a very elegant solution—only exposed silicon, polysilicon, and metal areas act as nucleation sites for selectively depositing the tungsten plugs. Theoretically, the surrounding oxide field areas do not receive any tungsten deposition, thus eliminating the need for the plug etchback step. Through most of the 1980s, equipment companies and semiconductor companies attempted to develop production-worthy selective tungsten processes. However, the process was plagued with technical problems and narrow windows of operation. US equipment companies such as Applied Materials, Genus, and Novellus switched gears in the late 1980s and focused instead on the blanket tungsten market. Japan-based companies such as Anelva and Ulvac and European companies such as Spectrum CVD/Balzers are continuing their selective tungsten efforts.

Dataquest believes that the viability of the selective tungsten CVD market depends on the availability of effective pre-clean/wafer surface conditioning processes that can be integrated with the tungsten CVD process in a vacuum environment. Such wafer-surface conditioning techniques include low-damage plasma cleaning, sputter etching, and organic solvent/HF-based vapor phase clean. Dataquest predicts that the selective tungsten process will be implemented first in easier applications such as vias between metal levels and later in more difficult applications such as contacts to doped silicon junctions and polycide gates. The wild card in the future selective tungsten CVD market is that with enough persistence, researchers may yet find a stable operational window for selective tungsten CVD using integrated wafer-surface conditioning/deposition equipment architectures. Dataquest predicts that the selective tungsten CVD equipment market may grow explosively from $5 million in 1990 to $60 million by 1994.

HOW DOES THE COMPETITION STACK UP?

Anelva: The Japan-Based Thin Films Market Leader

Anelva worked on selective tungsten CVD processes throughout the 1980s. Selective tungsten CVD technology still has to overcome some technical barriers before being implemented in production. Dataquest believes that Anelva may have shifted its focus to blanket tungsten CVD process development and integration with its Series 1551/1051 cluster tools for CVD, PVD, and dry etch applications. Among Japan-based thin films equipment companies, Anelva has great potential to offer an integrated interconnect solution using cluster tool architecture. Anelva's close relationship with NEC, the largest semiconductor company in the world, will be useful in timely, joint development of advanced process technologies.

Applied Materials: The Formidable Global Competitor

Applied Materials, with its PE5000 cluster-tool based tungsten CVD/etchback system, represents a formidable challenge to Genus, the current market leader. Applied claims that its tungsten CVD system revenue will exceed $25 million by the end of 1990, thus representing 28 percent of the 1990 worldwide $90 million tungsten CVD market. Applied was the first company to offer an integrated deposition/etchback capability for tungsten plugs. Dataquest believes that Applied's marketing strategy for its PE5000 WCVD system will focus on the system's modularity, integration capability, and compatibility with its Endura 5500 PVD system. Sematech's Equipment Improvement Program (EIP) involving both Applied Materials and National Semiconductor will provide valuable feedback to Applied on its system's performance.

Dataquest predicts that Applied may introduce integrated PVD/CVD/dry etch capabilities on its Endura 5500 system in 1991. Such an integrated process would allow the Endura 5500 system to perform the complete interconnect process in situ: titanium/titanium nitride PVD adhesion layer, blanket tungsten CVD, plug formation through RIE etchback, and finally, aluminum interconnect PVD. After such an integrated process sequence, the wafer can directly proceed to the lithography area for the interconnect patterning step.

Genus: The Current Market Leader

Genus essentially pioneered the tungsten CVD market in the early 1980s. Its batch 8400/8700 Series systems were the first production systems available in the market for silicide/blanket tungsten applications. Dataquest estimates that Genus owned more than 80 percent of the $75 million worldwide tungsten CVD equipment market in 1989. Genus will benefit significantly from the experience of Sematech and its member companies with the Sematech equipment improvement program for the 8720. Dataquest believes that IBM has used the Genus 8720 system, in combination with Plasma-Therm's dry etch modules, in an integrated cluster tool configuration for its 16Mb DRAM via plug application.

Genus recently announced that it will launch its new Series 6000 deposition/etchback tungsten cluster tool in mid-October. The Series 6000 system will use the Genus 8720 batch CVD chamber together with Plasma-Therm's dry etch module in an integrated hardware configuration. Dataquest believes that the success of the Series 6000 is crucial to Genus' strategy for penetrating the integrated process applications market. In many ways, the Series 6000 represents Genus' biggest challenge for the early 1990s as it attempts to leverage off its tungsten CVD experience of the 1980s. In the future, Dataquest believes that Genus may focus on strategic MESC-based cluster tool equipment partnerships and joint development with key global customers in order to offer integrated PVD/CVD/dry etch solutions in the 1990s.

Novellus: The New Challenger

Novellus, which recently introduced its Concept One-W blanket tungsten CVD system, is the new challenger in the metal CVD market. Novellus will attempt to leverage off its highly successful Concept One dielectric CVD equipment architecture by extending it to the new Concept One-W system.

Dataquest believes that Novellus has consciously adopted a "not-first-to-market" market strategy in order to learn from the semiconductor industry's production tungsten CVD experience. There is always a delicate balance between the high risks and initial profits associated with being first-to-market versus the lower risks and longer-term profits associated with entering the market later. Novellus is striving to achieve optimum market entry timing with its new Concept One-W introduction.

The Concept One-W system utilizes the same sequential batch architecture used in the original Concept One system. Novellus claims that its Concept One-W architecture offers high-quality, cost-effective, production-worthy blanket tungsten CVD films. Dataquest believes that Novellus will benefit favorably from the original Concept One's market success and cumulative field experience. Novellus has to climb the tungsten CVD production learning curve quickly, using strategic partnerships with key customers in order to meet advanced device design-in time windows. Dataquest believes that Novellus also will introduce its MESC-compatible cluster tool platform in 1991. Novellus probably will port its Concept One family to its cluster tool platform. Dataquest speculates that Novellus also may be actively pursuing strategic PVD and dry etch partnerships with other synergistic global equipment companies in order to quickly offer best-of-breed integration solutions to its customers.

Spectrum CVD/Balzers: The European Selective Tungsten Competitor

Motorola New Enterprises has recently divested its interest in Spectrum CVD to Balzers, which is a major European thin films company. Balzers recently introduced its Clusterline CLC 9000 family of cluster tools for PVD applications. Balzers will focus on quickly integrating Spectrum CVD's Vision selective tungsten process into its cluster tool architecture. Dataquest believes that Balzers' strategy will focus on positioning itself as an integrated European solution for deposition applications involving sputtered and CVD conductor films. Balzers will also use Spectrum CVD's facilities in Phoenix, Arizona, as a launching pad to penetrate the US equipment market.

Ulvac: The Japan-Based Selective Tungsten Leader

Ulvac is in the vanguard of companies pursuing selective tungsten CVD technology. Many semiconductor manufacturers are using its ERA-1000 Series system to characterize their selective tungsten processes in a research and development environment. Dataquest believes that Ulvac is striving to identify a robust window of operation for its process. Ulvac may be developing more effective integrated wafer-surface conditioning techniques in order to preserve the selectivity of the tungsten CVD process. Dataquest believes that Ulvac also may hedge its bets in the near term by offering blanket tungsten CVD as an interim solution on its ERA-1000 system. Ulvac's joint venture in the United States and Europe, BTU/Ulvac, should enable it to tap into global semiconductor manufacturing production experience.

Varian Exits the Tungsten CVD Reactor Market

Varian has decided to exit the standalone tungsten CVD reactor market. The company will sell its tungsten CVD technology. However, Varian has stated that it will continue to offer tungsten CVD as a process module on its flagship M2000 PVD cluster tool. Varian has consistently maintained its US PVD market leadership position in the 1980s through its 3000 Series and M2000 cluster tool products. Dataquest believes that Varian may partner with the buyer of its tungsten CVD technology in order to offer PVD/CVD/dry etch integration products to the market.

Watkins Johnson: The APCVD Blanket Tungsten Lone Ranger

Watkins Johnson recently announced its atmospheric pressure CVD (APCVD) process for blanket tungsten deposition. All the other tungsten CVD equipment companies have elected to use low-pressure CVD technology. Watkins Johnson has elected to retain its highly successful belt furnace reactor architecture for the blanket tungsten application. Dataquest believes that Watkins Johnson's track record as the APCVD/BPSG dielectric market leader will prompt semiconductor manufacturers to evaluate its unique blanket tungsten CVD approach carefully with regard to its production capabilities.

DATAQUEST CONCLUSIONS

Competition is heating up in the tungsten CVD market. US-based equipment companies such as Applied Materials, Genus, Novellus, and Watkins Johnson are actively involved in the race for blanket tungsten market leadership. Japan-based companies such as Anelva and Ulvac, together with Europe-based companies such as Spectrum CVD/ Balzers, have focused their long-term efforts on the high-risk/high-reward selective tungsten technology. Japanese and European companies also may develop competitive blanket tungsten CVD/ etchback systems in order to cater to the more immediate contact/via plug application market.

Semiconductor manufacturers ultimately will decide the winners and losers in the tungsten CVD market based on comparisons of their net cost per good chip processed on different tungsten CVD systems. Comparisons of nominal vendor specifications such as batch versus single-wafer architecture, gross throughput, integrated versus standalone plug etchback, backside tungsten removal procedure, gas utilization efficiencies, film conformality, automation, defects, etc., are important preliminary benchmarks for the semiconductor manufacturer. But these parameters merely represent one part of the semiconductor factory's production equation. The choice of the appropriate tungsten CVD system ultimately depends on the manufacturer's development time schedule, device application, design rule, process flow integration, and manufacturing expertise. Equipment companies that can jointly develop technology with their strategic semiconductor customers will have the advantage of being designed early into their customer's process on a global basis.

The tungsten CVD market may ultimately blend with the barrier metal/aluminum PVD market for sequential applications such as PVD titanium/ CVD or PVD titanium nitride/CVD tungsten plugs with etchback/PVD aluminum interconnect films. Dataquest predicts that companies offering refractory barrier/aluminum PVD, tungsten CVD, and dry etch integration solutions on a global basis will gain market share in the thin films deposition/etch markets. Such integrated process solutions may be offered globally by one-stop shop "super" equipment companies or by strategic best-of-breed vendor partnerships. Dataquest believes that the timely evolution of worldwide SEMI/MESC standards will accelerate the trend toward vendor partnerships in the CVD, PVD, and dry etch markets using standard wafer handling platforms and proprietary process modules.

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Research Newsletter

US COMPANIES DOMINATE THE CVD EQUIPMENT MARKET

SUMMARY

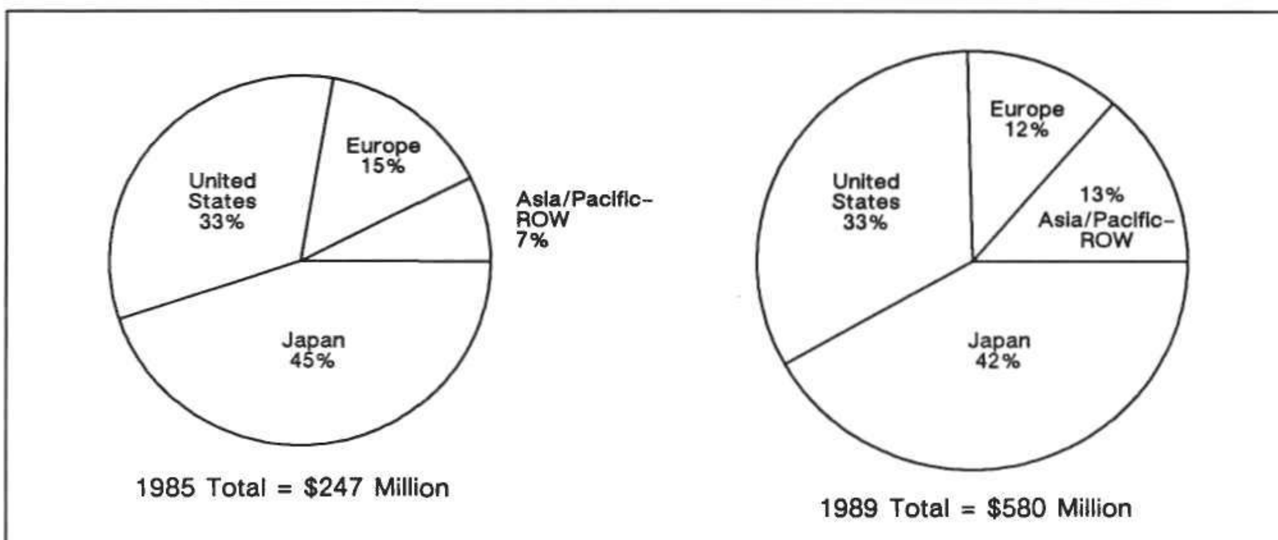
CVD equipment continues to be one of the key technology drivers in the push toward submicron processes. High-quality thin-film technology is a crucial element of cost-effective submicron manufacturing. The CVD equipment market has grown at a CAGR of 24 percent from $247 million in 1985 to $580 million in 1989. The CVD equipment market growth has outpaced the overall wafer fabrication equipment market, which has grown at a lower CAGR of 15 percent from $3.4 billion in 1985 to $5.9 billion in 1989. Such high growth of the CVD equipment market underscores the importance of thin-film technology in the submicron era.

US companies captured a dominant share (64 percent) of the CVD equipment market in 1989 even though their biggest market is in Japan, which constitutes 42 percent of the worldwide CVD equipment market. US companies dominated the market due to their lead in the development of dedicated (nontube) CVD reactors for advanced device applications. The high-growth, nontube reactor market segment has grown at a CAGR of 39 percent compared with 8 percent for the tube CVD market between 1985 and 1989. Dataquest believes that Japanese and European companies may challenge US companies' CVD market dominance by offering competitive nontube reactor products in the near future.

JAPAN IS THE WORLD'S LARGEST CVD EQUIPMENT MARKET

Figure 1 displays the evolution of the regional CVD markets between 1985 and 1989. Japan, with

FIGURE 1
Regional CVD Equipment Market
(Millions of Dollars)



Source: Dataquest (August 1990)

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42 percent of the 1989 market, is the world's largest CVD equipment market. This is in line with the stature of Japan as the world's largest semiconductor production, consumption, and wafer fabrication equipment market. Large-volume devices such as the 4Mb/16Mb DRAM generations and submicron 200K/500K gate-array products will ensure Japan's key role in defining CVD requirements for the 1990s.

The US CVD market has maintained its 33 percent share of the world CVD market between 1985 and 1989. The US has traditionally been the leading producer of high-performance microprocessors, microcontrollers, and VLSI logic. All these product families are random logic devices, which rely heavily on advanced CVD films for multilevel interconnect technology. Dataquest expects the US market to continue dictating advanced CVD requirements for high-volume microprocessor and ULSI-level system-on-a-chip architectures.

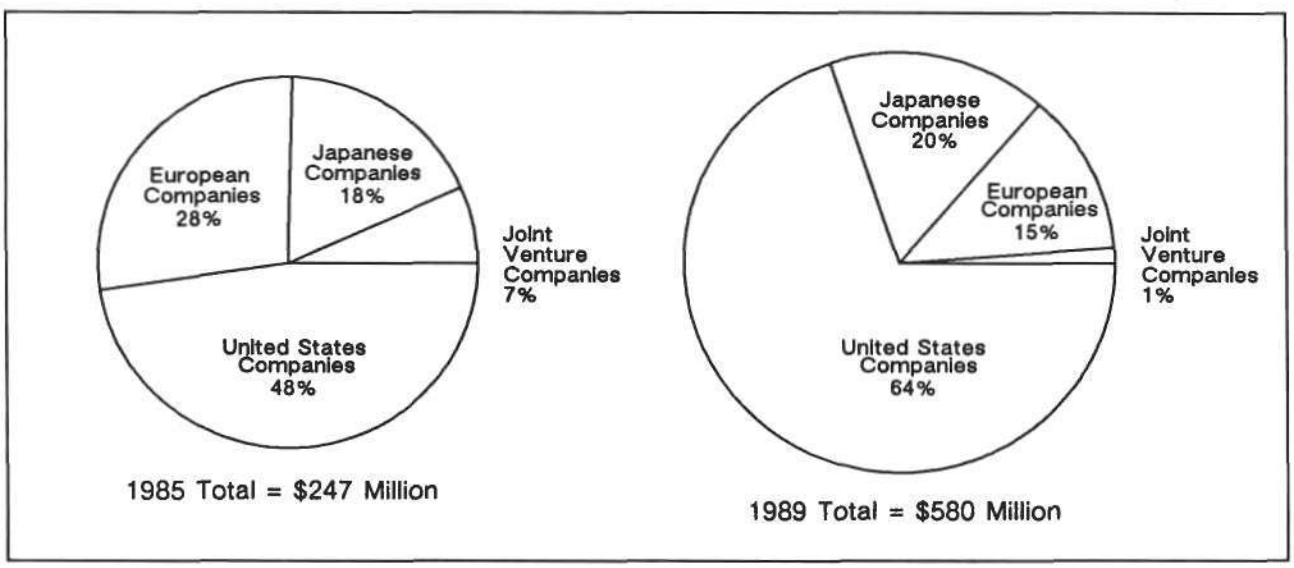
The Asia/Pacific region's share of the world CVD market has grown dramatically from 7 percent in 1985 to 13 percent in 1989. South Korea's meteoric production ramp up of advanced 1Mb/4Mb DRAM chips, together with the more recent Taiwanese production ramp up of DRAMs, PC chip sets, and ASICs, have stimulated the growth of the Asia/Pacific CVD equipment market. The Asia/Pacific CVD market has surpassed the European CVD market for the first time in 1989.

The European region's share of the world CVD market has shrunk from 15 percent in 1985 to 12 percent in 1989. However, Dataquest believes that the European CVD market is poised for robust growth in the 1990s as global semiconductor companies race to set up fabs in Europe that comply with the 1992 doctrine of domestically diffused chips. The JESSI R&D initiative, together with the DRAM market penetration strategies of companies such as Siemens and SGS-Thompson, is bound to create a demanding European CVD market with a heavy emphasis on advanced, multilevel interconnect technology.

WHY DO US COMPANIES DOMINATE THE CVD MARKET?

Figure 2 shows the trends in world CVD equipment market ownership between 1985 and 1989. The CVD equipment market is one of the few areas in which US companies have actually increased their market share between 1985 and 1989. From 48 percent of the $247 million 1985 CVD market, US companies have increased their market share to 64 percent of the $580 million 1989 CVD market. US companies' pioneering efforts in developing the dedicated (nontube) LPCVD and PECVD reactor market for submicron applications have enabled them to assume a commanding position of market leadership. US companies have led in the development of nontube CVD reactors for interlayer oxide dielectrics and tungsten-based conductor films for submicron applications.

FIGURE 2
World CVD Equipment Market Ownership
(Millions of Dollars)



Source: Dataquest (August 1990)

Japanese companies gained a few market share points between 1985 and 1989. Dataquest attributes most of the Japanese companies' 1989 20 percent market share to the vertical and horizontal tube LPCVD arena. Japan's focus on low-cost/high-volume DRAM and gate array markets has led to a heavy emphasis on automated, large batch tubes for film applications such as polysilicon, thermal nitride, and low-temperature oxides (LTO).

European companies lost significant market share between 1985 and 1989. European companies' market share has declined from 28 percent of the $247 million 1985 market to 15 percent of the $580 million 1989 market. ASM International, a company based in the Netherlands, accounted for 82 percent of the $85 million 1989 European company-owned CVD market. ASM's major CVD products are in the horizontal LPCVD/PECVD and vertical LPCVD market segments. The tube CVD market growth has been outpaced by the nontube CVD market. European companies such as ASM International and Electrotech have recently introduced cluster tool-based dedicated PECVD reactors in an attempt to tap into the fast-growing nontube CVD segment.

WORLDWIDE 1989 CVD EQUIPMENT COMPANY RANKINGS

Table 1 ranks the major worldwide players by their 1989 revenue in the CVD marketplace. Four of the top five spots and five of the top ten spots are occupied by US companies. Two European companies and three Japanese companies are included in the top ten CVD company rankings. It is apparent that US companies have thus far dominated the CVD market.

Applied Materials is, by far, the largest CVD equipment company with 1989 CVD revenue of $158 million, representing 27 percent of the total market. Applied's CVD revenue was more than twice that of ASM International, the second-ranked CVD company. Applied's mainstream PE5000 CVD system revenue almost doubled between 1988 and 1989. Dataquest attributes the success of the PE5000 system to its process versatility, cluster tool architecture, worldwide customer support, and compatibility with Applied's complementary dry etch and PVD systems.

ASM International, the second-ranked CVD company, captured 11.9 percent of the market,

TABLE 1
1989 Worldwide CVD Equipment Company Rankings
(Revenue in Millions of Dollars)

Company	Revenue	Market Share	Market Segment
Applied Materials (United States)	158.0	27.2%	Nontube APCVD, nontube PECVD
ASM International (Europe)	69.0	11.9	Tube LPCVD, tube PECVD
Genus (United States)	62.0	10.7	Nontube LPCVD
Watkins-Johnson (United States)	49.0	8.4	Nontube APCVD
Novellus (United States)	47.0	8.1	Nontube PECVD
Kokusai Electric (Japan)	34.7	6.0	Tube LPCVD
Tokyo Electron (Japan)	20.7	3.6	Tube LPCVD
Amaya (Japan)	19.0	3.3	Nontube APCVD
BTU International (United States)	17.5	3.0	Tube LPCVD
Electrotech (Europe)	15.5	2.7	Nontube PECVD
Silicon Valley Group (United States)	14.0	2.4	Tube LPCVD, nontube LPCVD
Others	73.8	12.7	
Worldwide Market Total	580.2	100.0%	

Note: Countries within parentheses denote company regional ownership. Calendar year 1989 prime systems revenue; spares and service not included.
Source: Dataquest (August 1990)

mainly due to the success of its industry standard tube PECVD systems for low-temperature intermetal and passivation dielectric applications. ASM's systems were especially popular in the Japan-Asia/Pacific region for 1Mb/4Mb DRAM applications. ASM's global presence has enabled it to stay close to leading production trends in the all-important Japan-Asia/Pacific market.

Genus, through its pioneering efforts in the tungsten CVD market, captured the third spot CVD ranking. The company virtually owned the blanket tungsten and tungsten silicide CVD market in 1989. Genus is a classic example of a company creating its own market through new film development. Competition is, however, heating up in the tungsten CVD market as companies such as Anelva, Applied Materials, Spectrum CVD/Balzers, Ulvac, and Varian introduce their products.

Watkins-Johnson and Amaya occupy positions in the top ten CVD rankings through their APCVD BPSG reactor products. Their BPSG processes have offered the low-temperature reflow film of choice before first-level metal in 1Mb/4Mb DRAM products and other 1.0- to 1.2-micron VLSI logic products.

Novellus displayed explosive growth in 1989 and grabbed 8 percent of the CVD market. It doubled its revenue in 1989 compared with 1988. Its highly successful Concept One PECVD systems are penetrating leading-edge dielectric applications as well as replacement capacity additions for more mature process fabs. Novellus is currently embarking upon further international expansion in Japan-Asia/Pacific as well as in Europe.

Kokusai Electric and TEL led the vertical tube LPCVD market in 1989. The vertical tube LPCVD market grew phenomenally (56 percent) in 1989 compared with 1988. Worldwide momentum is building up for vertical LPCVD systems for submicron applications involving in-situ gate oxide/polysilicon, thermal nitride, and TEOS LTO film CVD. Vertical LPCVD systems offer advantages such as lower footprint, easier automation, better process control, and better compatibility with 200mm wafer handling. Japanese companies have the technological lead in vertical LPCVD systems due to Japan's early move to vertical furnace processes. US companies such as BTU International and SVG and European companies such as ASM international are only now catching up with their products in this fast-growing market segment.

DATAQUEST CONCLUSIONS

The CVD market continues to be in the throes of a technology revolution. New materials, new thin films, and new cluster tool reactor architectures promise an exciting decade of growth and challenge for the CVD equipment market in the 1990s. Dataquest believes that US companies thus far have dominated the CVD market due to innovative process technologies implemented in first-to-market reactor configurations. US companies have set a trailblazing path in dedicated reactor CVD markets such as low-temperature PECVD dielectrics and refractory metal CVD. Can US companies continue their technology innovations and effective time-to-market product strategies in the globalized semiconductor market of the 1990s?

Dataquest believes that competition will intensify in the high-stake, high-growth CVD market. Japanese and European companies are racing toward their dedicated reactor designs for LPCVD and PECVD applications. Japanese companies have a lead in the important emerging area of ECR CVD films. US companies must look offshore for leading-edge DRAM technology requirements because most US semiconductor companies have exited the DRAM business. The emergence of cluster tools and open architecture SEMI/MESC standards in the 1990s may lead to intensified competition from small, innovative process companies in the CVD market. Dataquest believes that the 1990s may be the decade of CVD as new process technologies and film applications are developed by global competitors in a global marketplace.

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Research *Bulletin*

CLUSTER TOOL EQUIPMENT MARKET MAY SURPASS $2.2 BILLION BY 1994

THE NEED FOR CLUSTER TOOLS

Submicron semiconductor processes are increasing exponentially in complexity. The increasing number of process steps and increasing sensitivity to process-related defects in submicron technologies mandate a new approach to cost-effective semiconductor manufacturing in the 1990s. Cluster tools for integrated processing applications offer the benefits of improved overall throughputs, lower costs, lower defect sensitivity, and better process control. Cluster tools are being perceived as a competitive manufacturing advantage in the race toward leadership in a global semiconductor market driven by the compelling forces of time to market and production costs. Dataquest expects the cluster tool market to outpace the growth of the overall wafer fabrication equipment market during the next five years. Equipment companies with world-class cluster tools can expect to get a piece of a pie worth $2.2 billion by 1994.

RIGID MULTICHAMBER TOOLS ARE PRECURSORS TO FLEXIBLE CLUSTER TOOLS

Dataquest considers the traditional rigid multichamber tool (RMT) to be the precursor to the flexible cluster tool (FCT) of the 1990s. RMT-type tools were used through most of the 1980s for traditional applications such as multichamber sputtering and dry etch/dry strip processes. RMTs embodied centralized control and communications architecture using proprietary closed standards. Process chambers in RMT equipment were essentially "dumb" and acted as enabling process slaves to the command from the central control module.

Dataquest observed the emergence of FCTs in the late 1980s. A typical FCT will have distributed control and communications architecture. Essentially, the FCT of the 1990s will consist of modular, intelligent subsystems such as wafer-handling platforms (engines), process modules, I/O loadlock modules, docking modules, etc. As the SEMI/MESC international cluster tool standards emerge, the equipment industry may migrate toward open architecture conforming to these standards.

Such a standardized hardware market will allow for many synergistic partnerships between equipment companies with complementary products and regional presences. We also may see the emergence of wafer-handling platform companies that supply core platform engines to small process-oriented equipment companies. Dataquest believes that even the large equipment companies may look toward buying rather than making wafer-handling subsystems.

TOTAL AVAILABLE MARKET FOR CLUSTER TOOLS

Figure 1 shows the growth of the worldwide cluster tool market between 1989 and 1994. Over the next five years, applications for cluster tools include thin-film processes such as chemical vapor deposition (CVD), physical vapor deposition (PVD), silicon epitaxy, dry etch/dry strip, and RTP equipment. Dataquest estimated the total available market (TAM) for cluster tools to be $1.8 billion in 1989. This TAM represents the total CVD, PVD, silicon deposition, dry etch/dry strip, and RTP equipment market in 1989. Only $1.0 billion of this $1.8 billion TAM is actually served by RMT and FCT systems. The remaining $800 million of the TAM is served by traditional equipment configurations such as batch systems and tube furnaces.

SERVED AVAILABLE MARKET FOR CLUSTER TOOLS

The actual sales of RMT and FCT systems in any given year represents the served available

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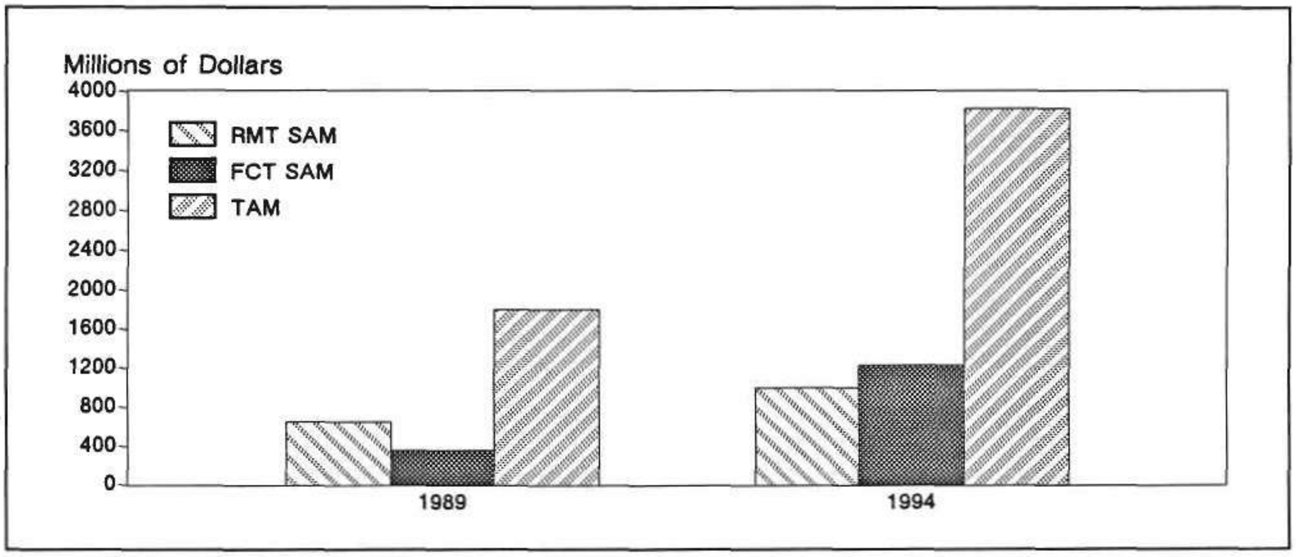
FIGURE 1
Worldwide Cluster Tool Market Growth (Millions of Dollars)



Source: Dataquest (August 1990)

market (SAM) for cluster tools. The cluster tool SAM thus is a subset of the cluster tool TAM. The combined 1989 RMT and FCT market, which represents the cluster tool SAM, was $1 billion. RMT system sales for applications such as dry etch/dry strip and aluminum PVD films were $650 million (64 percent); FCT system sales for advanced PECVD and multilayer refractory barrier/aluminum PVD applications accounted for the remaining $360 million (36 percent) of the $1 billion cluster tool SAM.

Dataquest observes that FCT systems currently available in the market are closed-architecture systems with limited flexibility and distributed control features. As the SEMI/MESC standards evolve during the 1990s, we can expect truly flexible open-architecture systems that embody distributed control and communications architecture. Such a standardized market environment will expand business opportunities for small, entrepreneurial wafer-handling platform and process module companies. Essentially, these small companies can serve as OEM component suppliers to large, multiproduct, global companies that will offer integrated turnkey customer solutions.

CLUSTER TOOL MARKET IS FORECAST TO GROW DRAMATICALLY

Dataquest predicts that cluster tools (RMTs and FCTs) will rapidly penetrate the thin films deposition/etch TAM. The TAM for cluster tools is expected to grow at a compound annual growth rate (CAGR) of 16 percent from $1.8 billion in 1989 to $3.8 billion by 1994. The cluster tool SAM is projected to increase at a CAGR of 17 percent from $1.0 billion in 1989 to $2.2 billion by 1994. The FCT portion of the cluster tool market is predicted to grow at a high CAGR of 28 percent from $ 360 million in 1989 to $1.2 billion in 1994 due to the rapid migration toward flexible processing equipment with standardized SEMI/MESC architecture. In contrast, the relatively mature RMT portion of the cluster tool market is expected to grow at a sedate CAGR of 9 percent from $650 million in 1989 to $1 billion in 1994.

DATAQUEST CONCLUSIONS

Dataquest believes that the wafer fabrication equipment industry is poised on the threshold of a new era. The move toward cluster tools will usher in a more cost-effective way of semiconductor manufacturing. The evolution of the SEMI/MESC standards will benefit equipment vendors and semiconductor manufacturers by standardization of hardware configurations. New industry players such as wafer-handling platform vendors and process module vendors may emerge as OEM component suppliers to global integration companies. Equipment companies that quickly adjust to the 1990s decade of synergistic partnerships and joint development in order to better serve their customers can expect to reap rich rewards from the rapidly growing cluster tool market, which may exceed $2.2 billion by 1994.

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Research Newsletter

1990 EPI EQUIPMENT FORECAST REVISED DOWNWARD

INTRODUCTION

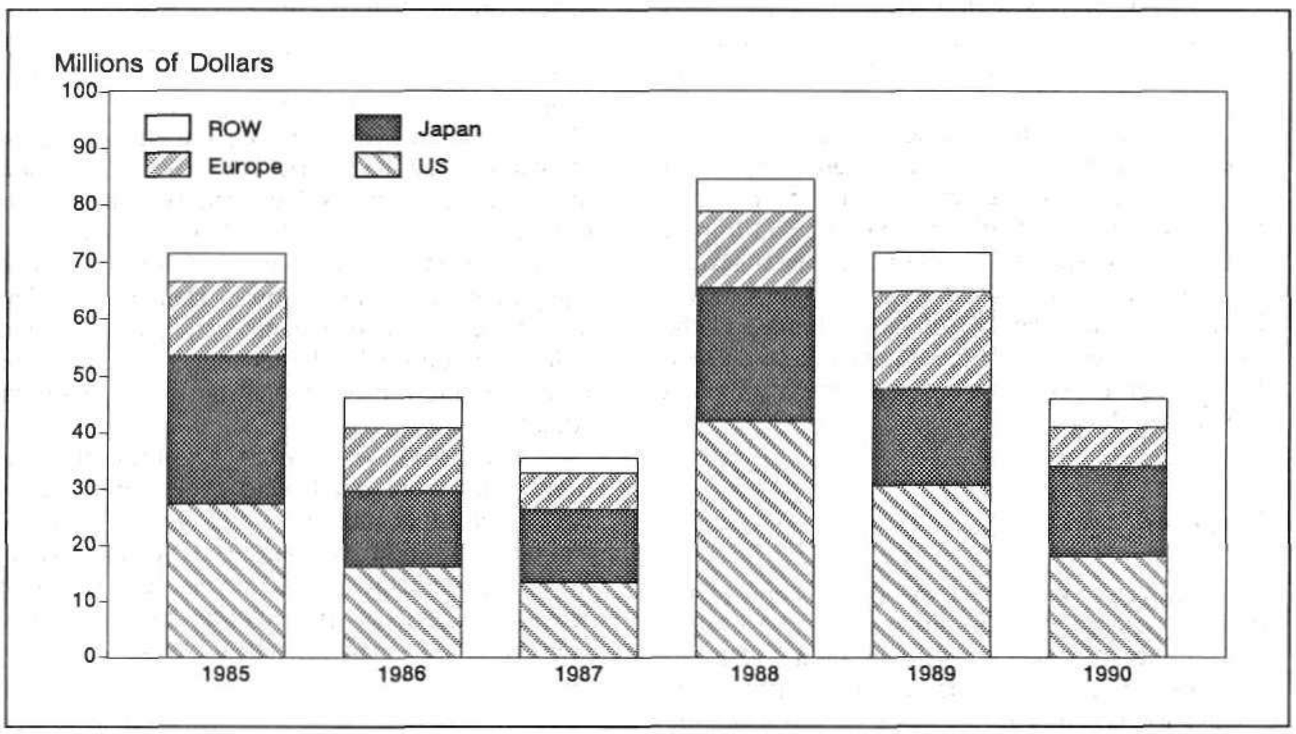
Dataquest is downsizing its 1990 forecast for new silicon epitaxial reactors sales. The worldwide sales forecast for calendar year 1990 has been cut from $62.9 million to $46.0 million (see Figure 1), a decrease of 26.9 percent. The adjustment is attributed to the factors discussed in this newsletter.

MARKET CONDITIONS

The first factor contributing to Dataquest's adjusted forecast is that the BiCMOS market is not developing as fast as previously anticipated. SRAM device manufacturers were expected to shift quickly from CMOS to BiCMOS technology because of the speed advantages. Yet, the cost of BiCMOS devices is proving to be a hurdle for the personal computer and workstation manufacturers. This obstacle is slowing the ramp up of BiCMOS production facilities and is causing decisions to purchase new epi equipment to be deferred.

Second, the automotive market, which is a large consumer of power MOSFETs and bipolar transistors, is flat. Consequently, semiconductor manufacturers are becoming cautious about adding

FIGURE 1
1990 Silicon Epi Equipment Sales Forecast



Source: Dataquest (July 1990)

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capacity for automotive discrete applications, and this hesitance is translating into slower bookings for production equipment.

The final factor impacting the forecast revision is the announcement by Lam Research that it is closing the Gemini division. Dataquest believes that the reactor deals currently under negotiation will be delayed as customers carefully evaluate their options.

COMPETING TECHNOLOGY

A broader trend affecting new equipment sales is the trend of epi wafer manufacturers to upgrade existing systems. Two companies currently offer expansion kits for existing reactor designs, Moore Technologies and Concept Systems Design Inc.

Moore Technologies markets an epitaxial reactor upgrade that increases throughput of the Applied Materials 78XX series reactors. This kit increases throughput from 30 to 100 percent, depending on wafer size. Fourteen of these systems have been installed since November 1988.

Concept Systems Design markets a kit to upgrade a Lam Research Gemini I system to a Gemini II. This upgrade increases the capacity of the system by 50 percent. In 1989, two upgrade kits were sold.

Expansion kits have gained acceptance among companies depositing epi films because expansion kits represent an inexpensive solution to capacity constraints. Dataquest believes that kits will impact the sale of new epi equipment over the next several years, and we have folded this into the forecast. However, because the sale of kits is limited to the existing installed base of epi equipment, expansion kits are not expected to impact new equipment sales in the long term.

REGIONAL OUTLOOK

Dataquest expects the worldwide demand for new epi equipment to be down on a year-to-year basis. Although down 41 percent from 1989, the US market will remain the largest in 1990. The demand for new reactors will be driven primarily by the growth in the CMOS epi market, which currently is short on capacity.

The Japanese market is expected to be flat in 1990 because of the sluggish growth in demand for bipolar and discrete devices. The bright spot in the Japanese market is the strong growth in the charge-coupled device (CCD) market. On the other hand, the Japanese CMOS epi market, historically much smaller than the US market, remained stagnant as the Japanese continued to design out expensive epi films in CMOS devices.

The European and Rest of World (ROW) markets are much smaller than either the US market or the Japanese market. The European market is forecast to decline 59 percent in 1990 because there is little demand for additional capacity. Sales of new equipment into ROW are forecast to be flat in 1990 as Korean and Taiwanese semiconductor manufacturers digest the equipment purchased over the last two years.

DATAQUEST CONCLUSIONS

The silicon epi equipment market is a mature business. New equipment sales are driven largely by capacity expansions. Consequently, there are large cyclic swings in equipment sales. Substrate vendors rush out to purchase new equipment when capacity tightens, and typically several years pass before this capacity is fully utilized, thus leading to another round of equipment purchases.

In some respects, epi equipment is a leading indicator of the managerial challenges semiconductor equipment vendors increasingly will face with other equipment lines such as CVD and etch. In the decade ahead, as the rate of change in process equipment technology slows, Dataquest believes that the decision to add new equipment to a fab will not be driven by the technical advantages of a new generation of equipment but by capacity constraints.

This trend will further aggravate the traditional equipment purchasing cycles, much as we have seen over the past five years in the epi equipment market. If equipment vendors wish to avoid the attendant revenue swings, we believe that they will need to pay closer attention to the management of their installed bases.

Mark FitzGerald

Research *Bulletin*

APPLIED MATERIALS ENTERS THE PVD EQUIPMENT MARKET

OVERVIEW

Applied Materials recently announced its widely anticipated entry into the PVD equipment market with its Endura 5500 cluster tool platform. The system is targeted toward aluminum alloy and barrier metallization applications for advanced interconnect processes. Applied has positioned this system to be the first offering in its MasterFab family of integrated processing systems for the 1990s. The MasterFab architecture is compatible with Applied's successful PE5000 CVD and dry etch systems that currently comprise an installed base of over 400 systems. The MasterFab architecture has a five-stage vacuum design that can progressively take a wafer from atmosphere to ultrahigh vacuum (UHV). Such a system architecture may be able to effectively integrate the different vacuum and process requirements for CVD, PVD, and dry etch technologies. Applied Materials is thus setting the stage to becoming a billion dollar company by broadening its product offerings to address the integrated CVD, PVD, and dry etch/dry strip equipment market. Dataquest forecasts the combined deposition and dry etch/dry strip equipment market to exceed $3.5 billion by 1994.

LARGE UNTAPPED MARKET FOR INTEGRATED PROCESSING EQUIPMENT

Dataquest believes that the CVD, PVD, silicon deposition, dry etch, and dry strip equipment markets are advancing rapidly toward integrated process solutions. This viewpoint is supported by companies such as IBM, which has announced extensive use of integrated cluster tools in its 16Mb DRAM manufacturing processes. Figure 1 shows the growth of the worldwide deposition and dry etch/dry strip equipment market between 1989 and 1994. Dataquest estimates the combined worldwide 1989 deposition and dry etch/dry strip market to be $1.8 billion. In 1989, a majority of the deposition and dry etch/dry strip equipment was sold as standalone dedicated process reactors with very small degrees of integration. However, by 1994, Dataquest anticipates that a significant portion of the estimated $3.7 billion market for deposition and dry etch/dry strip equipment may be served by highly integrated process solutions. The evolution of worldwide cluster tool interface standards such as the SEMI/MESC effort may hasten the adoption of integrated processing systems. Applied Materials, with its new PVD tool and its global market leadership position in the CVD and dry etch markets, is well positioned to take advantage of the growing integrated process equipment market. Dataquest predicts that Applied Materials may augment the PE5000/Endura 5500 platforms with single-chamber cluster tool versions of silicon deposition and dry strip equipment.

APPLIED MATERIALS CHALLENGES ENTRENCHED PVD MARKET LEADERS

Four companies (Anelva, Materials Research Corporation (MRC), Ulvac, and Varian) dominated the 1989 PVD market. These four companies collectively owned 80 percent of the 1989 worldwide sputtering equipment market of $337 million. Varian is the only major U.S.-based PVD equipment company; the other three companies are Japan-based. (MRC, a U.S.-based company, was acquired by Sony Corporation in 1989.) MRC has the unique advantage of offering both target materials and equipment capabilities to its customers. Anelva, Ulvac, and Varian also offer cluster tool capabilities for sputtering capabilities. All four companies have in-depth experience in aluminum and refractory barrier metallization. Any competitor challenging these market leaders has to offer some unique, superior process advantages. Applied

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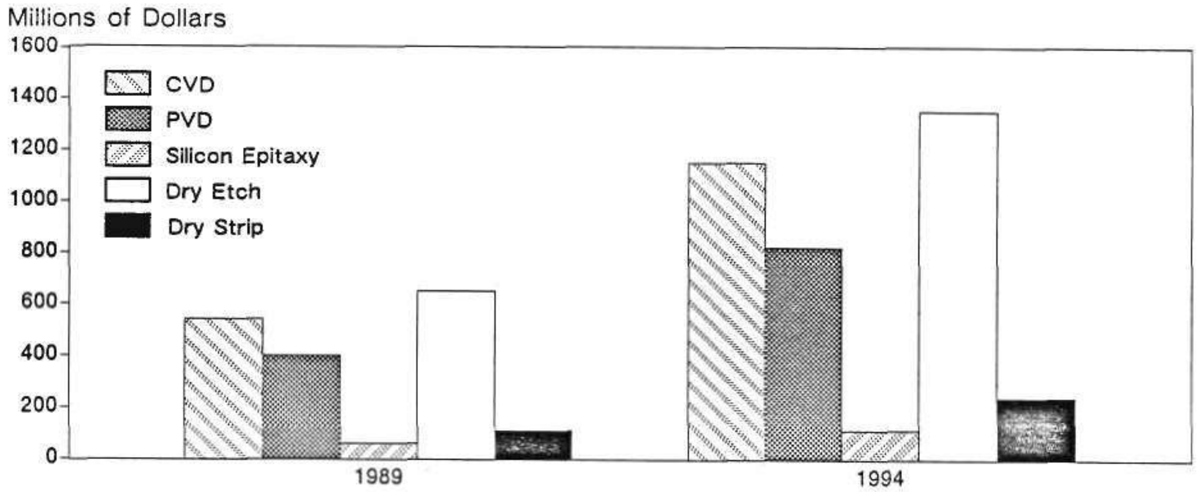
FIGURE 1
Worldwide Deposition, Dry Etch, and Dry Strip Equipment Market Forecast



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Source: Dataquest
May 1990

Materials hopes to do precisely that with its UHV staged vacuum design and its compatibility with other CVD and dry etch processes.

WHY IS THE ENDURA 5500 A SIGNIFICANT INTRODUCTION?

Dataquest sees the boundary lines between CVD, PVD, and dry etch technologies blurring as the semiconductor industry migrates toward integrated processing systems for increasingly complex submicron wafer fabrication. The Endura 5500 system fills out Applied's thin-film market portfolio by offering an integrated PVD solution to complement the highly successful PE5000 CVD and dry etch system. Although the system has just been announced, Applied claims to have already received commitments for 11 systems from leading semiconductor manufacturers in the United States, Japan, and Europe. This fact is indicative of the device manufacturers' high degree of interest in integrated processing platforms. Taken together with Applied's CVD and dry etch capabilities in dielectric and tungsten films, the company may be able to offer "one-stop shopping" capability worldwide for advanced interconnect technology.

APPLIED'S SECRET SAUCE FOR A TASTY PVD PROCESS RECIPE

Applied claims that it has developed a unique down-sputtering source with rotating permanent magnets that allows for more uniform target erosion, giving better step coverage symmetry and uniformity even on 200mm wafers. The staged vacuum environment may offer high-quality film purity due to the UHV sputtering environment. Dr. Tadahiro Ohmi (Tohuku University, Japan), a leading exponent of ultraclean submicron processing, claims that Applied's Endura 5500 system is the first production PVD system to offer UHV process capability. The Endura 5500 system can accommodate up to four PVD chambers per system. Additionally, the mainframe platform has been designed for future integration of two additional chambers for RTP, CVD, or dry etch processes. The system features a low-voltage preclean chamber for cleaning the wafer surface prior to metal deposition.

DATAQUEST CONCLUSIONS

Dataquest views Applied Materials' entry into the PVD equipment market as a strategic move. We expect competition to heat up in the growing PVD market in the near-term future. Applied Materials will face stiff competition from the entrenched market leaders (Anelva, MRC, Ulvac, and Varian) that have extensive field experience in sputtered film applications. Dataquest expects Applied Materials to position the Endura 5500 PVD system as a key element in its overall strategy of offering integrated deposition and dry etch/dry strip process solutions.

Krishna Shankar

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Research Newsletter

DEPOSITION AND CLUSTER TOOL EQUIPMENT TRENDS IN JAPAN

OVERVIEW

Several Japanese equipment companies recently introduced new deposition and cluster tool equipment for submicron device fabrication. Most of the chemical vapor deposition (CVD) equipment introductions use atmospheric CVD or low-pressure vertical-tube CVD technology for applications such as undoped oxide, borophosphosilicate glass (BPSG), thermal nitride, and polysilicon. Japanese equipment companies lag behind U.S. companies in penetrating the high-growth plasma-enhanced CVD reactor market for interlayer dielectric (ILD) and passivation applications. Japanese equipment companies also have introduced several cluster tools for sputtered aluminum and barrier metallization applications. This newsletter highlights significant recent deposition and cluster tool equipment introductions in Japan.

DEPOSITION

Chemical Vapor Deposition (CVD)

Alcan Tech

Alcan Tech is a joint venture between Alcatel CIT and Canon. Alcan Tech has introduced the APT-4800, an atmospheric four-chamber CVD reactor based on a tetraethylorthosilicate (TEOS)/ozone process. The average selling price (ASP) for the system is ¥150 million ($1.1 million). Applications for the system include doped and undoped oxides.

Amaya/Kanematsu

Amaya has upgraded its APCVD reactor series with the AMAX-200. The system is targeted primarily toward the premetal BPSG dielectric market. The AMAX-200 is fully automated and uses silicon carbide coated trays to minimize particles. The system is priced at ¥90 million ($652,000).

ASM Japan

ASM has introduced its PXJ-200 series horizontal plasma-enhanced CVD system for low-temperature oxide and passivation nitride applications. This system represents an upgrade to ASM's earlier tube PECVD series. The robotic handling system and loader mechanisms are new features on the PXJ-200 system. The ASP for a two-tube stack with the handling robot and loader is ¥157 million ($1.2 million). The system can deposit silane-based oxides as well as TEOS-based oxides. ASM also is marketing its new horizontal single-tube PXJ-8000 system, which is 200mm compatible. The PXJ-8000 system initially will be offered with manual or cantilever loading options. In the future, ASM plans to introduce robotic handling and loading options. The ASP for the single-tube PXJ-8000 system is ¥100 million ($725,000).

ASM Japan, meanwhile, continues to ship its VDF and VMP-100 PRO series of vertical diffusion and LPCVD systems targeted toward submicron gate oxide. These systems were introduced at SEMICON/Tokyo in 1987.

Kokusai Electric

Kokusai Electric has commenced marketing its new Vertex DJ-803V vertical diffusion and LPCVD tube systems. The system is capable of handling wafer sizes up to 200mm in diameter. Wafers can either be loaded into the boats singly or in batches of five wafers each. The diffusion tube is priced at ¥58 million ($420,000) per tube; the LPCVD tube is priced at ¥60 million ($435,000) per tube.

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Nissin Hi-Tech

Nissin Hi-Tech is a wholly owned subsidiary of Nissin Electric, Japan. The company has introduced its NPC 625 batch PECVD reactor aimed at the plasma nitride/oxynitride passivation film market. The system is capable of 200mm wafer processing.

Tokyo Electron Limited (TEL)

TEL continues to ship its flagship VCF-615S vertical tube systems in production quantities. The systems are fully automated and targeted toward 4Mb DRAM fabs for diffusion and LPCVD poly/nitride applications. ASPs for the series range from ¥50 million to ¥60 million ($362,000 to $435,000) per tube.

Ulvac/BTU

Ulvac/BTU, a joint venture between Ulvac and BTU International, is shipping the 2100 Series vertical tube reactors (VTRs) in production quantities for diffusion and LPCVD applications. The 2110 system is a nonloadlocked system; the 2120 system is a loadlocked system. The ASP for the loadlocked 2120 system is ¥83 million ($600,000) per automated tube. Ulvac/BTU also is offering a two-tube version, the 2130 system. Main applications for the 2100 VTR family include thin oxides, thermal nitride, TEOS oxides, and polysilicon.

Physical Vapor Deposition

Anelva

Anelva continues to migrate its customers from the older 1015 sputtering system toward its latest 1051 sputtering system. The 1051 system has beltless pick-and-place type wafer handling. It is capable of performing RF- or DC-biased aluminum sputtering for improved metal step coverage. The system has an ASP of ¥200 million ($1.5 million) and is capable of 200mm wafer processing.

Ulvac

Ulvac is marketing a new flexible cluster tool-based sputtering system, the MLX-3000 series. The system allows up to five individually isolated sputtering process chambers arranged around a central wafer handler. The ASP for the MLX-3000 is ¥230 million ($1.7 million). The system is capable of 200mm wafer processing. Meanwhile, Ulvac continues to ship its older two-chamber MCH-4500 system.

CLUSTER TOOLS

Japan has considerable activity in cluster tool development for integrated processing applications. Dataquest believes that the driving forces for cluster tool development in Japan include process simplification, defect reduction, and fab automation. Japanese equipment companies are closely monitoring the SEMI/MESC cluster tool standards development while simultaneously working toward designing their own cluster tools. We will highlight major cluster tool products being developed and marketed by Japanese equipment companies in the following paragraphs.

Anelva

Anelva is shipping production volumes of its ILC-1051 series cluster tool for sputtered interconnect applications. The system can accommodate up to four process chambers around a central loadlocked wafer handling platform. A typical configuration for the ILC-1051 system includes a RF etch/clean module and three sputtering modules for titanium, titanium nitride barrier, and aluminum interconnect film deposition. The system is capable of 200mm wafer processing and uses pick-and-place beltless wafer transfer. The system is priced at approximately ¥200 million ($1.5 million).

The ILC-1551 series, introduced by Anelva about two years ago, is a development/pilot line flexible cluster tool (FCT). The system can accommodate up to three process modules from a wide choice of processes such as ECR deposition/etch, sputtering, RF sputter etch, plasma clean, RIE, and tungsten CVD. Anelva claims that processes developed on the ILC-1551 system are directly transferrable to production FCT systems such as the ILC-1051. The ASP for the ILC-1551 series can range from ¥100 million to ¥150 million ($725,000 to $1.1 million) depending on the number and type of process modules used.

Ulvac

Ulvac continues to promote a simulation concept for its future megacluster tool, the C-2111 Stellar system. This system will consist of two radial FCTs linked by a common gangway. Each of the four chambers on each cluster can accommodate a variety of processes, such as dry etch, CVD, PVD, and RTP, from Ulvac's product portfolio. Ulvac states that it is soliciting feedback from major device customers before finalizing the design of the system. Ulvac will ship prototype versions of the system in 1990.

Kokusai Electric

Kokusai Electric is marketing its new Nebula Series cluster tool. This system will be initially offered in a three-chamber dry-etch system version using magnetron RIE technology for oxide-etch applications. A two-chamber version of this system is priced at ¥150 million ($1.1 million). Dataquest believes that Kokusai Electric also has a CVD module development effort under way for the Nebula cluster tool.

DATAQUEST CONCLUSIONS

Dataquest believes that the Japanese deposition equipment market is driven mainly by the requirements for automated, cost-effective 4Mb/16Mb DRAM mass production, which has resulted in a short-term focus on atmospheric CVD and vertical tube LPCVD technology for applications such as reflowed BPSG oxides, thermal nitride, and polysilicon. In the long term, we believe that Japanese equipment companies will introduce plasma-enhanced CVD reactors to address the fast-growing market for low-temperature interlayer oxides and passivation nitrides.

Japanese equipment companies are closely monitoring the SEMI/MESC cluster tool standards efforts while developing their own integrated processing platforms. Sputtering systems for interconnect applications are being used as the entry vehicle for Japanese companies to penetrate the integrated processing equipment market.

Kunio Achiwa
Krishna Shankar

Diffusion/Implant

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Research Newsletter

ION IMPLANT EQUIPMENT TRENDS IN JAPAN

OVERVIEW

Submicron devices fabricated on 200mm wafers impose stringent requirements on ion implant equipment. Implant equipment companies have to efficiently tackle issues such as dose uniformity, symmetry, defects, shadowing, throughput, and varying dose/energy applications. Device manufacturers expect enhanced reliability, process control, flexibility, and user-friendly automation in order to maximize equipment productivity in today's environment of skyrocketing fabrication equipment costs.

Japanese equipment companies, with their sustained R&D spending, have invested heavily in ion implant equipment development. Table 1 lists recent ion implant equipment introductions in Japan. These product introductions challenge the United States' leadership position in the ion implant equipment market. This newsletter describes some of the major new ion implant equipment introductions in Japan.

COMPANIES

Hitachi

Hitachi introduced its IP-825A high-current implanter. Hitachi claims that the system's microwave ion source, which has no filaments, enables it to offer high beam accuracy, throughput, and ease of maintenance. The system is capable of processing wafer sizes up to 150mm. Dual-batch wafer disks are used to improve the productivity of the equipment. The system is capable of accelerating voltages in the 20- to 120-KV range. Maximum beam currents are 12mA for arsenic and phosphorus; boron beam current is limited to 4mA.

TABLE 1
Recent Ion Implant Equipment Introductions in Japan

Company	Model	Implanter Type	Comments
Hitachi	IP-825A	Batch, high current	Microwave ion source
Nissin Electric	NH-20SP	Single wafer, medium current	Parallel scanning, variable tilt angle
Sumitomo	NV-8200 GD	Batch, medium current	Small footprint
Eaton Nova	NV-GSD	Batch, high current	Enhancement to NV-10
	NV-200	Batch, high current	Oxygen implants for SOI
	NV-1002	Single wafer, high voltage	For CCDs and DRAMs
TEL/Varian	E-220	Single wafer, medium current	Parallel scanning, variable tilt angle
	E-1000	Batch, high current	200mm wafer capability
Ulvac	IPX-7000	Single wafer, medium current	Parallel scanning, variable tilt angle

Source: Dataquest
March 1990

SEMS Newsletters 1990 Ion Implantation
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Nissin Electric

Nissin's new NH-20SP medium-current implanter is 200mm wafer size compatible and features parallel scanning and continuously variable tilt angle for better implant uniformity. The average selling price (ASP) for the system is approximately ¥140 million ($1 million).

Meanwhile, Nissin continues to ship its NT-1000P MeV high-voltage ion implant system. The system can accelerate singly charged ions up to 2.0 MeV. The ASP for the system is ¥250 million ($1.8 million).

Sumitomo Eaton Nova

Sumitomo Eaton Nova (SEN), the joint venture between Sumitomo and Eaton, recently began marketing several new implant systems in Japan. Some of the systems are manufactured by Eaton in the United States and marketed by SEN in Japan, and other systems are designed, manufactured, and marketed by SEN.

The NV-8200 GD is a medium-current system with 200mm wafer capabilities and parallel scanning abilities. It is designed and manufactured by SEN of Japan and can carry out medium currents with boron beam currents up to 1.5mA and phosphorus/arsenic beam current up to 3.0mA. The system is a small-footprint batch medium-current system. The system's ASP is approximately ¥125 million ($0.9 million).

The company also introduced the NV-GSD high-current implanter, which is an enhancement to Eaton's NV-10 high-current implanter. It currently is manufactured and marketed in the United States. The system featured improved wafer-handling and process-control features. The system can carry out implants with beam currents up to 15mA and energies in the 80- to 180-KeV range. First shipments of the system were scheduled in November 1989. The cost of the NV-GSD implanter is approximately ¥230 million ($1.7 million). Meanwhile, SEN continued to ship its high-end NV-20A high-current implanter, which is capable of beam currents up to 25mA and beam energies up to 200 KeV.

SEN also manufactures and markets the NV-200 oxygen implanter, which can carry out oxygen implants with 200-KeV energies and a 75mA beam current. The system is targeted at silicon-on-insulator applications for radiation-hardened (rad-hard) device applications. The ASP for the system is ¥450 million ($3.3 million). Much of the technology for this oxygen implanter was derived from NTT Laboratories of Japan.

The NV-1002 is SEN's successor to the older Eaton NV-1000 high-voltage implanter. The system includes enhancements such as a shorter linac acceleration length, higher beam energies, and 200mm wafer-size capability. The ASP for the 200mm wafer version of the 2-MeV implanter is approximately ¥430 million ($3.1 million). Applications for the system include charge-coupled devices (CCDs) and other advanced research applications.

TEL/Varian

TEL/Varian markets the E-220 medium-current system and the E-1000 high-current systems, which were originally introduced by Varian at SEMICON/West 1989. The E-220 medium-current system was the first medium-current system that offered the features of parallel scanning, continuously variable tilt angle, and 200mm wafer-size capability. The E-1000 high-current system has been designed to share many of the operator interface and end-station features of Varian's flagship M2000 integrated processing platform.

Ulvac

Ulvac introduced its new IPX-7000 medium-current implanter. The system is targeted at 4Mb and 16Mb DRAM applications. The IPX-7000 features 200mm wafer processing capability, parallel beam scanning, and variable tilt angle. The ASP for the system is approximately ¥200 million ($1.5 million). Ulvac reportedly is developing a new compact high-current implanter that it plans to introduce in the first half of 1990.

DATAQUEST CONCLUSIONS

The recent ion implant equipment introductions in Japan highlight the sustained development efforts by Japanese companies in this area. Dataquest believes that these efforts may pose a challenge to the market leadership position enjoyed in Japan by current joint-venture companies such as TEL/Varian and Sumitomo Eaton Nova.

Kunio Achiwa
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Research *Newsletter*

CD SEM EQUIPMENT—SMALLER GEOMETRIES LEAD TO LARGER MARKET

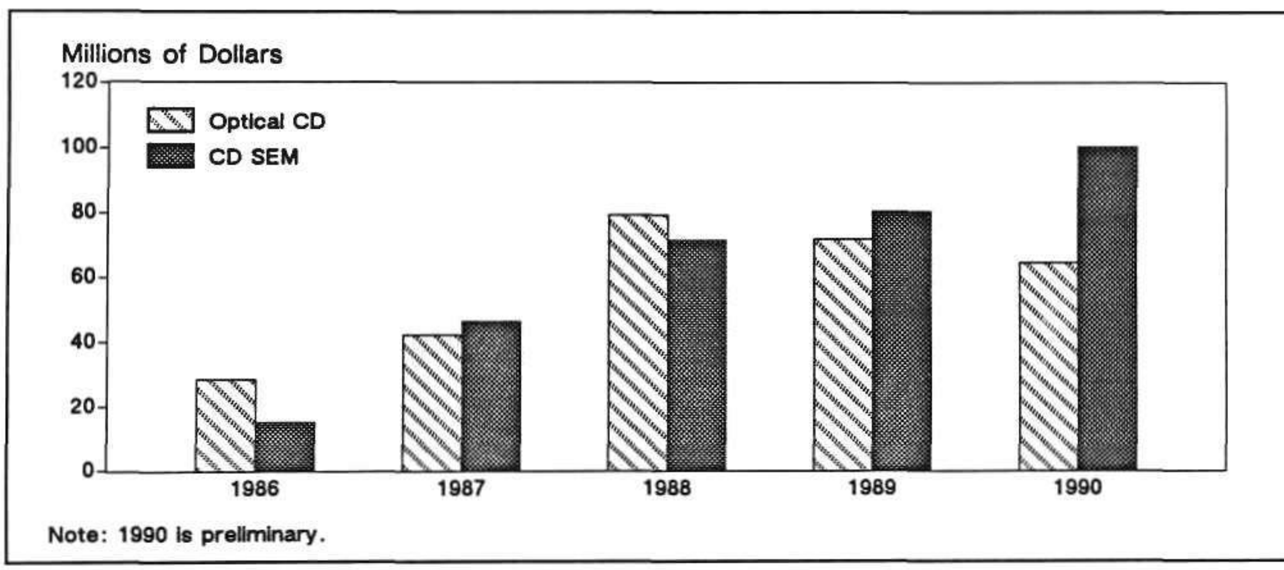
SUMMARY

The critical dimension scanning electron microscope (CD SEM) equipment market has experienced robust growth during the past five years, and, as shown in Figure 1, now exceeds the optical CD equipment market by a sizable margin. Dataquest's preliminary estimate of the 1990 CD SEM equipment market is $100.6 million, up almost 25 percent from its 1989 level of $80.6 million. This healthy growth is all the more impressive when measured against a total wafer fabrication equipment market in 1990 that is expected to be down a few percentage points from its 1989 level. This newsletter examines several of the factors that are behind the emergence and acceptance of CD SEM measurement equipment in today's semiconductor manufacturing environment.

WHY CD SEM?

In the latter half of the 1980s, the field of CD measurement diversified into a multitude of technologies. Historically, conventional CD tools have been white-light microscopy systems. These systems are considered adequate for measurements down to about 1.0-micron geometries. Several of the white-light microscopy systems have been enhanced with sophisticated image processing capabilities to extend their performance. In addition, laser-based measurement systems, confocal scanning laser microscopy (CSLM), and coherence-probe imaging (CPI) technologies have been developed to perform CD measurements in the submicron regime. CSLM and CPI systems have received only modest market acceptance to date because of the significant effort required to

FIGURE 1
Optical CD and CD SEM Equipment Markets



Source: Dataquest (December 1990)

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characterize the equipment for the measurement of CDs in a production environment.

At the same time, SEM tools, traditionally relegated to the analytical lab, have been redesigned to meet the needs of submicron manufacturing for the production environment. The SEM tools designed for IC metrology are low-voltage systems because of the concern regarding damage to the wafer at higher levels of electron irradiation. In addition, equipment manufacturers have designed the tools to be more user friendly than their analytical counterparts by simplifying the operator control panel.

CD SEM ADVANTAGES

The advantages of CD SEM equipment include better measurement resolution and depth of focus than optical tools. Some manufacturers report better-than-0.2-micron measurement capability; however, most agree that today's CD SEM tools are fully characterized for production only down to about 0.5-micron geometries. CD SEM equipment, like the advanced optical techniques of CSLM and CPI, also has the ability to capture three-dimensional information of the line profile. The slope of the sidewalls becomes increasingly important in linewidth measurement as manufacturers move to submicron geometries and features with higher-aspect ratios necessitating tighter CD control.

Throughput

Throughput of CD SEM tools remains a major issue. Compared with optical tools, most CD SEM tools still have relatively low throughput, typically on the order of 8 to 12 wafers per hour at five measurement sites per wafer. This is because in most systems, wafers are processed serially between the load lock and measurement chamber. Several companies have specifically incorporated throughput enhancement features in their design to overcome this factor. Opal (a subsidiary of printed circuit board inspection manufacturer, Optrotech) increases system throughput by measuring one wafer while a second wafer is being pumped down in the load lock. An internal exchange unit allows the first wafer to move aside upon completion of its CD measurements so that the second wafer can be moved from the load lock to the measurement chamber. Opal claims a throughput of approximately 20 wafers per hour and expects it to be even higher in the future. Nanoquest (the former Vickers Instruments operation acquired by BioRad in 1989) takes a different approach; its system accepts a full cassette of wafers into the load lock rather than a single wafer. The full cassette is pumped down, and a wafer transport mechanism is used to move individual wafers into the measurement chamber.

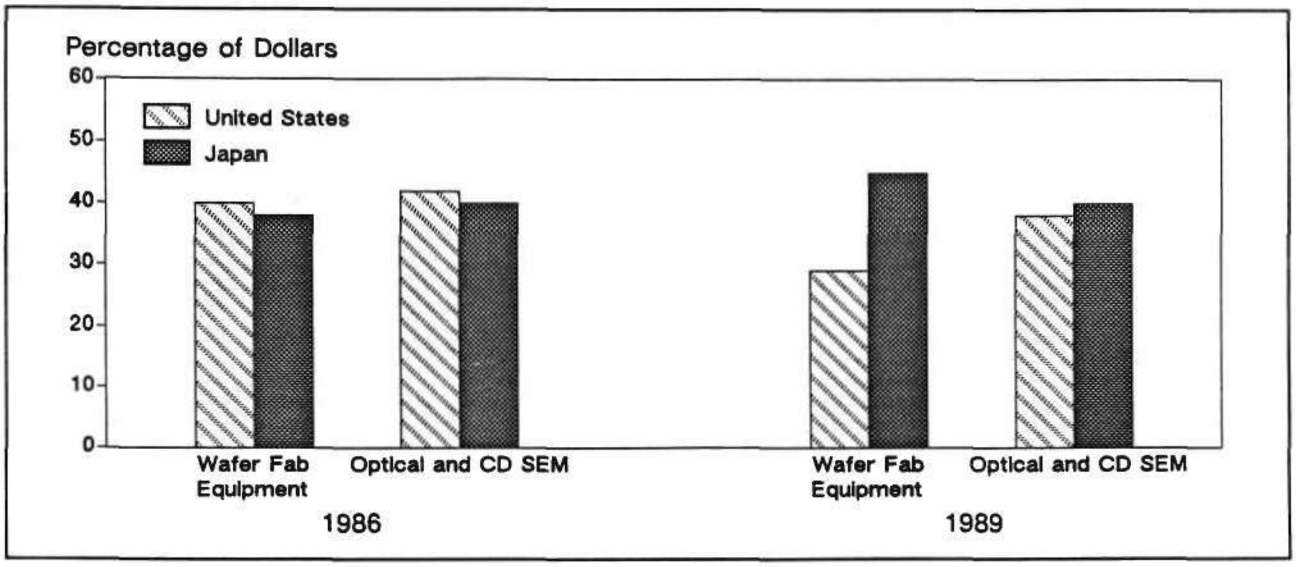
REGIONAL MANUFACTURING PRACTICES

One of the interesting aspects of the CD measurement equipment market is that some semiconductor manufacturers tend to perform less measurement and inspection than other companies. These companies have adopted a manufacturing philosophy to completely characterize and understand their process in the R&D environment prior to moving the device into high-volume production. Once the device is fully characterized for production, only minimal measurement and inspection is performed to monitor the fabrication process. Thus, fewer measurement tools are needed. This is in contrast to the practice of characterizing the process in a production mode, which requires more measurements and adjustments on the fly more frequently.

Figure 2 illustrates that in the last several years, regional variations have emerged in the use of CD measurement equipment. In 1986, manufacturers in the United States and Japan accounted for almost equal share of the worldwide wafer fab equipment market as well as almost equal share of the combined optical and CD SEM equipment market. By 1989, however, this situation had changed substantially. Although the United States as a region accounted for 29 percent of the wafer fab equipment market, it represented 38 percent of all spending on CD measurement systems. In contrast, Japan accounted for 45 percent of the wafer fab equipment market, but only 40 percent of the CD equipment market.

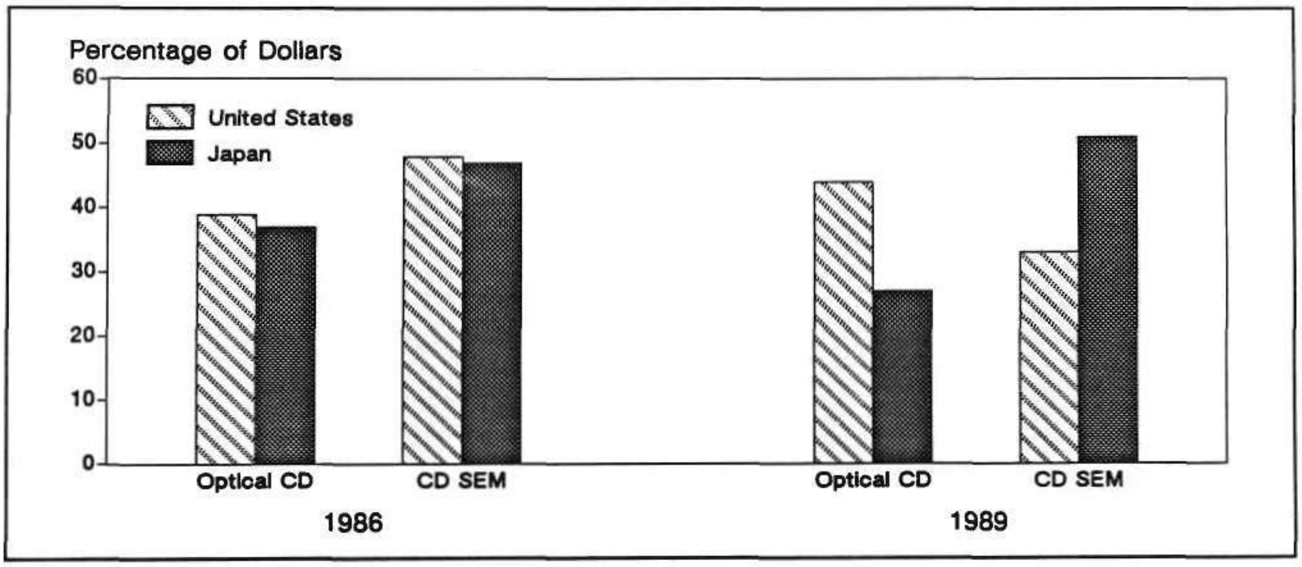
Even further regional manufacturing distinctions exist within the category of CD measurement equipment. Manufacturers in Japan use significantly more CD SEM systems than do their counterparts in the United States. Figure 3 shows that in 1986, semiconductor manufacturers in Japan and the United States accounted for approximately equal share of both the optical CD and CD SEM equipment markets. In 1989, the United States spent more on optical CD measurement equipment with 44 percent share of the world market, while Japan had only 27 percent share. Japan, however,

FIGURE 2
Regional Equipment Market Trends
United States and Japan, 1986 and 1989



Source: Dataquest (December 1990)

FIGURE 3
Regional Trends—CD Equipment Market
United States and Japan, 1986 and 1989



Source: Dataquest (December 1990)

accounted for over one-half of the CD SEM equipment market in 1989 with 51 percent share, in contrast with U.S. share of 33 percent.

This move by Japanese manufacturers to CD SEM equipment is due, in part, to the prevalence of DRAM manufacturing in Japan, which is the technology driver for processing submicron geometries. Dataquest believes, however, that Japanese semiconductor manufacturers have chosen to leapfrog the advanced optical CD measurement technologies and move directly to SEMs because they are not convinced yet that advanced optical technologies can be pushed to or beyond the 0.5-micron processing regime. There are also concerns that the advanced optical tools have not been characterized fully for the semiconductor production environment. Finally, semiconductor manufacturers in Japan historically have been supported by a strong domestic vendor base in CD SEM.

CD SEM COMPANIES

Many companies currently are pursuing the CD SEM equipment market, including the following U.S. companies: Amray, Angstrom Measurements, Metrologix, Nanometrics, Nanoquest, and Opal. Japanese CD SEM companies include Akashi Beam Technology (recently acquired by Toshiba), Hitachi, Holon, and JEOL. This market includes well-established equipment companies as well as start-ups. Hitachi, however, held and maintained dominant market share throughout much of the 1980s. As shown in Table 1, Dataquest estimates that Hitachi commanded 75 percent of world market share in 1990. In 1986, when the world market for CD SEM equipment was only $15.4 million, Hitachi still accounted for more than one-half of the market with 56 percent share. Dataquest believes that Hitachi's success is due, in part, to the company's extensive experience in e-beam technology for electronics as well as other applications, in addition to its early product focus on developing a user-friendly CD-SEM tool for semiconductor production applications.

TABLE 1
1990 CD SEM Equipment Company Preliminary Market Share (Millions of Dollars)

Company	Revenue	Percent Share
Hitachi (Japan)	75.5	75.0
Holon (Japan)	9.4	9.3
Nanoquest (U.S.)	6.9	6.9
Nanometrics (U.S.)	3.1	3.1
Opal (U.S.)	2.4	2.4
Others	3.3	3.3
Total	100.6	100.0

Source: Dataquest (December 1990)

NEW OPPORTUNITIES—CLUSTER TOOL PROCESSING

As linewidth geometries continue to shrink, the overall market opportunities for CD SEMs are growing. One of the interesting opportunities in the CD SEM equipment market comes from the developing market for cluster tools. CD SEM measurement equipment is particularly well suited for a cluster tool vacuum environment designed for etch, strip, and deposition processes. Linewidth measurement would be performed on the wafer after etch/strip processing. The wafer then would be moved directly to a deposition module, thus eliminating the need to remove the wafer from the cluster tool for CD measurement prior to deposition. Metrologix, acquired by venture capital firm Nazem and Company in July 1990, is well suited to pursue such a strategy because of its association with Tegal. Tegal, another company funded by Nazem, is a well-established player in the plasma etch and strip equipment markets.

DATAQUEST FORECAST

Dataquest anticipates CD SEM tools will continue to experience healthy growth in the years to come as a larger percentage of the semiconductor device product mix moves into the submicron processing regime. CD SEM measurement technology has already gained widespread acceptance in Japan, the largest semiconductor manufacturing region in the world. CD SEM equipment is establishing a presence in front-end manufacturing in the other manufacturing regions of the world as well. Dataquest expects the CD SEM equipment market to be approximately $245 million by 1995, reflecting a 19.5 percent compound annual growth rate (CAGR) between 1990 and 1995.

Dataquest notes, however, that optical CD measurement tools are not likely to disappear entirely. Several of the advanced optical tools have been designed specifically for submicron measurement performance and thus will compete directly with CD SEM. Conventional optical CD tools still provide a cost-effective, high-throughput option for the measurement of 1.0-micron geometries and larger. Finally, optical CD tools still will be required to perform overlay measurements in most applications. CD SEM equipment is not particularly well suited for overlay measurement because of the physics of the measurement procedure. An optical tool can "see" through a transparent film to the alignment marks on an underlying layer. CD

SEM measurement technology primarily relies on secondary electrons scattered off the wafer surface to determine its measurement signal, and thus, in most applications, is restricted to the measurement of surface features. Therefore, optical CD tools with joint linewidth and overlay measurement capabilities or dedicated overlay tools will continue to be purchased in the 1990s. Dataquest forecasts the optical CD equipment market to be $105 million in 1995, reflecting a five-year CAGR of 10.1 percent.

DATAQUEST CONCLUSIONS

A single company has dominated the CD SEM equipment market to date. The other nine companies in this market segment face significant challenges. They must overcome the "play it safe" attitude of semiconductor manufacturers that chose to buy from the market leader. These companies must establish a market presence strong enough to allow them to generate a sufficient income stream to invest in future technology development. At the same time, they must expand their international operations. Partnerships and alliances with larger equipment companies can provide the support that some of these companies will need to nurture long-term growth. For the U.S. equipment vendors of CD SEM tools, the Japanese market will be particularly difficult to penetrate because of the overwhelming strength of the domestic vendor base and the significant cost of doing business in Japan. Opportunities, however, always exist for a company able to sell, service, and support its equipment in an increasingly demanding customer base.

Kunio Achiwa
Peggy Marie Wood

The topics covered by SEMMS newsletters are selected for their general interest to SEMMS clients, which include wafer fab equipment suppliers, semiconductor materials companies, and semiconductor device manufacturers. The topics selected indicate the broad range of research that is conducted in the SEMMS group. Clients, however, often have specific information requirements that either go beyond the level of detail contained in the newsletters or beyond the scope of what is normally published in the newsletters. In order to provide complete decision support to our clients, Dataquest has a consulting service available to handle these additional information needs. Please call Stan Bruederle at (408) 437-8272 or Joe Grenier at (408) 437-8206 to discuss your custom requirements.

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Research Newsletter

NEW PRODUCTS, NEW ENTITY IN CD/WAFER INSPECTION

Early October was a busy time for companies in the critical dimension (CD) and wafer inspection equipment markets. Insystems and KLA Instruments announced their latest product offerings in advanced automated defect detection systems on October 5 and October 10, respectively. Also on October 5, Nanometrics and Optical Specialties, Inc. (OSI), jointly announced that they had entered into a letter of intent whereby Nanometrics would acquire OSI. Dataquest believes that these seemingly unrelated events are significant when viewed together, because they clearly reflect the link between advanced technology product offerings and the need for critical mass in corporate revenue in today's semiconductor equipment industry.

NEW PRODUCTS

Over the last several months, the industry has anticipated the introduction of the new automated defect detection tools from Insystems and KLA Instruments. The major enhancements for both tools include improved sensitivity and throughput.

The Insystems 8800, like its predecessor the 8600, utilizes spatial frequency filtering holography to automatically detect defects across an entire wafer surface. The new system has enhanced defect sensitivity of 0.35 micron or better. Throughput for the 8800 has been improved such that it now requires approximately 20 minutes to detect defects on an entire wafer surface compared with the 30 minutes required by its predecessor, the 8600. System throughput is enhanced even further when the 8800 is utilized in partitioning studies on multiple process layers. In partitioning studies, a semiconductor manufacturer can choose to make holograms at any number of processing levels. This procedure takes only five minutes per hologram; therefore, an effective 10- to 12-wafer-per-hour throughput can be achieved when operating in this mode. The advantage of the Insystems technology is that at any time the previously made holograms from these process levels can be inspected for defects in order to determine at what level a killer defect was introduced in the device.

The new KLA product, the 2110, has significantly increased throughput and improved defect sensitivity over that of its predecessors in the 20xx family. The 2110, like the 20xx systems, uses sophisticated image processing to automatically detect defects on a wafer. The 2110, however, has been designed specifically for defect inspection of repeating pattern arrays such as DRAMs, SRAMs, EPROMs, EEPROMs, and gate arrays. In this sense, it competes directly with Insystems' products which, by nature of their technology, are optimized for inspection of highly repetitive patterns. KLA views the 2110 as complementary with its other 20xx product offerings, which have full pattern capability for all device structures such as logic devices.

In addition, the 2110 offers the user nine combinations of speed and sensitivity. The company provided specifications on three examples of system operation: engineering analysis (mode = very high sensitivity), line monitoring (mode = high sensitivity), and equipment monitoring (mode = very high speed). In an engineering analysis inspection, the 2110 cuts the inspection time for a 90-square-centimeter portion of a 16Mb DRAM from 102 hours on the older 2029 to just 45 minutes on the new 2110. The defect sensitivity of the 2110 in this example is 0.30 micron compared with the 0.35-micron sensitivity of the 2029. (In comparison, the Insystems 8800, which has 0.35-micron sensitivity or better, would take 20 minutes to automatically detect defects across an entire wafer surface.)

In a line monitoring example, the 2110 with sensitivity of 0.5 micron can inspect a 30-square-centimeter area of a 16Mb DRAM on three wafers

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in 23 minutes. Finally, in an equipment monitoring example, the 2110 with sensitivity of 1.2 micron can inspect a 30-square-centimeter area of a 16Mb DRAM on one wafer in 3 minutes. In this example, the 20 wafer-per-hour throughput is comparable with the patterned wafer particle detection systems offered by companies such as Hitachi, Inspex, and Tencor.

NEW ENTITY

The announced acquisition of OSI by Nanometrics represents the formation of a new larger entity in the metrology and inspection equipment markets. The companies' equipment offerings for front-end wafer fabrication are complementary. Nanometrics manufactures optical CD, film thickness, and scanning electron microscope (SEM) CD/inspection equipment. Among OSI's products are optical CD and inspection systems that include two new products: a new overlay registration tool, the Metra 2000, and a new automated defect detection system, the Inspectra 5000. Dataquest believes that both of these tools currently are undergoing customer evaluation.

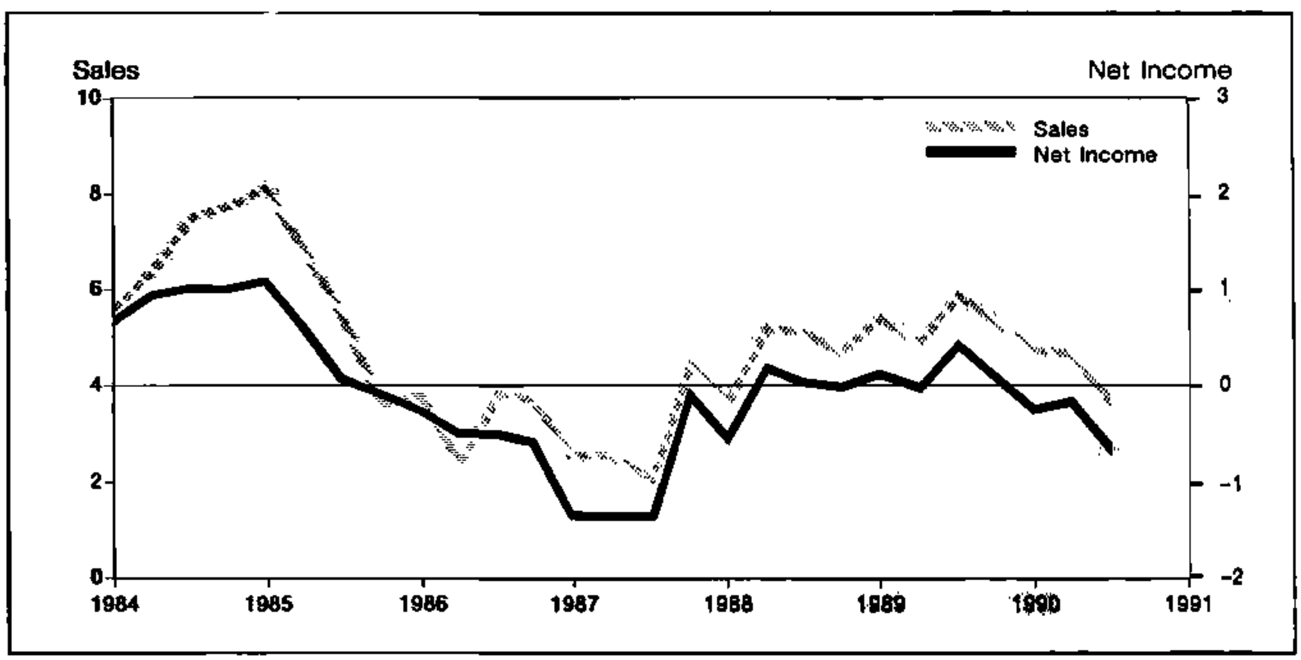
The acquisition, valued at approximately $3 million, includes an exchange of stock between the two companies. Under the agreement, OSI is expected to become a wholly owned subsidiary of Nanometrics, although Dataquest anticipates that financial economies of scale will eventually drive the companies to merge completely. The companies expect to complete the deal by the end of the year, although if they should fail to reach a definitive agreement, Nanometrics has an option to acquire approximately 20 percent of OSI's stock.

The announced acquisition was not entirely unexpected. As shown in Figures 1 and 2, both Nanometrics and OSI have experienced financial troubles over the past five years, suffering loss in net income much of the time since mid-1985.

DATAQUEST CONCLUSIONS

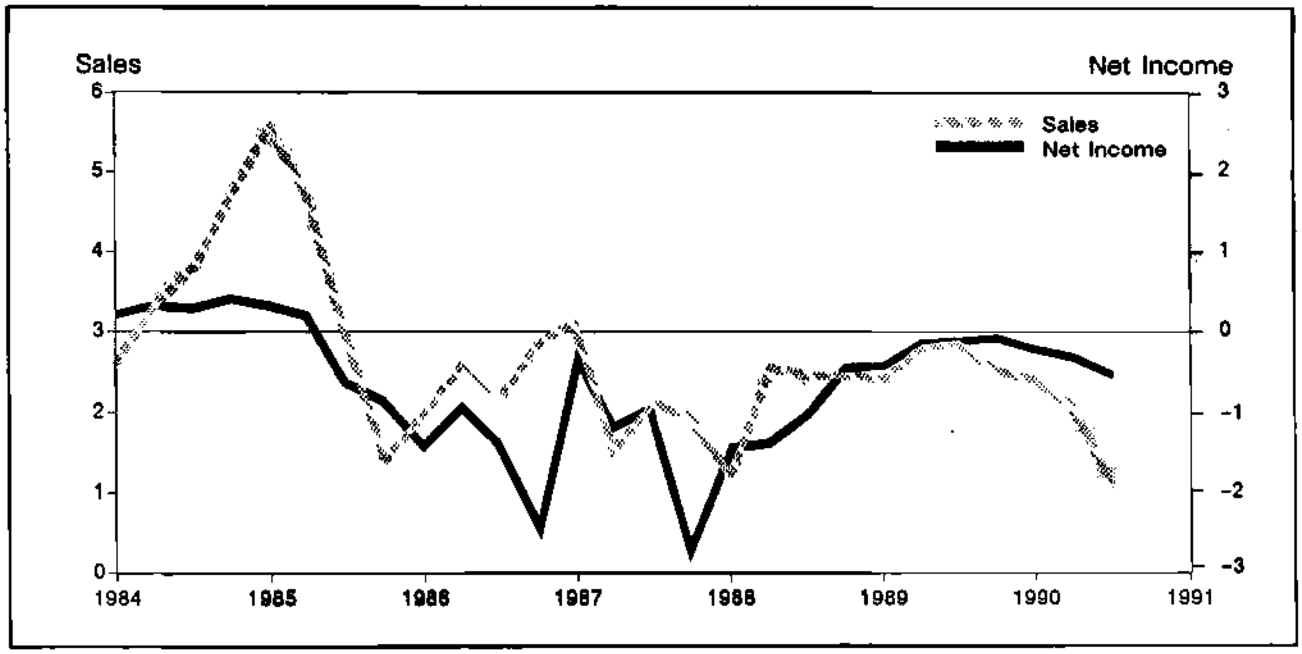
Dataquest believes that the new product announcements of Insystems and KLA Instruments and the announced acquisition of OSI by Nanometrics should be viewed together to understand the forces driving the companies and the market for CD/inspection equipment. The Nanometrics/OSI announcement is another example of consolidation in the metrology and inspection equipment market. Earlier this year, the merger of Cambridge Instruments and Wild Leitz was finalized resulting in the

FIGURE 1
Nanometrics
Sales and Net Income by Quarter
(Millions of Dollars)



Source: Nanometrics Financials, Dataquest (October 1990)

Figure 2
Optical Specialties, Inc.
Sales and Net Income by Quarter
(Millions of Dollars)



Source: Optical Specialties Financials, Dataquest (October 1990)

formation of the new company, Leica Plc. Dataquest believes that the long-term success of any equipment company depends on its ability to generate an income stream capable of supporting the significant R&D costs and globalization efforts demanded in today's semiconductor industry. OSI, in particular, has invested heavily over the last several years to develop its high-end product offerings but has been supported by a small revenue stream. The acquisition of OSI by Nanometrics should bring the new company closer to the required "critical mass" to survive in today's equipment industry.

With the Inspectra 5000, the new advanced automated defect detection tool from OSI, Nanometrics/OSI will be directly targeting the market that Insystems and KLA Instruments serve in automated defect detection. Automated defect detection tools, with their relatively high price tags of $1 million plus, have been the primary factor driving market growth in the wafer inspection equipment market in the late 1980s. One cannot underestimate the importance of advanced defect detection technology in this market segment. A company with relatively few units that incorporate advanced technology can command a dominant market position. With the announced acquisition, Nanometrics/OSI pins its hopes on long-term survival in the semiconductor equipment industry. The company, however, has its work cut out as it faces significant competition in the automated defect inspection market from the more established Insystems and KLA Instruments.

Peggy Marie Wood

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Research Newsletter

OPTICAL CD AND WAFER INSPECTION EQUIPMENT MARKET UPDATE

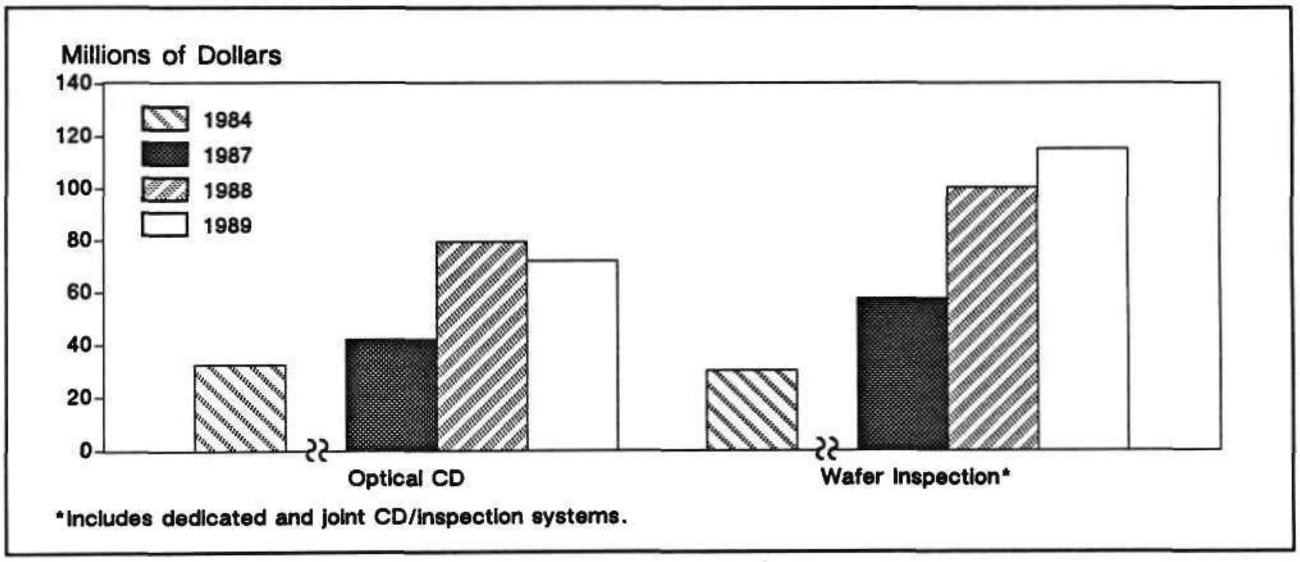
SUMMARY

The worldwide optical critical dimension (CD) and wafer inspection equipment markets experienced significant growth in the latter half of the 1980s because of increased demand for submicron measurement and automated defect detection capability (see Figure 1). In 1989, the wafer inspection equipment market (including joint CD/inspection tools) was $115.3 million, up 15 percent over its 1988 level. The optical CD equipment market, however, declined by 9 percent from its 1988 level of $79.4 million to $72.0 million in 1989. This newsletter examines the current status and market outlook for both the optical CD and wafer inspection equipment markets.

OPTICAL CD SYSTEMS

A variety of optical techniques are applied to the measurement of critical dimensions on a wafer. These techniques include traditional white-light microscopy, enhanced video imaging, laser-based metrology, confocal scanning laser microscopy, and coherence probe imaging. The ability to provide submicron measurement capability as well as automated equipment performance have been the two key factors driving the optical CD market on a vigorous growth track over the last several years. Between 1984 and 1988, this market experienced a compound annual growth rate (CAGR) of 25 percent. In 1989, however, the optical CD market declined for the first time since 1985. The 1985

FIGURE 1
Worldwide Optical CD and Wafer Inspection Market



Source: Dataquest (October 1990)

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market decline can be understood as part of an extended downturn in the wafer fabrication equipment industry overall. In 1989, however, the worldwide wafer fab equipment market grew 19 percent. Dataquest believes that the market decline in the optical CD equipment market in 1989 was due directly to the growing market acceptance of a competitive submicron measurement technology: CD SEM (scanning electron microscopy).

Figure 2 presents the regional and market ownership segmentation for the 1989 optical CD equipment market. Although Japan represented 45 percent of the worldwide wafer fab equipment market in 1989, it accounted for just 26 percent of the optical CD equipment sales. This difference is because many Japanese semiconductor manufacturers have opted to jump from conventional white-light microscopy and laser-based measurement systems directly to CD SEM measurement tools and thus bypass several of the advanced optical CD technologies that have generated interest as well as a market in the United States and Europe.

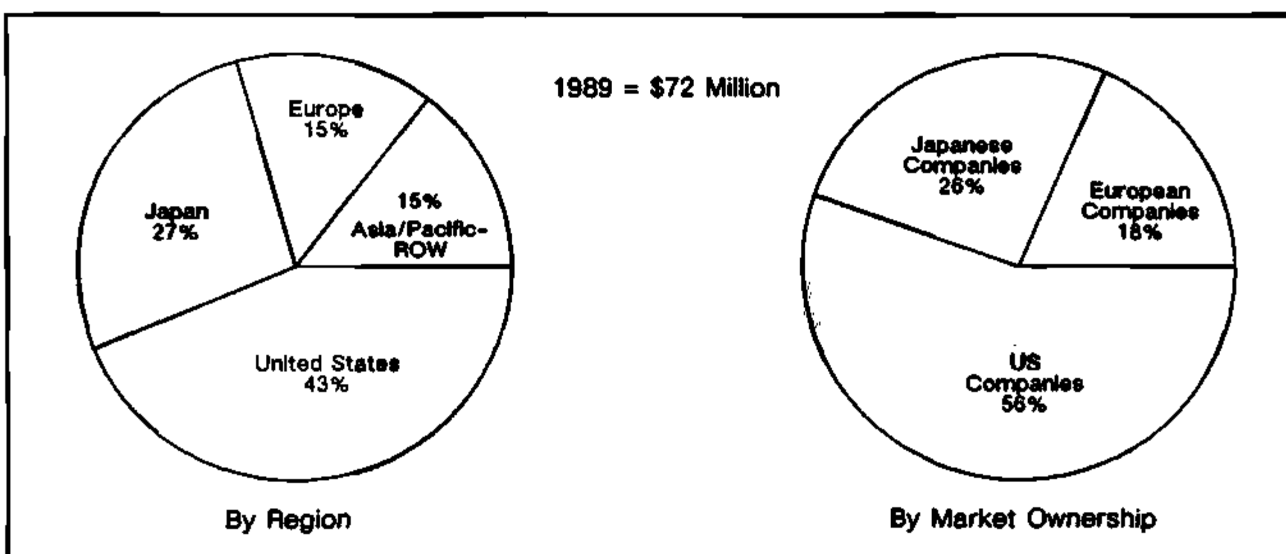
It has been primarily US and European companies that have pursued the development of advanced optical CD systems. As Figure 2 shows, US companies represented the largest share of the 1989 optical CD measurement market with 56 percent. European companies accounted for an additional 18 percent. These shares are in comparison with US and European company shares of the 1989 wafer fab equipment market of 40 percent and 10 percent, respectively. Dataquest believes that US and European companies will continue to dominate the optical CD equipment market in the 1990s. At the same time, however, Dataquest expects this market to experience slower growth relative to overall wafer fab equipment spending as CD SEM tools garner an increasingly dominant share of the critical dimension metrology market.

WAFER INSPECTION

Wafer inspection refers to the inspection of patterned wafers for process-related defects by visual and image-processing techniques. In 1989, the wafer inspection equipment market, including both dedicated and joint CD/inspection tools, was $115.3 million. Between 1984 and 1989, this market experienced a CAGR in excess of 30 percent. Automated defect detection tools, a segment of the wafer inspection equipment market, have been the primary factor driving market growth during this time period. Tools with automated defect detection capability, such as those systems from Insystems, KLA Instruments, and newcomer Micro-Controle, had an average selling price (ASP) on the order of $1.25 million in 1989. These three companies captured a 65 percent share of the wafer inspection equipment market while accounting for just 10 percent of unit shipments.

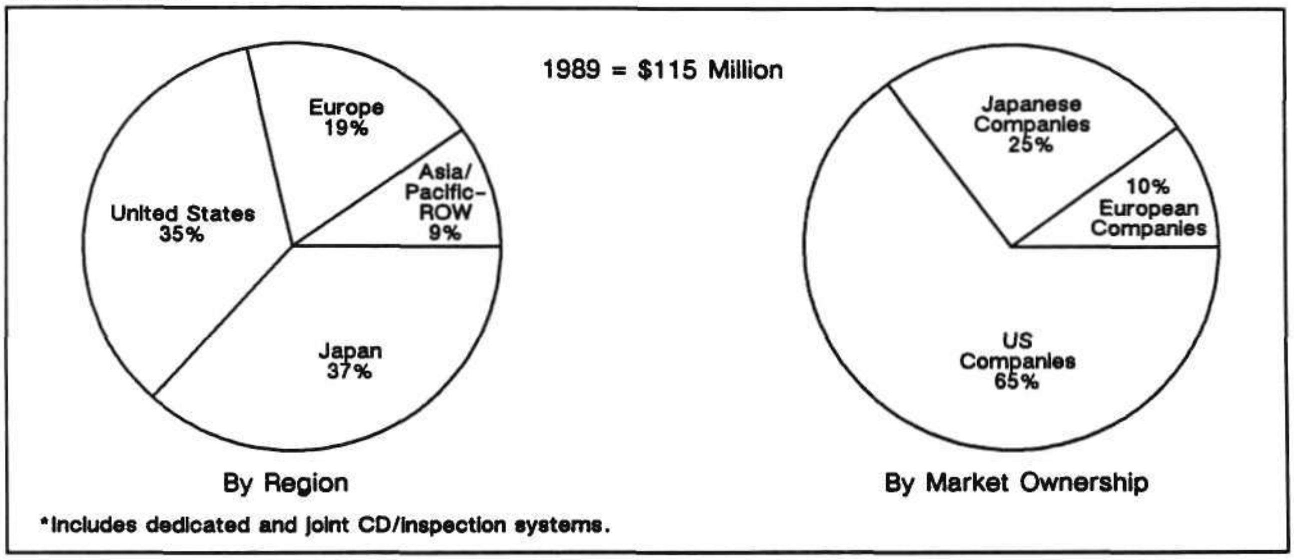
Figure 3 presents the regional and market ownership segmentation for the 1989 wafer inspection equipment market. On a regional basis, Japan

FIGURE 2
1989 Optical CD Equipment Market
(Percent Share)



Source: Dataquest (October 1990)

FIGURE 3
1989 Wafer Inspection Equipment Market (Percent Share)



Source: Dataquest (October 1990)

represented 37 percent and the United States 35 percent of worldwide sales of wafer inspection systems. However, the ASP of tools sold in the United States was $272,000 compared with $134,000 in Japan. This difference reflects the relatively higher amount of automated defect detection tools in the product mix of semiconductor manufacturers in the United States relative to Japan.

Figure 3 clearly shows that US companies dominate the wafer inspection equipment market, with a 65 percent share in 1989. Insystems and KLA Instruments, with their automated defect detection systems, account for the overwhelming majority of that share, together representing 62 percent of US company share. One cannot underestimate the importance of advanced defect detection technology in this market segment. A company with relatively few units that incorporate advanced technology can command a dominant market position because the ASP of its equipment is much higher than that of other companies.

Both Insystems and KLA Instruments are pursuing new opportunities in the automated inspection of liquid crystal and flat panel displays. Dataquest understands that Insystems currently is developing a tool for the inspection of active matrix liquid crystal displays (LCDs). In September of this year, KLA and Nippon Mining of Japan announced that they had signed an agreement to form a new joint venture company, KLA Acrotec Company, Ltd., for development of flat panel display inspection equipment. The automated defect detection technologies of Insystems and KLA are well suited for liquid crystal and flat panel display manufacturing, where it is critical to find defects before processing is complete so that the product can be reworked or repaired.

COMPANY RANKINGS

Table 1 ranks the top players in the optical CD and wafer inspection equipment market by their 1989 worldwide revenue.

KLA Instruments continues to dominate the overall market with its wafer inspection equipment family of 20xx advanced defect detection systems. In 1989, the company upgraded a number of 2020 tools in the installed base to 2030/2031 system capability. The company also offers an advanced optical CD measurement system, the KLA 5000, for submicron metrology. This system still is in the early stages of system shipments and competes with other advanced optical CD equipment as well as CD SEM tools.

Nikon historically has been a strong player in the optical CD and wafer inspection equipment markets, with its LAMPAS laser-based CD measurement tools and Optistation wafer inspection stations. Dataquest expects Nikon, in particular, to feel the market impact of CD SEM metrology tools on its optical CD equipment business. Nikon, with a 36 percent share, was the leading supplier of optical CD systems in Japan in 1989. Japan, however, is the semiconductor manufacturing region of

TABLE 1
1989 Worldwide Optical CD and Wafer Inspection Equipment Company Rankings (Revenue in Millions of Dollars)

Company	Revenue	Market Share	Optical CD	Dedicated Wafer Inspection	Joint CD/ Inspection
KLA Instruments	63.6	34.0	X	X	X
Nikon	27.1	14.5	X	X	
Leica*	16.7	8.9	X	X	
Insystems	14.3	7.6		X	
Nanoquest	8.9	4.8	X		
IVS, Inc.	7.2	3.8	X		
Optical Specialties, Inc.	6.7	3.6	X	X	
SiSCAN Systems	6.7	3.6	X		
Hitachi	6.6	3.5	X		
Nidek	5.6	3.0	X	X	
Micro-Controle	5.3	2.8	X	X	
Other Companies	18.6	9.9	X	X	
Worldwide Market Total	187.3	100.0%			

*Includes Wild Leitz and Wild Leitz Instruments
Source: Dataquest (October 1990)

the world that has shown the most interest and commitment to CD SEM metrology. Hitachi, ranked second in Japan's optical CD market with 33 percent share in 1989, is well positioned to survive the technology jump to CD SEM because it is the leading supplier of CD SEM systems today.

Leica, formed by the recent merger of Cambridge Instruments and Wild Leitz, is the dominant European company in the optical CD and wafer inspection equipment market. Leica offers optical CD measurement systems based on white light microscopy as well as confocal scanning laser technology. The confocal laser technology, acquired from Heidelberg Instruments, is an advanced optical CD measurement technique that provides submicron measurement capability and 3-D profilometry. Leica competes with SiSCAN Systems in the confocal equipment market for CD wafer metrology. Both companies also offer confocal measurement tools for mask metrology. A new company is entering the confocal measurement technology arena. In May of this year, Prometrix announced its development of a new confocal CD measurement system for wafer metrology, the Conquest 2000.

Insystems' advanced automatic defect detection system, the Model 8600, has received good acceptance by the industry. The 8600 uses spatial frequency filtering holography to perform automated defect detection on the entire wafer surface. Insystems' competitors, KLA Instruments and Micro-Controle, rely on pattern matching and sophisticated image processing to detect defects automatically on the wafer. Micro-Controle is a newcomer to this market segment; 1989 was the first year of system shipments for the company's IDIS wafer inspection station.

Optical Specialties, Inc., was one of the early companies to provide optical CD and wafer inspection equipment for the industry. Earlier this year, OSI announced a family of new high-end products for optical metrology and wafer inspection, including the Metra 2000 (overlay registration), Vista 1000 (wafer inspection), and the Inspectra 5000, an advanced automated defect detection system.

In April 1989, OSI announced that it had entered into a combined R&D and licensing agreement with PruTech R&D Partnership II and Toray Industries of Japan. This agreement was established to allow OSI to complete the development of the Inspectra system. The agreement called for joint engineering development by both Toray and OSI. Toray made an initial payment for a technology license and will continue royalty payments based on the future sale of the final product. OSI also has contracted to build initial systems for product introduction in Japan. OSI and Toray share marketing rights with Toray retaining exclusive distribution rights for the Inspectra in Japan.

DATAQUEST CONCLUSIONS

In semiconductor manufacturing, device complexity, processing steps, mask levels, and wafer size are increasing at the same time that line geometries are shrinking. CD measurement and wafer inspection are recognized as essential elements of the production environment to verify that the manufacturing process is in control. Because measurement and inspection represent such vital aspects of semiconductor manufacturing, Dataquest expects the CD and wafer inspection equipment markets to continue healthy growth into the 1990s. In CD measurement, improved submicron measurement capability and automated equipment performance are two of the key challenges facing equipment companies. Clearly, the technology transition from optical to CD SEM affected growth for the optical CD market in 1989. Dataquest expects this transition to continue, with CD SEM becoming the dominant submicron measurement technology in the 1990s. The technical challenges facing wafer inspection equipment companies include improved defect sensitivity and faster automated defect detection. Future requirements may include automated classification capability as well. Finally, as with all categories of wafer fab equipment, the increasing cost of CD and wafer inspection systems will necessitate increased levels of equipment reliability and uptime so that semiconductor manufacturers can maximize the utilization of their capital investments in the 1990s.

Peggy Marie Wood

Semiconductor Materials

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Research *Newsletter*

JAPANESE 200mm MARKET POISED TO GROW

Since 1988, a small demand has existed in Japan for 200mm silicon wafers. Dataquest estimates consumption to be less than 100,000 pieces in 1990. However, the demand for 200mm silicon wafers in Japan is forecast to increase (see Table 1) and the market is poised to grow. Several manufacturers soon will begin 200mm production lines to manufacture 4Mb DRAMs (see Table 2), pushing demand up to 300,000 pieces in 1991.

Dataquest expects the demand for 200mm wafers to accelerate very quickly starting in 1993 as 16Mb DRAM production lines begin ramping. The 16Mb DRAM will be the first device built exclusively on 200mm wafers. We also expect the 64Mb and 256Mb DRAMs to be built using 200mm wafers. The demand for 200mm wafers is estimated to reach a peak in its life cycle between the years 2004 and 2007. Even so, demand for 200mm wafers will continue well into the next century. The 1-gigabit (1Gb) DRAM is forecast to be built on a larger wafer—either 250 or 300mm. Demand for this larger wafer size is still ten years off, however.

Our five-year forecast is based on the 200mm plants that have been announced by semiconductor manufacturers. In our calculations, we have assumed a relatively slow plant start-up because we expect start-up delays associated with integrating 200mm process equipment into the production line.

The forecast will not be achieved if the current economic climate deteriorates into a worldwide recession. The prospect for a serious recession is low according to the current economic outlook of The Dun & Bradstreet Corporation. If there are regional economic problems outside of Japan, we would still expect Japanese companies to continue their capital investments in 200mm production plants.

Kunio Achiwa
Mark FitzGerald

TABLE 1
200mm Wafer Demand in Japan by Device Type (Millions of Pieces)

Application	1990	1991	1992	1993	1994	1995
64Mb	0	0	0.02	0.03	0.04	0.05
16Mb	0	0.02	0.24	0.63	1.18	1.77
4Mb	0.10	0.28	0.74	1.17	1.51	1.65
Others	0	0	0.02	0.10	0.22	0.37
Total	0.10	0.30	1.02	1.93	2.96	3.83

Source: Dataquest (December 1990)

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TABLE 2
200mm Wafer Manufacturers

Company	City	Fab Name	Type *	Products	Wafer Capacity per Month		Start of Production
Toshiba	Yokkaichi	Phase 2	F	4Mb DRAM, 16Mb DRAM	25,000		1992
	Yokkaichi	Phase 3	F	4Mb DRAM, 16Mb DRAM	20,000		1994
	Yokkaichi	Phase 4	F	16Mb DRAM	25,000		1996
	Tamagawa	NA	P	4Mb DRAM, 16Mb DRAM	2,500		1990/end
	Oita Bldg #4	No. 2	F	16Mb DRAM	20,000		1991
	Oita Bldg #4	No. 3	F	16Mb DRAM	20,000		1992
	Oita Bldg #4	No. 4	F	16Mb DRAM	20,000		1993
Fujitsu	Mie	No. 3	P	4Mb DRAM, 16Mb DRAM	3,000		1989
	Mie	No. 4	F	16Mb DRAM, 1Mb SRAM	10,000		1991/11
	Iwate	No. 4	F	16Mb DRAM, 1Mb SRAM	25,000		1992/4
	Kagoshima	NA	F	16Mb DRAM	NA		1992
Hitachi	Musashi	NA	P	4Mb DRAM, 16Mb DRAM	8,000		1990/9
	Kofu	Imasuwa	P	4Mb DRAM, 16Mb DRAM	8,000		1991/1
	Naka	NA	F	NA	NA		1991/9
IBM	Yasu	NA	F	1Mb DRAM, 4Mb DRAM	15,000	(4,000)	1990/4
	Yasu	Rsrch Ctr	P	1Mb DRAM, 4Mb DRAM	8,000		1988/5
Mitsubishi	Saijo	A-1F	F	16Mb DRAM	20,000		1991/2
Motorola	Sendai	NA	F	32-Bit MPU, RISC, DSP	20,000		1994
NEC	Sagamihara	G-2	P	16Mb DRAM	5,000		1990/2
	Kumamoto	Fab 8	F	4Mb DRAM, RISC, MPU	20,000		1992/3Q
	Hiroshima	Phase 2	F	4Mb DRAM, EPROM	30,000		1993-1994
	Hiroshima	Phase 3	F	16Mb DRAM, MPU, EPROM	22,000		1994
	Hiroshima	Phase 4	F	16Mb DRAM, MPU, EPROM	22,000		1995
NKK	Keikin	Phase 2	F	4Mb DRAM, 16Mb DRAM	NA		1997
	Keikin	Phase 3	F	16Mb DRAM	NA		2000
TI	Hiji	NA	P	4Mb DRAM, 16Mb DRAM	7,000		1989/12
	Hiji	Expand	F	16Mb DRAM	NA		NA
KTS	Nishiwaki-Shi	NA		Logic ASIC	16,000		1992/8
Oki	Hachioji	V4	P	NA	5,000		1991/4Q
	Miyazaki	M4	F	NA	20,000		1993/1Q
Sanyo	NA		P	NA	NA		1992/3Q
			F	NA	NA		1993/4Q
Sharp	NA	No. 1, Phase 2	F	NA	NA		NA
Sony	Atsugi		P	NA	NA		1990 End
	Nagasaki		F	NA	NA		1991/3Q

*F = Fab
P = Pilot
NA = Not available
Source: Dataquest (December 1990)

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Research Bulletin

MERCHANTS VIEW EPI WAFERS AS AN OPPORTUNITY

INTRODUCTION

Merchant silicon wafer vendors continue to look for opportunities to supply epitaxial wafers because they typically sell at prices two to three times the price of a silicon wafer (see Table 1). In addition to being a higher-value-added product, epi wafers have better margins than silicon wafers because of their higher technical content. Dataquest expects the epi wafers to continue to provide better returns than silicon wafers.

THE EPI WAFER MARKET

The demand for epi wafers varies from region to region. The worldwide sales of merchant silicon epitaxial wafers grew 6.9 percent in 1989. Sales in 1989 totaled $537.6 million versus $503.0 million in 1988 as shown in Table 2.

Most of 1989 worldwide growth occurred in the US market. The United States consumed a total of 54 million square inches (MSI) of merchant epi wafers. Captive production accounted for another

TABLE 1
Silicon and Epitaxial Wafers
Weighted Average Selling Price by Region, 1989
(in US Dollars)

	Silicon	Epitaxial
United States	0.96	2.70
Japan	1.37	4.29
Europe	1.04	3.01
Asia/Pacific-ROW	0.94	2.85

Source: Dataquest (October 1990)

TABLE 2
1989 Merchant Epitaxial Wafer Sales
by Process Technology
(Percentage)

Region	CMOS	Bipolar	Discrete	CCD/Other	Merchant Epi MSI	Epi Wafer Sales ($M)
United States	66	0	33	0	54	145.8
Japan	15	39	34	13	76	326.4
Europe	51	15	32	2	18	52.7
Asia/Pacific-ROW	19	0	81	0	5	12.7
Total					153	537.6

Source: Dataquest (October 1990)

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25 MSI by our estimates. A large part of this captive production was used to make bipolar devices. Bipolar devices have buried layers and require a mask step. Yet, US device manufacturers are unwilling to supply their masks to merchant epi wafer vendors for proprietary reasons.

Merchant sales in the United States were fueled by the demand for CMOS epi substrates as a solution to latchup. The consumption of merchant CMOS epi wafers totaled 35.6 MSI in 1989, an increase of 29.8 percent from the previous year. The demand for discrete epi wafers in the United States totaled 17.8 MSI in 1989. This segment of the market grew only 1.5 percent.

Japanese consumption of merchant epi wafers totaled 75 MSI. The size of the merchant market is attributable to Japan's leadership in the production of semiconductors coupled with a small base of captive epi wafer producers. In Japan, very little captive production exists because of the close relationship between wafer vendors and semiconductor manufacturers. The demand in Japan for merchant epi wafers was flat in 1989 because Japanese semiconductor manufacturers continued to design out expensive epi films in DRAM applications.

Both the European and Asia/Pacific-ROW markets experienced solid growth on a percentage basis—20 and 25 percent, respectively. In 1989, 18 MSI of merchant epi substrate were purchased in Europe, and Asia/Pacific-ROW purchased 5 MSI. However, the demand for merchant epi substrates in these regions is small in comparison with the US and Japanese markets. As a result, their growth had little impact on the worldwide market.

DATAQUEST CONCLUSIONS

Dataquest expects the merchant epitaxial wafer market to continue to grow over the next five years at a compound annual growth rate (CAGR) of 11.1 percent. Demand will be driven by a 17.2 percent growth in MOS devices and a 9.1 percent growth in discrete devices during the 1990 to 1994 time frame. The demand for epi wafers is expected to grow rapidly in the second half of the decade because Dataquest expects Japanese manufacturers to incorporate epi films in the design of the 64Mb DRAM. Much of this growth will be supplied by merchant wafer vendors.

Mark FitzGerald

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Research *Newsletter*

ENERGY IMPACT ON SEMICONDUCTOR MATERIALS

SUMMARY

The increase in oil prices because of the Middle East crisis is widely expected to slow the growth of gross national product (GNP) for the industrialized nations. Semiconductor material suppliers will be impacted by this slowdown as the demand for semiconductor devices slows.

Less well understood are the probable microeconomic effects of higher oil prices on semiconductor material vendors. A permanent increase in oil prices is expected to have the greatest impact on material vendors' transportation costs—shipping and travel—and electric power costs. The impact will vary, depending on the industry's or individual company's exposure. Some of the higher costs will be passed readily through to the semiconductor manufacturers, while others will be absorbed by the vendors.

TRANSPORTATION

An increase in oil prices quickly translates into higher fuel costs. As the driving public all over the world is aware, the price of fuel at the pump increased even before the higher-priced oil arrived at the refinery. For material vendors, the higher fuel prices have resulted in higher shipping costs.

However, Dataquest does not expect shipping costs to pose a major problem for material suppliers. Because these costs are easily broken out, Dataquest expects suppliers to pass the higher shipping costs on to the semiconductor manufacturers.

A more difficult problem is defraying the increased costs of business travel. It is widely believed that material vendors will absorb these costs. Creative companies will manage their travel expenses more efficiently; less creative companies will cut budgets.

ELECTRIC POWER

Many material suppliers have a high electrical power content associated with their production costs. But it is not immediately clear what impact higher oil prices will have on power costs, for several reasons.

First, the electric power industry is regulated in most countries, and all rate hikes must be approved by government boards. As a result, spikes in energy prices are not quickly transferred to end users.

Second, electric utilities' exposure to oil prices varies widely among countries and even among regions within countries. Utilities use five major energy sources to generate electric power—oil, coal, nuclear, hydroelectric, and natural gas (see Table 1). The price of electric power in a country or region (see Table 2) reflects the mix of energy sources.

Long-term higher oil prices will impact power price rates to the degree that a region's power generation is leveraged on oil. The Middle East crisis may also cause utilities to move to more stable energy sources, such as coal and nuclear power. But because these sources have safety and environmental issues associated with their use, switching to coal or nuclear-fired plants may not provide an optimal mix from a cost point of view.

In fact, power rates are expected to increase in countries that have a high percentage of coal-fired plants as the industrialized countries begin fighting acid rain (nitrogen oxides and sulfur oxides discharges) and the greenhouse effect (carbon dioxide discharges). In Asia and Europe, nuclear power was considered an inexpensive energy source. However, since the Chernobyl disaster in 1986, doubts about nuclear power have spread, and development plans are being postponed or scaled down.

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TABLE 1
Electric Power Generation by Energy Source (Percent)

	Japan	United States	South Korea	Germany
Nuclear	27.6	8.8	47.0	20.3
Oil	24.7	22.9	48.0	25.3
Natural Gas	22.4	29.8	>1.0	-
Coal	9.5	33.5	-	46.2
Hydroelectric	13.7	4.7	4.0	7.4
Others	2.1	0.3	-	0.8
Total	100.0	100.0	100.0	100.0

Source: Dataquest (October 1990)

TABLE 2
World Prices for Electric Power (US$1 per Million Kilowatt Hours)

Country	Price
Germany	85,000
Japan	78,700
South Korea	81,381
United States	
Salem, Oregon	27,500
San Jose, California	79,000
Morristown, New Jersey	82,084

Source: Dataquest (October 1990)

ASSUMPTIONS

Any analysis of energy costs at this time is very speculative, because much depends on how the Middle East crisis is resolved. However, we can address some of the pricing pressures for the different semiconductor materials by assuming a long-term trend for oil prices and understanding how energy costs impact different material suppliers in different regions.

This newsletter assumes that the crisis in the Middle East will lead to a permanent increase in oil prices in the $23 to $28 per barrel range. This price is based on the assumption that a political solution to the crisis is reached without an outbreak of war. Economic and political disruptions in the region will prevent oil prices from returning to pre-crisis levels.

MATERIALS

The semiconductor materials reviewed are silicon, gases, chemicals, photoresist, and sputtering targets. Each has a variable cost component related to energy prices.

The energy component of silicon wafer costs is 3 to 10 percent. Currently, most of the world's production is located in Japan, the United States, and Germany. A permanent increase in oil prices is expected to impact Japanese wafer plants the hardest. Japanese utilities rely on oil-fired power plants for 24.7 percent (see Table 1) of their power. US wafer plants are located primarily in the Northwest and are supplied with low-cost hydroelectric power. Wacker, the major European supplier, has its own hydroelectric plant. Because Japanese plants produce about one-half of the world's silicon wafer supply, Dataquest expects wafer prices to be marginally impacted by higher power costs.

Industrial gases also have a high energy cost associated with their manufacturer. This is especially true for the bulk gas products (i.e., nitrogen and oxygen), which are manufactured using cryogenic separation technology. The electrical power component of bulk gases is roughly 50 to 60 percent of their production cost. Consequently, the price of industrial gases will be impacted significantly by higher power rates.

Photoresist and wet chemicals including acids and solvents, are not expected to be impacted if power rates increase. The manufacturing processes for these materials are not energy intensive; they are less than 3 percent of total manufacturing cost. However, photoresist and some of the solvents have petroleum feedstocks. In the case of photoresist, the raw material costs are a small percentage of the overall product cost, but for some of the solvents (e.g. toluene xylene), raw material costs could drive up prices 25 to 40 percent. Dataquest expects photoresist and wet chemicals prices to continue to be driven by performance issues and purity specifications.

Sputtering targets do not have a high energy cost associated with their manufacturer. A more important factor is the price of metals, and Dataquest does not expect the Middle East crisis to affect prices for these materials. In fact, metal prices are forecast to be flat because we anticipate a low rate of inflation worldwide.

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Research Newsletter

LIQUID REPLACEMENTS: POINT, COUNTERPOINT

OVERVIEW

Two of the most hazardous materials used in the manufacture of integrated circuits and devices are arsine and phosphine. Both are highly toxic gases used as dopants in silicon wafer processing (i.e., CVD, diffusion, and ion implant) and as source materials in compound semiconductor production (i.e., MOCVD films).

Currently, American Cyanamid Company is offering replacement materials tertiarybutylarsine (TBA) and tertiarybutylphospine (TBP) (see Figure 1). Both TBA and TBP are less toxic than their gas complements. In addition, they have a much lower dispersion value because they are low vapor-pressure liquids.

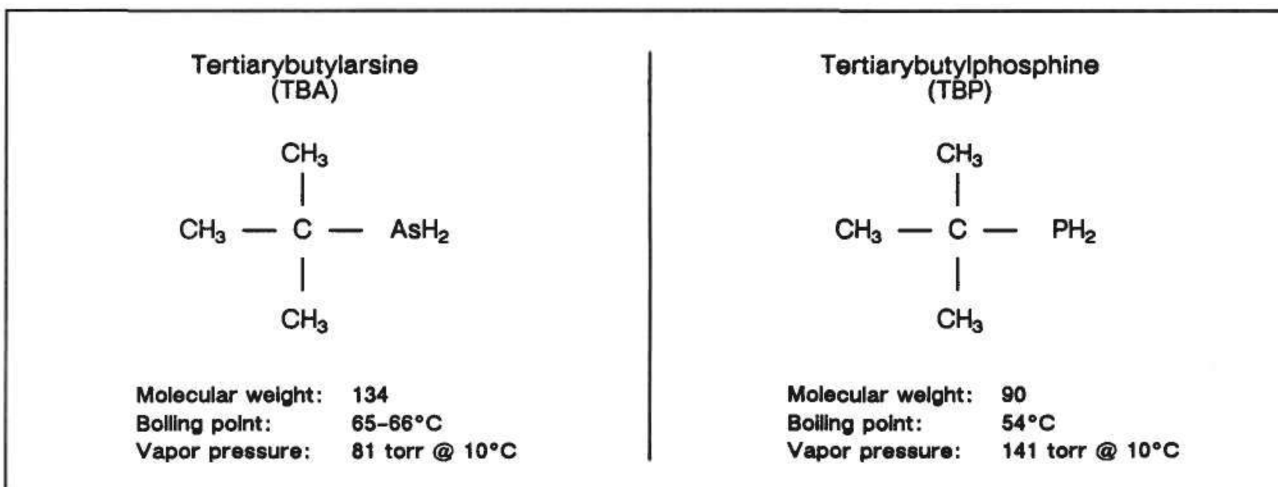
Although TBA and TBP have recognized safety advantages over arsine and phosphine, equipment and device manufacturers have not been aggressive in developing processes around these materials. The slow pace of replacement is curious in light of the daunting maze of regulatory restrictions and costs associated with using arsine and phosphine gas.

POINT

Advocates of liquid replacements have a two-pronged argument. They point out that high-purity TBA and TBP either meet or exceed the technical performance of arsine and phosphine. In addition, the materials are several orders of magnitude less hazardous than are the gases.

Suppliers, recognizing that TBA and TBP's acceptance is not predicated on safety issues alone, are focusing first on defining the technical advantages of the materials. Important to all applications

FIGURE 1
Liquid Replacements



Source: American Cyanamid

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is the fact that the liquids can be purified to a higher degree than can the gases. The liquids also decompose at lower temperatures, and the efficiency of utilization is higher, resulting in smaller amounts of materials consumed and exhausted.

In MOCVD processes, TBA and TBP have grown films with electron mobilities equal to high-quality gas results. Furthermore, a wide range of complex films and devices have been manufactured using TBA and TBP. The performances of these parts are equivalent to parts manufactured using gas-based processes. In in-situ doped polysilicon processes, TBP produces a much faster rate of film growth than does phosphine gas. Texas Instruments has developed a doped polysilicon production process for its 16Mb DRAM using TBP. In addition, the initial work in the ion implant area suggests that TBA and TBP will have advantages over the gases and solid dopant sources that are now being employed.

Advocates of TBA and TBP also are quick to mention that these materials at their current purity levels do not contaminate the process with carbon. This criticism was true of previous organic compounds evaluated as replacements.

Accepting the fact that these products can be adopted to meet process parameters, the real benefits are those associated with improved safety. Because they are liquids with a low vapor pressure and because they are much less toxic than the gases, a spill is not nearly as serious. Because they are easier to handle and less of a hazard, the cost associated with handling these materials is much less.

Liquid replacements may have a multiplier effect that is not completely understood. There certainly will be benefits that are overlooked or are intangible. For instance, because TBA and TBP are less hazardous than the gases, regulatory approval for new facilities will be shorter. Also, companies that have switched to liquid dopants benefit from the goodwill earned by being responsible corporate citizens. With community right-to-know laws and other local community involvement increasing, the elimination of toxic gases from a site is an issue management will face more frequently.

Finally, the trend toward tougher regulations (i.e., the Santa Clara Toxic Gas Ordinance) will continually make it more difficult and costly for manufacturers to use arsine and phosphine in the future. What is happening in California today will likely spread to the rest of industry, both domestically and internationally. These pressures should ultimately ensure the success of TBA and TBP, especially when coupled with the technical performance of the materials.

COUNTERPOINT

The detractors of liquid replacements have three objections. First, they say that these materials are not universal replacements. They believe that the organic groups in the molecule produce carbon contamination, which is especially deleterious to the growth of certain MOCVD films. Because process performance is critical, this issue alone prevents the materials' acceptance by a segment of end users.

Second, gaseous processing has a strong momentum. Gas technology is well known and widely used throughout the semiconductor industry. TBA and TBP are liquid-phase materials. Liquid delivery systems are plagued with consistency and uniformity issues. In addition, there is little experience or support in dealing with hazardous liquid spills. These problems may either be real or perceived, but they do pose a hurdle when compared with well-defined gas technology, which is known to work.

Third, an environmental-controls industry, which regulates factors such as cabinets, detectors, and piping, has grown up around gases. The industry has shown that it can handle hazardous gases. Management is comfortable with accepting the risks, because the technology to provide safeguards is available at reasonable costs.

Moreover, the industry's record is perhaps the best indicator that hazardous gases are manageable. To date, there are no serious accidents associated with either the use or transport of arsine or phosphine.

DATAQUEST CONCLUSIONS

Dataquest estimates the worldwide market for arsine and phosphine to be from \$13 million to \$16 million in 1990. TBA and TBP sales are expected to be less than \$1 million. It is fair to say that liquid replacements have not penetrated much of the traditional gas market. This fact is emphasized when one recognizes that the average selling price for the liquids is roughly 15 times the selling price for their gaseous complements.

Although demand is small today, Dataquest estimates that TBA and TBP will grow to be a \$6 million to \$8 million worldwide market in the next five to seven years. There are two hurdles for suppliers in building this market. First, they must convince the engineering community of the technical performance of these materials. The most likely way to accomplish this task is to work closely with development programs at equipment and device companies.

Second, suppliers must improve the marketing and distribution of TBA and TBP. For example, the misconception that TBA and TBP produce organic contaminants is widely held. The market for liquid replacements is at a juncture where strong applications support is required. The more muscle vendors throw into this effort, the faster the market will ramp. American Cyanamid has addressed this issue by recently signing up Sumitomo Chemical to market TBA and TBP in Japan.

Introducing new materials is traditionally a slow process, and liquid replacement materials are no exception. Dataquest expects compound semiconductor manufacturers to adopt these materials first, partly because MOCVD processes require relatively large volumes of concentrated source gas. We view development programs in this area as the likeliest avenue for gaining acceptance for the liquid replacements. The commercialization of TBA and TBP is timely, because most MOCVD efforts could be defined as being in the development stage.

Silicon applications pose a different problem. These processes have evolved relying on gaseous dopants, and the inertia factor is high. Also, the volume of arsine and phosphine used in silicon applications is smaller and more diluted than the volume used for MOCVD applications, so it does not pose as big a concern. Consequently, Dataquest expects liquid dopants to have a minimal impact on this segment in the near term.

Mark FitzGerald

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Research Newsletter

1989 US SPECIALTY GAS MARKET

SUMMARY

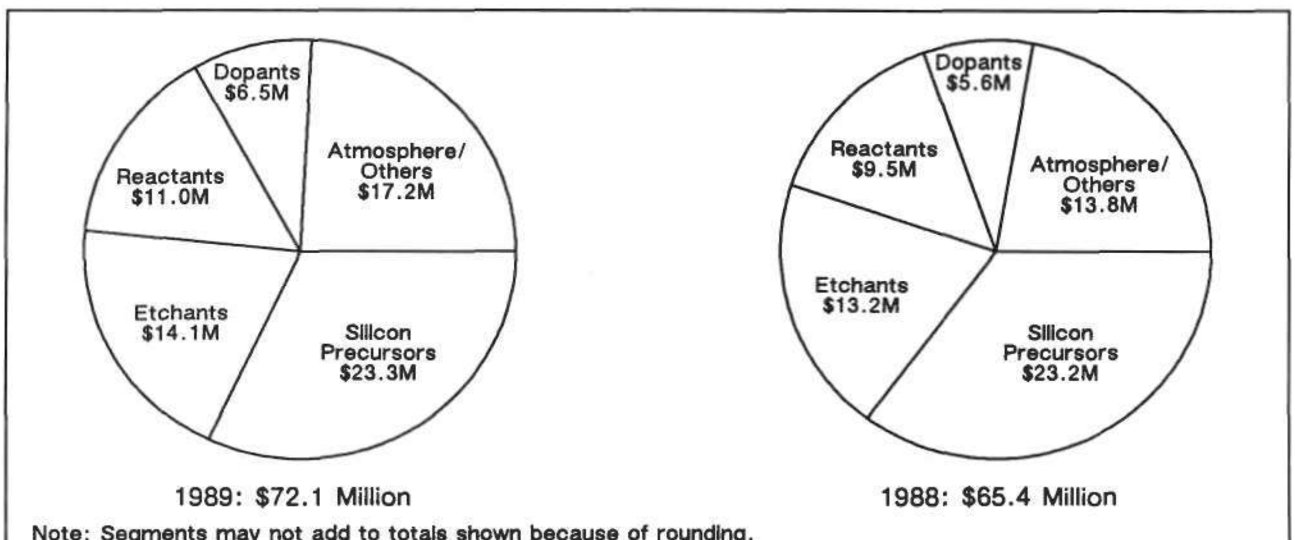
Revenue from specialty gases used in the manufacture of semiconductors grew a healthy 10.2 percent in North America during 1989. Total sales were $72.1 million in 1989 versus $65.4 million in 1988 (see Figure 1). The growth in revenue is attributable to three trends. First, volume is increasing as semiconductor manufacturers move to more gas-based processes. Second, as microcontamination issues gain more attention, the demand for more expensive, higher-grade gases is growing. Finally, the overall growth in North American semiconductor production, 8.5 percent in 1989, is driving the increase in demand for specialty gases.

PRODUCT TRENDS

Every category of specialty gas grew in 1989 except that of silicon precursors, which was flat with sales of $23.3 million. Silicon precursors include silane, trichlorosilane, dichlorosilane, and silicon tetrachloride (see Figure 2). The three chlorinated silane gases had total sales of $8.2 million, an increase of $1.0 million. On the other hand, silane sales were $15.1 million, down $1.1 million. Because silane sales contracted, the strong growth in chlorinated products was offset, resulting in flat growth for the silicon precursor category.

It is difficult to pinpoint the reason for the decrease in silane sales, particularly in light of the fact that silane is a product strongly impacted by

FIGURE 1
US Specialty Gas Market
(Millions of Dollars)



Source: Dataquest (September 1990)

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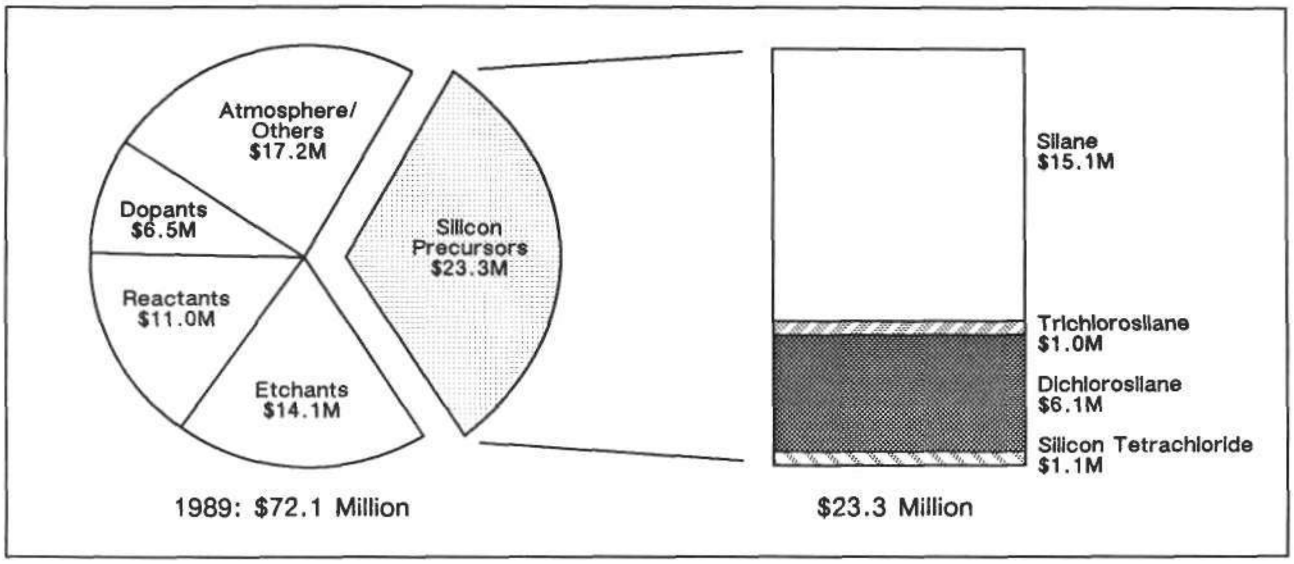
Figure 2
1989 US Specialty Gas Market
(Millions of Dollars)



Source: Dataquest (September 1990)

the trend toward more expensive, higher-purity grades. However, the increased popularity of TEOS for oxide films is displacing some silane sales. In addition, the import of an estimated two to four metric tons of Japanese-produced silane caused some price erosion.

Etchant gas sales were $14.1 million in 1989, up 6.8 percent. This category includes gases used for both plasma etch and plasma clean applications. CF_4 comprises about 65 percent of the plasma etch materials; NF_3 and C_2F_6 comprise the majority of the plasma clean sales.

The dopant market also grew in 1989; sales in the United States totaled $6.5 million, up 16.1 percent. The safety considerations surrounding arsine, diborane, and phosphine appear not to have impacted the use of these gaseous dopants. Tertiarybutylarsine (TBA) and tertiarybutylphosphine (TBP) are liquid source replacements for arsine and phosphine actively being marketed today. Dataquest believes that both TBA and TBP will begin displacing their gaseous complements as semiconductor equipment and device manufacturers gain more experience with these new materials.

Atmosphere/others was the fastest-growing category in 1989, increasing 19.8 percent to $17.2 million. The surge in sales was largely because of one product, tungsten hexafluoride (WF_6).

The demand for WF_6 is being driven by the growth in blanket tungsten applications. One measure of this growth is new equipment sales. Dataquest estimates that blanket tungsten CVD equipment sales increased 105.0 percent worldwide in 1989. Because we expect continued strong growth in this equipment segment, a 39.1 percent compound annual growth rate (CAGR) over the next five years is forecast for WF_6 gas sales.

Finally, the reactant category, which includes NH_3, HCl, and N_2O, also spurted ahead. Sales totaled $11.0 million, an increase of 15.8 percent in 1989. Growth in plasma and thermal nitride films helped push up the demand for NH_3. In addition, a continued strong demand for epitaxial wafers resulted in a healthy growth in HCl sales. US consumption of merchant epitaxial wafers increased from 46 million square inches (msi) in 1988 to 54 msi in 1989.

Market Share

There were some notable shifts in electronic specialty gas market share during 1989 (see Table 1). Airco and Air Products ranked first and second, respectively. Both companies benefited from the sharp increase in demand for WF_6 and the overall growth of the US semiconductor market. However, Linde, the gas division of Union Carbide, fell from second place in 1988 to third place in 1989. Linde suffered because of the flat market for silane. In addition, Dataquest believes that the

TABLE 1
1989 US Specialty Gas Market
Company Sales and Share

	1989		1988
Company	Sales ($M)	Share (Percentage)	Share (Percentage)
Airco	23.4	32.4	31.1
Air Products	13.5	18.7	17.1
Linde UCC	11.7	16.2	20.4
Matheson	10.2	14.2	13.5
Scott	4.8	6.7	7.7
Others	8.5	11.8	10.2
Total	72.1	100.0	100.0

Source: Dataquest (September 1990)

TABLE 2
US Specialty Gas Revenue
(Per Square Inch of Silicon Consumed)

	Specialty Market ($M)	Silicon Consumption (msi)	Specialty Gas Revenue/Square Inch
1985	39.2	398	0.098
1986	41.7	405	0.103
1987	48.6	435	0.112
1988	65.4	496	0.132
1989	72.1	571	0.126

Source: Dataquest (September 1990)

delays in bringing the new Kingman, Arizona, plant on-line prevented Linde from capitalizing on the growth in the market during 1989.

Matheson and Scott Specialty Gases ranked fourth and fifth, respectively, in electronic specialty gas market share. Both are much smaller than the vertically integrated industrial gas companies with which they compete in this market, and consequently they have a more regional focus. However, Dataquest believes that the prospect of growth for both companies is good, despite their size, because of the increasing importance of service issues.

DATAQUEST CONCLUSIONS

Dataquest expects specialty gas revenue to increase faster than the overall production of devices. Historically, the consumption of specialty gases per square inch of silicon consumed has increased each year (see Table 2). Though this ratio was down slightly in 1989, we believe that the growth of specialty gas revenue will continue to outpace silicon consumption.

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Research *Bulletin*

SEMICONDUCTOR GAS SHORTAGE ATTRIBUTABLE TO SADDAM HUSSEIN

The military buildup and deployment of troops in the Middle East has aggravated an existing tight supply of a specialty gas, Freon-116 (C_2F_6). Freon-116 is used by semiconductor manufacturers in plasma etching processes. DuPont Corporation, which is a primary manufacturer of Freon-116 in North America, has received purchase orders from the US government that carry a priority rating, DOD1. These purchases have temporarily put a severe constraint on the availability of Freon-116. Dataquest estimates that DuPont will not ship any product to commercial customers until October 1990. Consequently, supplies will be very tight through the end of 1990.

FREON-116 SHORTAGE

Even prior to Saddam Hussein's invasion of Kuwait, the demand for Freon-116 exceeded supply. For the past 18 months, DuPont has been operating a controlled distribution program for Freon-116. DuPont has distributed its production among its established customer base during this period, and Dataquest estimates that supplies were running at 80 to 90 percent of DuPont's customers' requirements just prior to the Middle East crisis. In addition, we believe that no new customers were being accepted by DuPont. DuPont is working to ease the bottleneck at its plant in order to expand production capacity.

Several Japanese companies have the capability to manufacture Freon-116—among them Asahi Glass, Daiken Industries, Kanto Denko, and Showa Denko—but the demand in Japan for the product is small, and Dataquest believes that there is only a small installed plant capacity. Therefore, there is little opportunity for the United States to import additional pounds of the specialty gas.

FREON-116 APPLICATIONS

Several industrial applications exist for Freon-116. These applications include the following:

- Electronics applications
  - Plasma etchant
  - Dielectric gas
- Government/military
- Automobile
- Refrigeration
- Proprietary applications

Freon-116 is used in different ways by semiconductor manufacturers. For example, Applied Materials uses it to clean the reaction chamber of the CVD 5000 after running a TEOS oxide process. Lam Research uses Freon-116 in its Rainbow series of plasma etch equipment.

Other materials such as NF_3 or CF_4 can be used to replace Freon-116 in plasma etchant applications, but they do not have the same optimal processing characteristics. In addition, changing to a new gas would require semiconductor manufacturers to change gas distribution systems and recalibrate mass flow controllers.

CURRENT OUTLOOK

Demand for the product is growing in most industrial segments. The government uses Freon-116 as a wave guide fluid in military electronic applications, and the current crisis prompted the US military to increase its stocks of this specialty gas. Dataquest believes that this will be a one-time spike in demand, although a protracted Middle East crisis or outbreak of war would certainly extend this shortage.

Mark FitzGerald

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Research Newsletter

SHORTAGE OF SILICON RIPPLES THROUGH GLOBAL MARKET

SUMMARY

The demand for silicon wafers exceeded worldwide plant capacity sometime in the first half of 1990. The shortfall is going to get more serious before it gets better. Dataquest expects the imbalance to exist through 1992. The supply will be especially tight through 1991 because there will be very little new capacity (see Table 1) to supply the growth in world demand (see Table 2).

US and Pacific Rim semiconductor manufacturers are at highest risk. In 1989, South Korean and Taiwanese manufacturers purchased 65 percent of their silicon wafers from US plants, which are now sold out. In addition, these two countries have the fastest-growing demand for silicon, which is

TABLE 1
Silicon Wafer Capacity Expansions/Retirements Announced since 1985

Region	Company	Plant	Wafer Size	Operational Status
US	Siltec	Salem, OR	125mm, 150mm	1988 Upgrade
	MEMC	N. Carolina	100mm	1988 Retire
	IBM	E. Fishkill, NY	200mm	1989 Retire
	Kawatec	San Jose, CA	150mm, 125mm	1990 Expand
	OTC	Mainville, OH	150mm	1992 Expand
	MEMC	St. Peters, MO	200mm	1992 Expand
Japan	Tosoh	Tokyo	Pilot	1988 Retire
	MEMC	Utsunomiya	Slicing	1989 Expand
	OTC	Saga	150mm, 125mm	1990 Expand
	Komatsu	Nagasaki	150mm	1990 Expand
	Jasil	Hikari	200mm	1990 Expand
	SEH	Shirakawa	150mm, 125mm	1990 Expand
	JASIL	Yonezawa	150mm	1990 Expand
	Toshiba	Hatano	200mm	1991 Expand
	JASIL	Ikuno	200mm	1991 Expand
	Hamado	Juko Kumamoto	150mm	1991 Expand
	JASIL	Yamagata	150mm	1991 Expand
	Komatsu	Nagasaki	150mm	1992 Expand
	OTC	Imari	200mm, 150mm	1992 Expand
Europe	MEMC	England	100mm	1989 Retire
	SEH	England	150mm	1991 Expand
ROW	Korsil	Gumi	Slicing	1989 Retire

Source: Dataquest (August 1990)

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TABLE 2
Forecast Silicon Consumption by Region, 1989-1994 (Million Square Inches)

	1989	1990	1991	1992	1993	1994	CAGR 1989-1994
US	571	578	647	757	929	924	10.1%
Growth	14.9%	1.8%	11.9%	17.0%	22.8%	(0.5%)	
Japan	909	985	1,029	1,151	1,368	1,345	8.2%
Growth	17.6%	8.5%	4.5%	11.8%	18.8%	(1.7%)	
Europe	218	253	311	385	483	505	18.2%
Growth	11.2%	15.7%	23.3%	23.7%	25.2%	4.6%	
ROW	127	181	217	255	301	315	19.8%
Growth	29.4%	42.4%	19.5%	17.6%	18.1%	4.6%	
Total	1,825	1,997	2,204	2,548	3,081	3,089	11.1%
Growth	16.7%	9.6%	10.4%	15.6%	20.9%	0.3%	

Source: Dataquest (August 1990)

spurred on by very strong growth in semiconductor production. South Korea is in a somewhat more secure position because manufacturers there have signed long-term contracts with suppliers.

US semiconductor manufacturers are particularly vulnerable because they typically contract with silicon wafer suppliers on a year-to-year basis. Lead times already are running in the range of 20 weeks and are forecast to get longer. As a result, spot prices have increased 10 to 20 percent on some wafer sizes in just the last couple of months.

The supply of silicon wafers is also very tight in Japan. Dataquest believes that Japanese plant expansions coming on-line in 1990 and 1991 (Table 2) will help to alleviate the short supply of the larger-diameter wafers. But, because of the expected growth in Japan for large-diameter wafers, Dataquest believes that Japanese plants will have little excess product for export to other markets.

European semiconductor manufacturers will increasingly feel the crunch, largely because they are dependent on US plants for 19 percent of their wafer supply. In addition there has been no investment in new capacity in Europe in the last five years (see Table 1).

The capacity shortage is across all wafer sizes, although currently the situation is most aggravated for 100mm and 150mm wafers. Shortfall exists in 100mm capacity because manufacturers are moving more of their production to the larger-diameter wafers (150mm and 200mm), which have better margins. Strong worldwide demand for larger-diameter wafers is the cause of the 150mm wafer shortage.

Silicon wafer manufacturers are also diverting substrate to their silicon epitaxial (epi) operations. They are under tremendous pressure to keep the epi area running because of the high overhead cost of these operations. Consequently, less substrate is available to meet the demand for polished wafers.

MARKET DYNAMICS LEADING TO SHORTAGE

Over the past five years (1985 to 1989), the worldwide consumption of silicon wafers has shot up by 55 percent on a million-square-inches (MSI) basis (see Table 3). The growth has been strong in all major regions of the world.

In terms of MSI, Japan is the largest market. From 1985 to 1989, the growth (321 MSI) in Japanese consumption alone was equivalent to the growth (327 MSI) in the three other major areas of the world.

During the same period, the demand for silicon in the Pacific Rim increased by 195 percent. This growth occurred predominantly in two countries, South Korea and Taiwan. Yet very little domestic capacity has been installed in either country to serve this growth.

In fact, US plants have received the lion's share of the new Pacific Rim business because they had excess capacity to serve this market and they had the lowest prices (see Table 4). For four out of the last five years, from 1985 through 1989, the

Table 3
Historical Silicon Consumption by Region, 1985-1989 (Million Square Inches)

	1985	1986	1987	1988	1989	CAGR 1985-1989
US	398	405	435	496	571	9.4%
Growth	(43.7%)	1.9%	7.3%	13.6%	14.9%	
Japan	588	642	670	772	909	11.5%
Growth	(11.0%)	9.1%	4.4%	15.2%	17.6%	
Europe	148	155	172	196	218	10.1%
Growth	(7.5%)	4.6%	10.9%	14.0%	11.2%	
ROW	43	64	78	98	127	31.2%
Growth	(15.7%)	47.9%	22.0%	26.8%	29.4%	
Total	1,177	1,266	1,355	1,562	1,825	11.6%
Growth	(25.5%)	7.5%	7.0%	15.2%	16.7%	

Source: Dataquest (August 1990)

Table 4
Silicon Wafers Weighted Average Selling Price by Region, 1985 to 1989 (Dollars per Square Inch)

	1985	1986	1987	1988	1989
Silicon Wafers					
United States	0.96	0.88	0.85	0.87	0.80
Europe	0.89	1.03	1.00	1.02	1.04
ROW	0.93	0.86	0.92	0.93	0.94
Japan	0.98	1.33	1.45	1.59	1.37
Japan (¥/square inch)	233	221	209	204	190

Source: Dataquest (August 1990)

US weighted average selling price of silicon wafers has been lower than in any other region of the world, which has proven to be very appealing to South Korean and Taiwanese semiconductor manufacturers.

At the same time, US domestic demand has expanded. In the last two years, consumption has grown about 15 percent per year (see Table 3). Domestic consumption, coupled with demand from the Pacific Rim and, to a lesser extent, Europe, has worked off the excess capacity of US-based silicon wafer producers. This phenomenon has led to the current shortage.

Technical Trends Exacerbating Shortage

As with all other semiconductor materials, the specifications for silicon wafers are getting tighter. Even test wafers are being impacted by this trend. Oxygen levels, site flatness, warp and bowing specifications, and particulate specifications are called for in many orders. DRAM manufacturers are especially demanding of their wafer suppliers.

The demand for tighter specifications has slowed the number of wafers that can be pushed through a line. Crystal pulling is slower in order to achieve lower oxygen content; lapping and polishing take longer because of the tighter specifications manufacturers are required to meet; and at every step, more quality assurance is required.

Historically, silicon wafer manufacturers have steadily improved their yields by using better equipment and manufacturing practices. But as the specifications have gotten tougher, this trend also is slowing.

As a result of these technical factors and in addition to the fact that no new capacity has been added since 1985, we assume that the worldwide production capacity actually has shrunk over the last five years. This contraction has occurred at the same time that demand for product has expanded dramatically.

DATAQUEST CONCLUSIONS

Dataquest believes that wafer manufacturers have not been able to justify any capacity expansion in their operations for the past five years because of excess capacity and low prices for their products. As the demand on worldwide plants expanded, the lack of investment in new capacity inevitably ended in demand finally catching up with supply.

Dataquest anticipates that improving profitably for wafer manufacturers will cause them to begin investing cautiously in new plants and equipment over the next several years. These investments will most likely be done on an incremental basis. However, because it takes 18 months to bring up new capacity and begin qualification programs, we expect the current shortage to last through 1992.

The wild card in the global picture is Japan. In 1989, Japanese producers exported 13 percent of their wafer production. Because the Japanese have quite a bit of new capacity coming on-line in 1990 and 1991, they may be in a position to increase their exports to other regions.

However, we believe that any excess capacity among Japanese producers will help more in relieving the shortage of 150mm wafers than 100mm wafers. Over the next several years, new capacity coming on-line in Japan (see Table 1) is all larger-diameter wafer sizes. Even so, Dataquest believes that most of this new capacity already is committed to domestic semiconductor manufacturers.

The outlook for wafer manufacturers is good from both a profit and a demand viewpoint for the next several years. The semiconductor manufacturers are going to have to accept price increases and longer lead times until the market moves back into balance. Dataquest believes that the next down cycle in the market will occur in 1993. We expect this downturn to be less severe because producers will be more cautious in adding capacity over the next several years.

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Research Newsletter

BULK GAS DEMAND IN US SEMICONDUCTOR MARKET GROWS

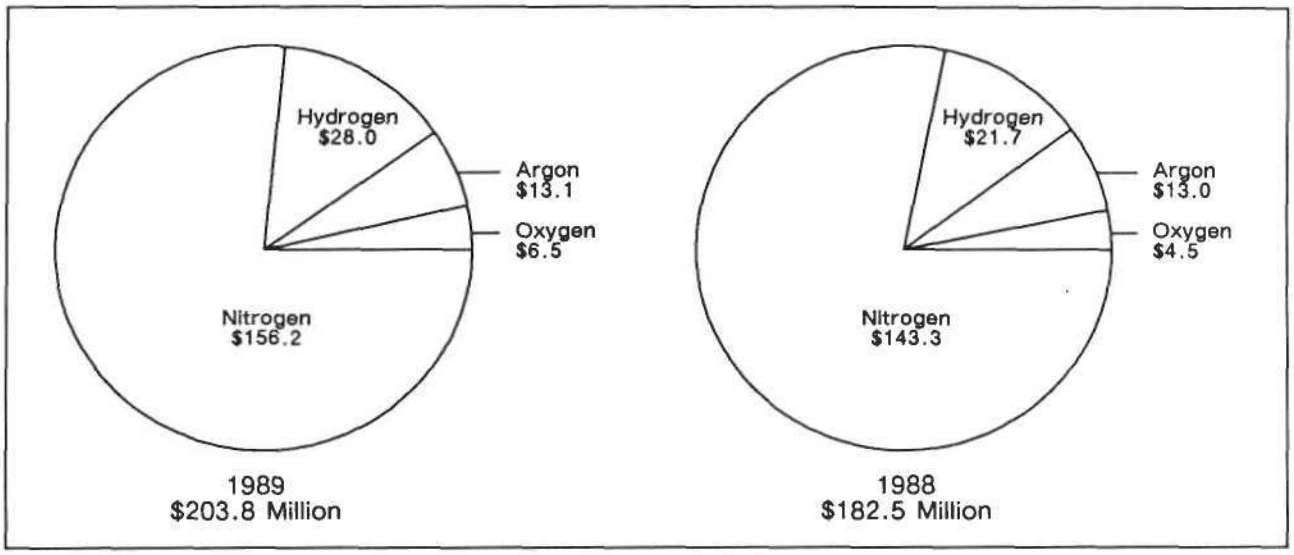
North American semiconductor manufacturers' demand for bulk gases—argon, hydrogen, nitrogen, and oxygen—totaled $203.8 million in 1989 (see Figure 1). The market grew 11.6 percent in 1989 over the previous year's sales of $182.5 million. By comparison, North American semiconductor production on a revenue basis increased 8.5 percent. The fact that the bulk gas market grew in 1989 can be attributed to a healthy growth in volume shipments, especially of liquid nitrogen.

In 1989, nitrogen sales were $156.2 million or 76.7 percent of the total bulk gas sales (see Figure 2). Liquid nitrogen was by far the largest single bulk gas product on a revenue basis; however, on a volume basis, more on-site nitrogen was used than any other bulk product. The explanation for this discrepancy is the higher selling price of the liquid product, which is 2.8 times the price of on-site nitrogen.

Other bulk gases experienced strong volume growth but from a small base demand. On a volume basis, hydrogen was the second largest bulk gas shipped to semiconductor manufacturers and accounted for 13.7 percent of total bulk gas sales in 1989 versus 11.9 percent of total bulk gas sales in 1988. The demand for oxygen also rose strongly. Argon consumption was flat in 1989.

Industrial gas vendors saw prices erode for most bulk gases in 1989 (see Table 1). This trend is worrisome because industrial gas manufacturers' costs are heavily dependent on energy costs, which have increased because of the Mideast crisis. Dataquest believes that in the long term this trend will prevent industrial gas companies from adequately investing in new plants and technology.

FIGURE 1
US Bulk Gas Market



Source: Dataquest (August 1990)

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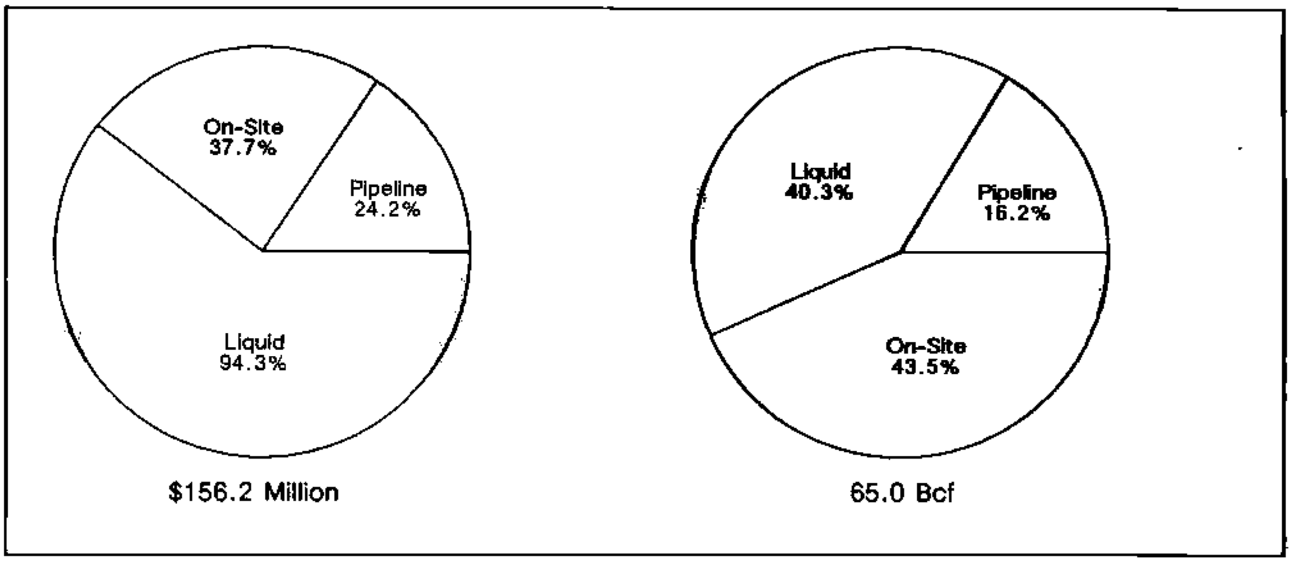
FIGURE 2
1989 North American Nitrogen Market



Source: Dataquest (August 1990)

TABLE 1
US Bulk Gas Market
Volume and Average Selling Prices

Bulk Gas Category	Volume 1989	bcf 1988	ASPs 1989	$/hcf 1988
Nitrogen				
On-Site	28.3	27.0	0.13	0.13
Pipeline	10.5	10.0	0.23	0.23
Liquid	26.2	22.2	0.36	0.38
Hydrogen	1.98	1.50	1.42	1.45
Oxygen	0.71	0.45	0.92	1.00
Argon	0.49	0.46	2.67	2.83
Total Sales	NM	NM	203.7	182.6
Growth	NM	NM	11.6%	NM

bcf = Billion cubic feet
hcf = Hundred cubic feet
NM = Not meaningful
Source: Dataquest (August 1990)

However, this pattern does not yet appear to be a critical issue for the gas industry because most companies hold long-term contracts with utilities; nevertheless, it is worth watching.

The bulk gas market in North America is dominated by four companies. Historically, there has been very little shift in market share from one year to the next because most bulk gases are sold on long-term contracts. Indeed, the 1989 market share data shown in Table 2 reinforces this trend. No single company gained or lost more than 1.0 percent of market share.

TABLE 2
1989 US Bulk Gas Market
Company Sales and Market Share

Company	1989 Sales ($M)	1989 Share	1988 Share
Air Products	97.1	47.6%	47.3%
Linde, UCC	52.2	25.6	24.9
Airco	25.8	12.7	13.4
Liquid Air	23.0	11.3	11.4
Others	5.6	2.8	3.0
Total	203.7	100.0%	100.0%

Source: Dataquest (August 1990)

DATAQUEST CONCLUSIONS

Dataquest believes that future equipment and manufacturing trends suggest that consumption of bulk gases, especially nitrogen, will continue to increase over the next decade. Single-wafer processing, which is rapidly being implemented today, is heavily dependent on efficient purging of load-lock chambers during each cycle. In addition, futuristic scenarios such as SMIF technology or fully integrated semiconductor manufacturing both depend heavily on high-purity nitrogen atmospheres.

The 1990 market is expected to be flat because semiconductor production is forecast to be down 3.3 percent. However, Dataquest believes that the demand for bulk gases in North America will have approximately a 6.0 percent compound annual growth rate (CAGR) over the next five years. This growth will be fueled by a 19.0 percent CAGR in semiconductor production in North America over this period and by technical trends that will increase the demand for high-purity bulk gases.

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Research Newsletter

GAS EQUIPMENT: CONSOLIDATION AS MARKET EXPANDS

Over the past year, the large industrial gas companies have scrambled to add gas-handling equipment, such as gas cabinets and purge panels, to their product portfolios. This chase has resulted in the acquisition of several small gas equipment manufacturers by the industrial gas suppliers (see Table 1).

The sudden interest in gas cabinets and purge panels is due to the growing trend among the semiconductor manufacturers to contract out the management of their on-site gas operations. In order to compete for these contracts, industrial gas companies must supply the gases as well as the gas-handling equipment.

MARKET SIZE

The market for gas-handling systems used in semiconductor fabs has grown from a $27.0 million worldwide business in 1985 to an $85.2 million business in 1989 (see Table 2). These numbers show a blistering compound annual growth rate (CAGR) of 33.3 percent. Dataquest expects this growth to fall off to a 16.0 percent CAGR over the next five years, which will result in a $178.9 million market in 1994.

Future growth will be fueled by several trends in semiconductor manufacturing. Originally, the demand for these systems was driven by toxic gas regulations. However, semiconductor manufacturers are recognizing the importance of gas-handling systems in delivering pure gases to their process tools. This necessity has led to gas cabinet systems and purge panels being used more extensively across the full range of specialty gases. In addition, the trend toward more gas-based semiconductor processes is increasing the number and types of cylinder gases used on a fab site.

Gas cabinet technology is also moving further ahead. This movement is reflected in higher automation content, tighter particulate and contamination specifications, and more sophisticated monitoring systems. The end result is that the capital spent for a typical state-of-the-art installation is increasing.

TABLE 1
Recent Acquisition

Acquiring	Acquired
L'Air Liquide	Labeille (France)
L'Air Liquide	ASGT (US)
Linde/Union Carbide	FloPure (US)
Air Products	Airgas Technologies (US)
Nippon Sanso	Semigas (pending) (US)

Source: Dataquest (July 1990)

REGIONAL MARKETS

North America led the world in gas cabinet production in 1989. US vendors sold $41.2 million in gas cabinets and purge panels. The performance of US vendors is attributable to the strict regulatory environment of the North American market. Toxic gas regulations have pushed US vendors into a leadership role in the development of gas-handling technology and resulted in strong export sales for several vendors in 1989.

The US vendor base is fractionalized. In 1989, there were 14 suppliers, most of them with less than $2 million in sales. The top 5 companies are responsible for 85.9 percent of the revenue. Dataquest anticipates that there will be further consolidation of market share as the market grows. Long-term, marginal players either will be acquired

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TABLE 2
Production of Gas Cabinets by Region—1989
(Millions of Dollars)

North American Production	
Semigas Systems	16.9
Air Products	8.8
SCI	4.0
ASGT/Air Liquide	3.7
FloPure/Union Carbide	2.0
Scott Specialty Gases	1.2
Airco/BOC	1.0
Matheson/Nippon Sanso	0.8
Others	2.7
Total North America	41.2
Percentage	48.3%
Japanese Production	
Tanaka/Nippon Sanso	14.0
Taiyo-Sanso	3.0
Teisan/Air Liquide	3.0
Toyoko	2.0
Ueki Gas Systems	2.0
Osaka Sanso/BOC	2.0
Tomoe	2.0
Suski Shokan	1.5
Daido Sanso/Air Products	1.2
Total Japan	30.7
Percentage	36.0%
European Production	
BOC	2.2
Air Products	2.2
Air Liquide/Labeille	1.7
Semigas Systems LTD	1.7
Messer-Gresheim	1.4
Druva/AGA (30%)	1.3
Others	1.3
Total Europe	11.8
Percentage	13.9%
ROW Production	
Hanyang	1.5
Percentage	1.8%
Worldwide Total	85.2
Percentage	100.0%

Source: Dataquest (July 1990)

or close their doors because they are unable to keep up with technical trends.

The production of gas cabinets in Japan totaled $30.7 million in 1989. The market has been dominated by Tanaka/Nippon Sanso with 45.0 percent of the market. The other 8 companies had significantly smaller market shares. Most of the Japanese vendors are associated with or wholly owned by an industrial gas company.

Historically, the Japanese semiconductor manufacturers have not faced the same regulatory pressures as US manufacturers; therefore, Japanese vendors are behind US companies in the development and application of gas-handling technology. However, Dataquest anticipates that Japanese vendors will quickly close this technology gap through acquisitions (e.g., Nippon Sanso's pending purchase of Semigas) or internal development programs.

European production is much smaller than either the North American or Japanese market. In 1989, there was a total of $11.8 million in gas systems produced in Europe, which accounted for 14 percent of world production. However, the demand for gas-handling systems is expected to double over the next two years as semiconductor manufacturers increase capital spending in the European market. Dataquest expects this demand to be supplied by local vendors.

Production of gas cabinets in the Rest of World (ROW) region is limited to South Korea, where systems are manufactured by Hanyang. Dataquest also expects ROW demand to grow rapidly. Over the next five years, both South Korea and Taiwan are expected to add production capacity to support their growing semiconductor base. New production facilities will most likely be added through joint development programs between a local partner and one of the five leading industrial gas companies.

DATAQUEST CONCLUSIONS

Dataquest believes that the size of the worldwide gas cabinet and purge panel market will double over the next five years. As this market enters its adolescence, Dataquest anticipates that the current consolidation will result in most of the world's production capacity being owned by industrial gas companies and their affiliates. This shift is expected to impact all the major regional markets.

The increasing awareness of safety issues in the Japanese market, in conjunction with the strong growth of semiconductor production, is expected to propel Japan into becoming the largest market for these types of systems.

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THE 1989 JAPANESE PHOTORESIST MARKET

In 1989, Japan remained the largest regional market for photoresist with sales of ¥16,647 million and 423,500 gallons. Photoresist consumption in front-end semiconductor processing grew 17.1 percent in volume from 1988 to 1989.

The growth in the Japanese market occurred exclusively in positive-type resists (see Figure 1). The consumption of positive resist shot ahead 30.2 percent on a volume basis and 31.7 percent on a revenue basis. This growth parallels the regional increase in semiconductor capacity, which requires the tighter performance of positive-type resists.

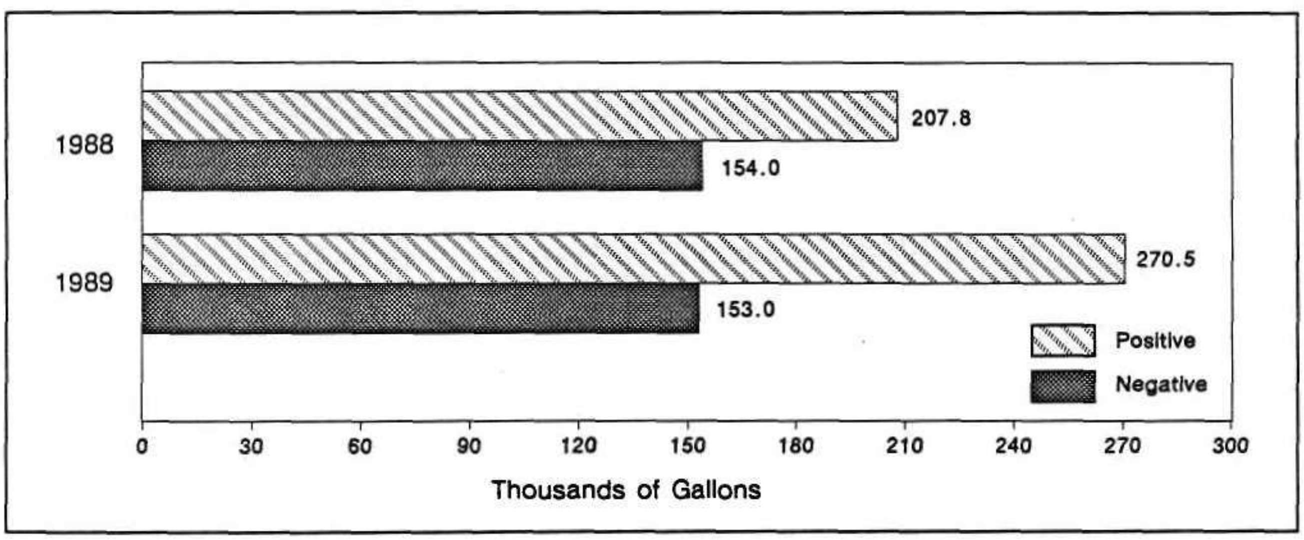
The market for negative-type resists was flat in 1989. Negative resists are sold primarily into lower-end technology applications (e.g., discrete devices), which experienced only moderate growth.

The major beneficiaries of positive-resist growth were Japanese-based companies. Their share of the market grew from 67.4 percent in 1988 to 78.6 percent in 1989 (see Table 1). Tokyo Ohka's shipment of positive resists increased by 30,000 gallons, and the company continued to dominate the Japanese market with a market share of 57.3 percent.

Three of the other Japanese vendors—Japan Synthetic Rubber, Mitsubishi, and Sumitomo—increased their positive-resist market share. Dataquest breaks out the sales of Mitsubishi and Sumitomo this year for the first time. We expect these three vendors to incrementally chip away at Tokyo Ohka's dominance in the positive market over the next few years.

The negative-resist market (see Table 2) is not expected to grow in the near term. Moreover, as device manufacturers learn to use resist materials more efficiently, Dataquest expects the demand for

FIGURE 1
Japanese Photoresist Market



Source: Dataquest (June 1990)

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TABLE 1
Japanese Optical Photoresist Market—Positive Resist (Thousands of Gallons)

Companies	1989 Volume	Millions of Yen	Millions of Dollars	Percentage of Volume
North American				
Nagase & Co[1]	10.0	520	3.7	3.7
Fuji-Hunt[2]	20.0	1,100	7.9	7.4
Shipley	18.0	990	7.1	6.7
Others	NM	NM	NM	0
Total	48.0	2,610	16.4	17.7
Japanese				
Japan Synthetic Rubber	39.0	2,132	15.3	14.4
Tokyo Ohka	155.0	8,440	60.7	57.3
Mitsubishi Kasei	10.5	572	4.1	3.9
Sumitomo Kagaku	8.0	352	2.5	3.0
Other	NM	NM	NM	
Total	212.5	11,496	82.7	78.6
European				
Ciba Geigy	NM	NM	NM	0
Hoechst[3]	10.0	435	3.1	3.7
Others	NM	NM	NM	0
Total	10.0	435	3.1	3.7
Rest of World	NM	NM	NM	0
Total—All Companies	264.5	14,211	102.2	100.0

[1]KTI Chemical in US
[2]Olin-Hunt in US
[3]AZ Photoresist in US
NM = Not meaningful
Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (June 1990)

TABLE 2
Japanese Optical Photoresist Market—Negative Resist (Thousands of Gallons)

Companies	1989 Volume	Millions of Yen	Millions of Dollars	Percentage of Volume
North American				
Nagase & Co[1]	8.0	130	0.9	5.2
Fuji-Hunt[2]	8.0	117	0.8	5.2
Others	NM	NM	NM	0
Total	16.0	247	1.8	10.5
Japanese				
Japan Synthetic Rubber	36.0	468	3.4	23.5
Tokyo Ohka	94.0	1,300	9.4	61.4
Others	7.0	91	0.7	4.6
Total	137.0	1,859	13.4	89.5
European	NM	NM	NM	0
Rest of World	NM	NM	NM	0
Total—All Companies	153.0	2,106	15.2	100.0
Exchange Rate (Yen per US$1)				139

[1]KTI Chemical in US
[2]Olin-Hunt in US
[3]AZ Photoresist in US
NM = Not meaningful
Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (June 1990)

negative-type resists to actually contract. Market shares for companies participating in this segment are not likely to shift significantly.

The demand for I-line type resists, which currently account for only 0.5 percent of the Japanese market, is expected to grow rapidly throughout the 1990s. Hitachi and Nikon shipped 130 units of I-line steppers in 1989. Furthermore, Canon introduced a new system earlier this year.

Dataquest anticipates that I-line equipment will be used by Japanese semiconductor manufacturers to produce 4Mb and 16Mb devices. With the introduction of the 64Mb device, Japanese manufacturers are expected to pursue a mix-and-match strategy, using I-line with excimer, X-ray, or e-beam technology.

New resist formulations will be required for the the production of the 64Mb device. Dataquest views this change as a window where fundamental shifts in vendors' market positions could occur. The chemical systems for this type of resist will require extensive characterization studies by device manufacturers. The photoresist vendors that win these battles will be positioning themselves for strong growth in the second half of the decade as demand for these new resists ramps up.

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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)

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)

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 parenthesis.
Source: Aztek 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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Gene Miles

Trade Shows

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Research *Bulletin*

SEMICON/JAPAN 1990: A STRONG DISPLAY OF SUBMICRON 8-INCH PROCESS TECHNOLOGY

SUMMARY

Major global equipment companies put on a strong display of submicron 8-inch process equipment at SEMICON/Japan 1990. Many new introductions in key equipment segments were made. The show's common theme was the widespread display of production 200mm equipment. Dataquest believes that many semiconductor manufacturers will ramp up 200mm-wafer-based device production in the 1991 and 1992 time frame, commensurate with 4Mb shrink production lines and 16Mb DRAM pilot lines. The movement to 200mm processes and 16Mb DRAM pilot lines implies a moderate growth year (up 5 to 10 percent) for the 1990 Japanese wafer fabrication equipment market.

Table 1 describes some of the key new equipment displayed at SEMICON/Japan. New wafer fab equipment introductions were made in key areas such as lithography, dry etch, wet clean, chemical vapor deposition (CVD), sputtering, diffusion, ion implant, CD measurement, and wafer inspection equipment. A majority of the production equipment displayed had 0.5-micron process capability at the 200mm wafer level. Equipment average selling prices (ASPs) continue to climb steeply in response to 0.5-micron design rule requirements and 200mm wafer processes.

Stepper ASPs are approaching $2 million; automated 200mm high-current implanter ASPs exceed $3 million. Vertical furnace ASPs are increasing dramatically ($500,000 to $800,000 per automated tube) because of increased automation and process control requirements. The move to complex new process technologies such as microwave-based electron cyclotron resonance (ECR) is rapidly driving up dry etch equipment ASPs. Flexible cluster-tool-based 200mm sputtering system ASPs have increased steeply compared with earlier-generation rigid multichamber sputtering tools. Dataquest believes that 16Mb DRAM fabs implemented in 200mm wafer processes will require enormous capital outlays that will strain even the deep pockets of vertically integrated Japan-based device companies.

TWIN DRIVING FORCES: NEW 4MB SHRINK/16MB DRAM PROCESSES, 200MM WAFERS

As 1Mb DRAM prices continue to fall, Japanese device manufacturers are shifting production to the more advanced 4Mb DRAM device. System manufacturers now are beginning to use 4Mb DRAMs and 100K gate arrays in high-growth end-use markets such as notebook PCs, workstations, laser printers, fax machines, and cellular telephone systems. A rapid shift to the 4Mb DRAM shrink and high-density gate array processes on 200mm wafers will enable device manufacturers to maintain their profit margins in an intensely competitive market environment. Dataquest believes that semiconductor manufacturers are attempting to maintain maximum modularity and flexibility in their equipment, processes, and fabs in order to extend payback periods on escalating fab costs in an uncertain market environment. The 4Mb DRAM shrink process implemented in 200mm fabs will be a good test bed for the future 16Mb DRAM volume production market.

DATAQUEST CONCLUSIONS

Japan's thrust into 200mm wafer fabs highlights SEMICON/Japan's role as an effective marketing forum for advanced chip production equipment from global equipment companies. Dataquest observes rapid diversification and globalization among worldwide equipment companies as they hasten to serve their increasingly globalized customers. Equipment companies based in the United States and Europe are targeting SEMICON/Japan as a key event for introducing submicron process equipment for next-generation DRAM technologies. Japan-based equipment companies are expanding their product repertoires to span a broader technology range from precision optics-based lithography tools to complex process-technology oriented thin-film deposition/etch tools.

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Table 1

Major Equipment Introductions at SEMICON/Japan 1990
(Millions of Yen, Millions of Dollars)

Company	Market Segment	Product Model	Nominal ASP (¥M)	Nominal ASP ($M)	Application/Comments
Anelva	Sputtering	Series 1052	350	2.7	200mm capability
	ECR etch	ECR 6011	170	1.3	200mm capability
Applied Materials	Dry etch	PE5000	200	1.5	Metal etch/dry strip
	Ion implant	9200J	350	2.7	200mm/high current
ASM Japan	Tube PECVD	PXJ-8000	100	0.8	200mm capability
	Epitaxy	Epsilon E2	150	1.2	200mm silicon epi
Canon	I-line stepper	FPA2000i1	210	1.6	0.5-micron resolution
Denko	VTR furnace	Erectus	70	0.5	200mm capability
Dainippon Screen	Track	D-SPIN 80A	90	0.7	200mm capability
	Wet station	WSW-625	100	0.8	200mm capability
ETEC	E-beam	MEBES4	520	4.0	16Mb/64Mb DRAM masks
Genus	Nontube LPCVD	Series 6000	190	1.5	Tungsten plug/etchback
Hitachi	Dry strip	UA-5200	55	0.4	Ozone ash/wet clean
	ECR etch	M-328EX	180	1.4	200mm capability
	E-beam	HL-700M II	550	4.2	Maskmaking
	E-beam	HL-700D II	600	4.6	Direct write
	Ion implant	IP-2500	460	3.5	200mm/high current
	I-line stepper	LD-5015iCW	240	1.8	0.5-micron resolution
Insystems	Inspection	8800 Series	180	1.4	0.3-micron capability
KLA Instruments	Inspection	2110 Series	190	1.5	0.3-micron capability
Lam Research	Nontube LPCVD	Integrity	200	1.5	BPSG deposition/reflow
Nikon	G-line stepper	NSR-2005G8C	210	1.6	20mm square field
	I-line stepper	NSR-1755i7A	225	1.7	0.5-micron resolution
	Excimer stepper	NSR-1755EX8A	NA	NA	64Mb DRAM application
Nissin Electric	Ion implant	Exceed 8000	325	2.5	200mm/high current
	Ion implant	NH-205P	225	1.7	200mm/medium current
Novellus	Nontube LPCVD	Concept One	130	1.0	Blanket tungsten CVD
OSI	Inspection	Inspectra	110	0.8	Defect detection
Ramco	Dry strip	RAM-280HAS	50	0.4	200mm batch system
Sumitomo Metals	ECR CVD	ECR 3000M	210	1.6	CVD TiN barrier metal
Tegal	Dry etch	Series 6000	130	1.0	200mm capability
Tokyo Electron	Dry etch	TE7000/8000	140	1.1	MERIE, 200mm
	Nontube LPCVD	C7000	160	1.2	Blanket tungsten
	Track	Mark V8	100	0.8	200mm upgrade
	VTR furnace	Alpha-8	100	0.8	Automated, 200mm
Ulvac	Ion implant	IPX-7800	225	1.7	200mm/medium current
Watkins Johnson	Nontube APCVD	WJ-999	130	1.0	TEOS BPSG, 200mm

NA = Not available
Source: Dataquest (November 1990)

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Research Newsletter

THE 1989 JAPANESE PHOTORESIST MARKET

In 1989, Japan remained the largest regional market for photoresist with sales of ¥16,647 million and 423,500 gallons. Photoresist consumption in front-end semiconductor processing grew 17.1 percent in volume from 1988 to 1989.

The growth in the Japanese market occurred exclusively in positive-type resists (see Figure 1). The consumption of positive resist shot ahead 30.2 percent on a volume basis and 31.7 percent on a revenue basis. This growth parallels the regional increase in semiconductor capacity, which requires the tighter performance of positive-type resists.

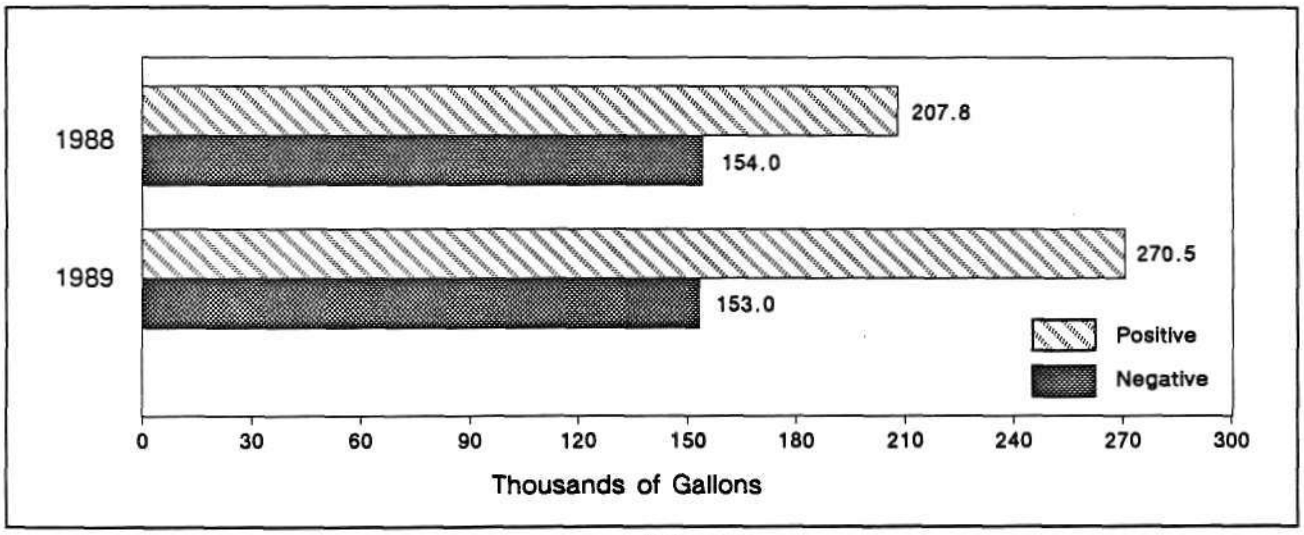
The market for negative-type resists was flat in 1989. Negative resists are sold primarily into lower-end technology applications (e.g., discrete devices), which experienced only moderate growth.

The major beneficiaries of positive-resist growth were Japanese-based companies. Their share of the market grew from 67.4 percent in 1988 to 78.6 percent in 1989 (see Table 1). Tokyo Ohka's shipment of positive resists increased by 30,000 gallons, and the company continued to dominate the Japanese market with a market share of 57.3 percent.

Three of the other Japanese vendors—Japan Synthetic Rubber, Mitsubishi, and Sumitomo—increased their positive-resist market share. Dataquest breaks out the sales of Mitsubishi and Sumitomo this year for the first time. We expect these three vendors to incrementally chip away at Tokyo Ohka's dominance in the positive market over the next few years.

The negative-resist market (see Table 2) is not expected to grow in the near term. Moreover, as device manufacturers learn to use resist materials more efficiently, Dataquest expects the demand for

FIGURE 1
Japanese Photoresist Market



Source: Dataquest (June 1990)

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TABLE 1
Japanese Optical Photoresist Market—Positive Resist (Thousands of Gallons)

Companies	1989 Volume	Millions of Yen	Millions of Dollars	Percentage of Volume
North American				
Nagase & Co[1]	10.0	520	3.7	3.7
Fuji-Hunt[2]	20.0	1,100	7.9	7.4
Shipley	18.0	990	7.1	6.7
Others	NM	NM	NM	0
Total	48.0	2,610	16.4	17.7
Japanese				
Japan Synthetic Rubber	39.0	2,132	15.3	14.4
Tokyo Ohka	155.0	8,440	60.7	57.3
Mitsubishi Kasei	10.5	572	4.1	3.9
Sumitomo Kagaku	8.0	352	2.5	3.0
Other	NM	NM	NM	
Total	212.5	11,496	82.7	78.6
European				
Ciba Geigy	NM	NM	NM	0
Hoechst[3]	10.0	435	3.1	3.7
Others	NM	NM	NM	0
Total	10.0	435	3.1	3.7
Rest of World	NM	NM	NM	0
Total—All Companies	264.5	14,211	102.2	100.0

[1]KTI Chemical in US
[2]Olin-Hunt in US
[3]AZ Photoresist in US
NM = Not meaningful
Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (June 1990)

TABLE 2
Japanese Optical Photoresist Market—Negative Resist (Thousands of Gallons)

Companies	1989 Volume	Millions of Yen	Millions of Dollars	Percentage of Volume
North American				
Nagase & Co[1]	8.0	130	0.9	5.2
Fuji-Hunt[2]	8.0	117	0.8	5.2
Others	NM	NM	NM	0
Total	16.0	247	1.8	10.5
Japanese				
Japan Synthetic Rubber	36.0	468	3.4	23.5
Tokyo Ohka	94.0	1,300	9.4	61.4
Others	7.0	91	0.7	4.6
Total	137.0	1,859	13.4	89.5
European	NM	NM	NM	0
Rest of World	NM	NM	NM	0
Total—All Companies	153.0	2,106	15.2	100.0
Exchange Rate (Yen per US$1)				139

[1]KTI Chemical in US
[2]Olin-Hunt in US
[3]AZ Photoresist in US
NM = Not meaningful
Note: Columns may not add to totals shown because of rounding.
Source: Dataquest (June 1990)

negative-type resists to actually contract. Market shares for companies participating in this segment are not likely to shift significantly.

The demand for I-line type resists, which currently account for only 0.5 percent of the Japanese market, is expected to grow rapidly throughout the 1990s. Hitachi and Nikon shipped 130 units of I-line steppers in 1989. Furthermore, Canon introduced a new system earlier this year.

Dataquest anticipates that I-line equipment will be used by Japanese semiconductor manufacturers to produce 4Mb and 16Mb devices. With the introduction of the 64Mb device, Japanese manufacturers are expected to pursue a mix-and-match strategy, using I-line with excimer, X-ray, or e-beam technology.

New resist formulations will be required for the the production of the 64Mb device. Dataquest views this change as a window where fundamental shifts in vendors' market positions could occur. The chemical systems for this type of resist will require extensive characterization studies by device manufacturers. The photoresist vendors that win these battles will be positioning themselves for strong growth in the second half of the decade as demand for these new resists ramps up.

Kunio Achiwa
Mark FitzGerald

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Research Newsletter

TAIWAN: WILL IT REAP THE BENEFITS OF AN INDUSTRIAL POLICY?

Taiwan has targeted high technology for growth and hopes to surpass Europe in semiconductor technology by 1995. The Taiwanese government is providing funds and tax incentives to stimulate growth in high technology. For semiconductor manufacturers, this program represents more competition; for equipment vendors, it represents an opportunity.

THE SUBMICRON PROCESS TECHNOLOGY DEVELOPMENT PROGRAM

This new program (the details of which are still being worked out) will be funded by the Taiwanese government, which will provide $160 million. It will be managed by the Electronics Research and Service Organization (ERSO) and is a ten-year program to develop advanced memory processes. In addition to ERSO's contributions, the program will receive funding and research staff from eight Taiwanese manufacturers: AMPI, Macronix, MOSel Taiwan Inc., Silicon Integrated Systems Corporation, Taiwan Semiconductor Manufacturing Company (TSMC), United Microelectronics Corporation (UMC), Vitelic Taiwan Corporation, and Winbond Electronics Corporation. Program goals include the development of a 0.8-micron process by 1991, a 0.5-micron process by 1995, and a 0.35-micron process by 2000. ERSO, through the Submicron CMOS Process Technology Development Program, hopes to stimulate production of 16Mb DRAMs by 1994.

The program will use a $250 million fab currently under construction by ERSO to develop a 4Mb DRAM process. This process then will be available for use by the program's member companies.

Also as part of its program to make Taiwan a center for electronics and other high-technology industries, ERSO recently announced that it has signed a joint technology-development agreement with Applied Materials to develop and qualify a number of etch and chemical vapor deposition processes.

TAX CREDITS FOR HIGH TECHNOLOGY

The Taiwanese Ministry of Economic Affairs has proposed a "statute for the enhancement of industries," which would take effect in January 1991. This statute would allow "crucial high-tech businesses" (such as semiconductors) or "major investment projects" to enjoy tax exemptions equal to as much as 20 percent of their initial capital investment.

Requirements for the tax credits are shown in Table 1.

TABLE 1
Requirements for Tax Credit

	Crucial High-Tech Business	Major Investment Project
Investment Amount	NT$1 billion ($38 million)	NT$2 billion ($76 million)
Machinery Purchase Value	NT$500 million ($19 million)	NT$1 billion ($38 million)
Plant Construction Time	3 years	3 years
(1989 Exchange Rate: US$1 = NT$26.41)		

Source: Dataquest (September 1990)

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DATAQUEST CONCLUSIONS

Dataquest believes that the Taiwanese government has a well-planned strategy to become technologically competitive. This strategy was designed to use the expertise and resources of the Taiwanese semiconductor industry and of the increasingly international offshore semiconductor industry. Through technology development programs such as that with Applied Materials and investment incentive programs such as the tax credit program, ERSO hopes to entice offshore technology to Taiwan.

The market for capital equipment in Taiwan today is approximately $900 million. By 1995, it should exceed $2 billion. Clearly, this is an opportunity for equipment vendors that have the resources for an international commitment and want to be at the forefront of participation in the growth of a promising new regional hub of electronics and semiconductor technology development and manufacturing.

One further consequence of Taiwan's drive to achieve parity in semiconductor technology could well be an increase in DRAM supply. Taiwan has chosen DRAMs as a process driver and has set goals to make its semiconductor industry state of the art by 1995. If Taiwan is successful, then competition among DRAM producers will heat up as DRAM supplies increase. Current low prices of DRAMs, unlike oil prices, then could be expected to continue.

George Burns

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Research Newsletter

IBM ADOPTS ISLANDS OF CLUSTER AUTOMATION IN 16Mb DRAM PROCESS

SUMMARY

IBM has adopted a radically new approach to cost-effective 16Mb DRAM manufacturing. It plans to use clustered islands of equipment automation to reduce wafer-handling-related defects while improving process control and manufacturing cycle times. IBM has defined three broad types of equipment clusters: photolithography island, diffusion-tube island, and thin-film deposition/etch island. Wafer handling and process flow are completely automated in each of the islands. IBM claims that early introduction of clustering concepts within the 16Mb DRAM process may result in improved manufacturing efficiencies if the process and the equipment tool set are sufficiently reliable.

HIGHLIGHTS OF THE IBM 16Mb DRAM PROCESS

Table 1 shows the highlights of IBM's 0.5-micron CMOS double-level-metal 16Mb DRAM process. The technology uses a mixture of mid-UV and deep-UV lithography (e.g., SVG Lithography's step-and-scan tool). IBM has implemented a self-aligned titanium silicide scheme to improve the device performance. Blanket tungsten plugs with etchback have been used to solve the step coverage problem in 0.5-micron contacts.

IBM has integrated the photoresist coat/develop/inspection operations with the exposure tool to achieve a completely automated lithography island. IBM claims that it can reduce the typical process time for any given masking step by an order of magnitude compared with conventional standalone equipment sequences.

IBM also has automated its diffusion and low-pressure chemical vapor deposition (LPCVD) tube operations into "hot cluster" islands. A typical application for such a tube cluster operation is the trench capacitor dielectric formation process. The wafer lots undergo a sequence of completely automated transfers within a bank of four clustered

TABLE 1
Highlights of IBM's 16Mb DRAM Technology

Feature	Comment
0.5-micron CMOS technology	Uses deep trench capacitor
Deep-UV lithography	SVG step-and-scan tool
Excimer laser lithography	245nm excimer laser stepper
0.15-micron junctions	Titanium silicide process
Tungsten plugs	Integrated deposition/etchback
Lithography cluster	Integrated track and steppers
Diffusion cluster	Integrated thermal processes
Thin-film cluster	Integrated deposition/dry etch

Source: IBM Corporation, Dataquest (August 1990)

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tubes dedicated to capacitor oxidation, nitridation, reoxidation, and polysilicon CVD refill processes.

The third class of clusters is the "deposition/etchback" thin-film processing area. Typical examples of deposition/etchback clusters include the deep-trench etch process, the planarization process, gate etch followed by sidewall spacer deposition and etch process, and metal dry-etch/dry-strip process. Dataquest believes that IBM has used Applied Materials' PE5000 CVD/dry-etch systems for these thin-film processes.

How Does IBM Rate the Clustered Equipment Strategy?

IBM claims that the clustered equipment configuration has enabled it to move up faster on the technology learning curve compared with the traditional standalone equipment configuration. The clustered approach has allowed for faster turnaround times, lower operating and labor costs, and better process control. IBM cautions that these advantages have to be balanced against the disadvantages of higher capital requirements and the need for extremely reliable process equipment with robust windows of operation. IBM also has observed that the clustered approach occasionally results in suboptimal utilization of equipment as the throughput of cluster tools is limited by the slowest (rate-limiting) process module.

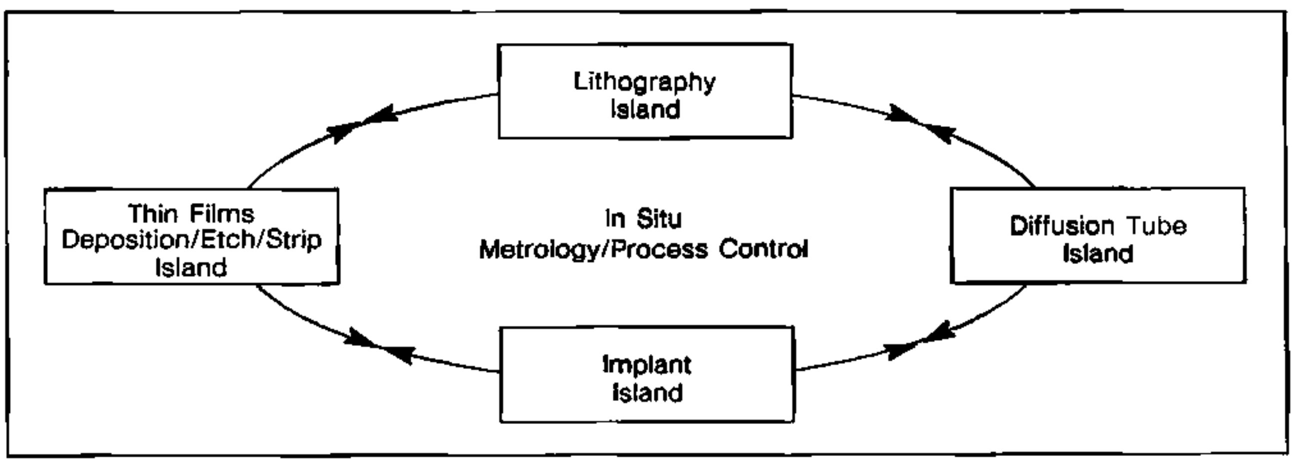
Dataquest Analysis

Dataquest believes that IBM's approach to 16Mb DRAM manufacturing exemplifies the current industry trend toward islands of automation in submicron semiconductor manufacturing. As shown in Figure 1, Dataquest believes that the semiconductor industry will gradually adopt island automation strategies in the four main fabrication segments: lithography, diffusion, implant, and thin films. We believe that in situ process control and metrology are essential to effective process integration. With the ongoing move toward single-wafer dry-clean/wet-clean processes, Dataquest predicts that the thin-film cluster may grow in size and complexity to encompass the entire process sequence between consecutive masking steps.

However, the semiconductor industry is not likely to witness a "lights out" style continuous-flow factory for the next decade. The fast pace of submicron process innovation coupled with rapidly changing equipment architecture hampers a systematic approach to fab automation. When will semiconductor process innovation slow down to such a pace that manufacturing automation strategies can catch up? Will the escalating cost of submicron fabs slow down the market penetration of advanced device technologies? When, if ever, will the semiconductor manufacturing industry become like the chemical industry with its penchant for large-scale automation and sedate growth?

Krishna Shankar

Figure 1
Islands of Fab Automation in the 1990s



Source: Dataquest (August 1990)

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Research *Newsletter*

WILL SEMATECH SPUR GROWTH OF THE U.S. ECR EQUIPMENT MARKET?

OVERVIEW

Sematech recently awarded several Joint Development Program (JDP) contracts to U.S. equipment companies for designing and manufacturing electron cyclotron resonance (ECR) dry etch and chemical vapor deposition (CVD) systems. Such systems have to be capable of 200mm wafer processing to ensure production economies of scale for advanced devices such as the 16Mb/64Mb DRAMs and submicron ASICs. Sematech also stipulated that the ECR systems be built with U.S.-designed components and conform to the SEMI/MESC open cluster tool standards. Dataquest views these contracts as significant for the following reasons:

- The contracts will speed up the development of production-worthy ECR CVD for applications such as low-temperature gate dielectrics and interlayer dielectric planarization. Conversely, ECR dry etch development efforts may challenge current low-damage dry etch technology such as magnetically enhanced reactive ion etching (MERIE).

- The contracts will spur process and hardware development in the United States, which has lagged behind Japan and Europe in ECR technology.

- The contracts pose a challenge to the ability of U.S. equipment and materials companies to cooperate in joint equipment development using open cluster tool standards.

- The contracts support the Dataquest viewpoint that technology diffuses readily across national boundaries in today's globalized marketplace. Strategic, mutually beneficial alliances will continue to flourish worldwide, albeit with more emphasis on product synergy and worldwide customer support capability.

WHY IS ECR TECHNOLOGY SO IMPORTANT?

In today's submicron era, it is increasingly important to lower processing temperatures while simultaneously improving film quality. ECR technology uses a high-frequency (2.45 GHz) microwave energy source to create the plasma in a confined region using a magnetic field of 875-gauss strength. The wafer experiences minimal ion radiation damage because it is located downstream from the plasma creation zone. ECR technology allows more freedom in tailoring etch or deposition profiles without sacrificing high ionization efficiency. A high-frequency RF bias (13.56 MHz) may be superimposed on the wafer stage to allow greater control on the process while minimizing ion bombardment damage. The process occurs at low temperatures (less than 100°C) since the wafer is decoupled from the upstream plasma zone.

JAPAN AND EUROPE LEAD IN ECR PROCESS CAPABILITY

Nippon Telephone and Telegraph (NTT) Laboratories in Japan and the French national CNRS/CNET Laboratories in Europe pioneered the

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development of ECR tools. NTT Laboratories developed a single-pole ECR technology and used a 13.56-MHz RF bias coupled with additional magnets below the wafer stage to achieve good process control and uniformity. Companies such as Anelva, Hitachi, and Sumitomo Metals have generally followed the NTT concept in designing their ECR reactors.

In contrast, the CNRS/CNET Laboratories in France developed a distributed multipolar ECR reactor that employs six symmetrically placed microwave energy sources and magnetic coils placed around a hexagonal chamber. European equipment companies such as Alcatel/CIT, E.T. Electrotech, and Plasma Technology have adopted the distributed ECR concept for their reactor designs.

ECR EQUIPMENT MARKET MAY GROW SUBSTANTIALLY

Dataquest estimates that the worldwide ECR equipment market, which includes CVD and dry etch applications, was approximately $75 million in 1989. More than 80 percent of the ECR equipment market is estimated to reside in Japan, which leads the world in production ECR applications. The ECR equipment market is expected to experience healthy growth and to exceed $250 million by 1994. Dry etch applications for polycide and metal interconnect patterning account for approximately 80 percent of ECR equipment sales in 1989, with oxide and nitride CVD applications making up the remaining 20 percent. ECR CVD equipment may gain increasing market share beyond 1993 for advanced interlayer dielectric applications in 16Mb DRAMs and submicron ASICs.

SEMATECH JDP CONTRACT ENHANCES LAM RESEARCH'S CVD MARKET STRATEGY

Lam Research Corporation (LRC) has a well-publicized corporate goal to penetrate the fast-growing CVD equipment market substantially. Dry etch and silicon epitaxy equipment accounted for more than 90 percent of LRC's fiscal year 1989 revenue of $126 million. Dataquest believes that LRC's Integrity CVD system, currently in the final stages of development, is targeted toward high-temperature atmospheric CVD applications such as DRAM trench refill and reflowed interlayer dielectrics prior to first-level metal.

The LRC/Sumitomo Metals partnership agreement gives LRC access to Sumitomo Metals ECR technology. LRC has exclusive marketing rights to Sumitomo Metals' ECR products in the United States and Europe. Dataquest observes considerable synergy between LRC's Integrity high-temperature CVD system and Sumitomo Metals' low-temperature ECR CVD system. We predict that Sumitomo Metals may obtain an exclusive license to manufacture and market the Integrity CVD system in Japan.

Sumitomo Metals apparently has not expressed any major concerns regarding its ECR technology license vis-à-vis the Sematech/LRC contract. In the long term, Sumitomo Metals may view the Sematech/LRC contract favorably because it increases the total available worldwide market for ECR equipment. Dataquest believes that the LRC/Sumitomo Metals partnership agreement is a win-win situation for both companies in view of the excellent synergies in their product portfolios and their relative strengths in different regional markets.

OTHER RELATED SEMATECH ECR JDP CONTRACTS

In other related recent developments, Sematech awarded JDP contracts to the University of Cincinnati, Ohio, and to Applied Science and Technology (ASTeX) in Woburn, Massuchasetts. The University of Cincinnati contract calls for development and optimization of different reactor configurations and processes for advanced dry etch equipment. We note that the University of Cincinnati holds the first patent for multipolar, magnetically confined etching; this patent was awarded in 1984.

ASTeX specializes in manufacturing ECR sources for advanced deposition and dry etch research applications. ASTeX's JDP contract with Sematech will focus on optimizing the plasma source design, developing a process chamber and supporting subsystems, and characterizing a preproduction prototype in Sematech's development laboratory.

POTENTIAL PITFALLS IN THE ECR EQUIPMENT MARKET

ECR equipment has been applied in a limited manner for current dry etch applications such as submicron polycide and metal patterning. Other low-damage dry etch technologies such as magnetically enhanced reactive ion etching (RIE) and low-temperature RIE may challenge ECR dry etch technology. Meanwhile, ECR CVD equipment needs to overcome problems such as high cost/complexity, adequate throughput, process uniformity on 200mm wafers, and integration into a cluster tool architecture. The incumbent plasma-enhanced CVD market leaders such as Applied Materials, ASM International, E.T. Electrotech, and Novellus continue to enhance their process capabilities for submicron applications.

DATAQUEST CONCLUSIONS

Sematech may galvanize the U.S. equipment industry into entering the nascent U.S. ECR equipment market and catching up with Japanese and European vendors. The Sematech ECR JDP contracts challenge the fragmented U.S. equipment industry to intensify its efforts at cooperative development. ECR technology is expected to face market challenges from conventional plasma etch and deposition equipment, which continues to evolve incrementally.

Dataquest expects advanced process technology to continue diffusing readily across national boundaries. We believe that synergistic global alliances between equipment vendors will continue to occur as equipment companies focus on worldwide customer support and service capability rather than glamorous technology solutions per se.

Krishna Shankar