Asia/Pacific-Rest of World Fab Database

October 26, 1992

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Market Statistics

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-MS-9204

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Asia/Pacific-Rest of World Fab Database

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Note: All tables show estimated data.

Asia/Pacific-Rest of World Fab Database

Background

The material in this document applies to the Asia/Pacific-Rest of World (ROW) portion of Dataquest's Semiconductor Equipment, Manufacturing, and Materials service wafer fab database. The wafer fab database is updated on an ongoing basis, employing both primary and secondary research methodologies. The tables included in this document highlight both production and pilot line wafer fabs.

Research Methodology

Dataquest takes a three-pronged approach to wafer fab database research. Information is gained through extensive annual primary research. This survey work is further supplemented with comprehensive secondary research conducted on an ongoing basis. The database is updated daily, which allows Dataquest to provide a snapshot of the marketplace at any time. The information gathered through primary and secondary research is then further supplemented and cross-checked with Dataquest's various other information sources.

General Definitions

Fab line: A fab line is a processing line in a clean room that is equipped to do all front-end wafer processing. Occasionally there are two separate product-specific fab lines or two different wafer sizes in a clean room. In this situation, a clean room will be documented as two fab lines if the equipment is dedicated to each wafer size or product line. There can be many fab lines at one location.

Front-end wafer processing: Front-end wafer processing is defined as all steps involved with semiconductor processing, beginning with initial oxide and ending at wafer probe.

Production fab: A production fab is defined as a wafer fab capable of front-end processing more than 1,250 wafers per week (type = F).

Pilot fab: A pilot fab is defined as a wafer fab capable of front-end processing less than 1,250 wafers per week (type = P).

Definition of Table Columns

The Products Produced column contains information for seven product categories. The information in this column can be very detailed, depending on its availability. The nomenclature used within the seven product groups of the fab database is as follows, with definitions where warranted:

- Analog
  - LIN—Linear/analog devices
  - A/D D/A—Analog-to-digital, digital-to-analog converters
  - AUTOMOTIVE—Dedicated to automobile applications
  - CODEC—Coder/decoder
  - INTERFACE—Interface IC
  - MESFET (GaAs)—Metal Schottky field-effect transistor
  - MODFET (GaAs)
  - MDIODE (GaAs)—Microwave diode
  - MFET (GaAs)—Microwave field-effect transistor
  - MODEM—Modulator/demodulator
  - MMIC—Monolithic microwave IC
  - OP AMP—Operational amplifier
  - PWR IC—Power IC
  - REG—Voltage regulator
  - SMART PWR—Smart power
  - SWITCHES—Switching device
  - TELECOM—Telecommunications chips
- Memory
  - MEM—Memory

- RAM—Random-access memory
- DRAM—Dynamic RAM
- SRAM 4 TR.—Static RAM uses a 4-transistor cell design
- SRAM 6 TR.—Static RAM uses a 6-transistor cell design
- VRAM—Video RAM
- ROM—Read-only memory
- PROM—Programmable ROM
- EPROM—Ultraviolet erasable PROM
- EEPROM or E2—Electrically erasable PROM
- FERRAM—Ferroelectric RAM
- FLASH—Flash memory
- NVMEM—Nonvolatile memory (ROM, PROM, EPROM, EEPROM, FERRAM)
- FIFO—First-in/first-out memory
- SPMEM—Other specialty memory (such as dual-port, shift-register, color lookup)

• Micrologic

- ASSP—Application-specific standard product
- BIT—Bit slice (subset of MPU functions)
- DSP—Digital signal processor
- MCU—Microcontroller unit
- MPR—Microperipheral
- MPRCOM—MPR digital communication (ISDN, LAN, UART, modem)
- MPU—Microprocessor unit
- LISP—32-bit list instruction set processor for AI applications
- RISC—Reduced-instruction-set computation 32-bit MPU

• Standard logic

- LOG—Standard logic

• ASIC logic

- ASIC—Application-specific IC
- ARRAYS—Gate arrays
- CBIC—Cell-based IC
- CUSTOM—Full-custom IC (single user)
- PLD—Programmable logic device

• Discrete

- DIS—Discrete
- DIODE
- FET—Field-effect transistor
- GTO—Gate turn-off thyristor
- HEMT (GaAs)—High-electron-mobility transistor
- MOSFET—MOS-based field-effect transistor
- PWR TRAN—Power transistor
- RECTIFIER
- RF—Radio frequency
- SCR—Schottky rectifier
- SENSORS
- SST—Small-signal transistor
- THYRISTOR
- TRAN—Transistor
- ZENER DIODE

• Optoelectronic

- OPTO—Optoelectronic
- CCD—Charge-coupled device (imaging)
- COUPLERS—Photocouplers
- IED—Infrared-emitting diode
- IMAGE SENSOR
- LASER (GaP)—Semiconductor laser or laser IC
- LED—Light-emitting diode
- PDIODE—Photo diode
- PTRAN—Photo transistor
- SAW—Surface acoustic wave device
- SIT IMAGE SENSOR—Static induction transistor image sensor

The Process Technology column lists four major types of technologies. This column also lists a few uncommon technologies along with

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available information on levels of metal, type of well, and logic structure. Definitions of the nomenclature used in the Process Technology column are as follows:

- MOS (silicon-based)
  - CMOS—Complementary metal-oxide semiconductor
  - MOS—n-channel metal-oxide semiconductor (NMOS) and p-channel metal-oxide semiconductor (PMOS). (More than 90 percent of the MOS fabs use n-channel MOS.)
  - M1—Single-level metal
  - M2—Double-level metal
  - M3—Triple-level metal
  - N-WELL
  - P-WELL
  - POLY1—Single-level polysilicon
  - POLY2—Double-level polysilicon
  - POLY3—Triple-level polysilicon
- BiCMOS (silicon-based)
  - BiCMOS—Bipolar and CMOS combined on a chip
  - BIMOS—Bipolar and MOS combined on a chip
  - ECL I/O—ECL input/output
  - TTL I/O—TTL input/output
- Bipolar (silicon-based)
  - BIP—Bipolar
  - ECL—Emitter-coupled logic
  - TTL—Transistor-transistor logic
  - STTL—Schottky TTL
- Gallium arsenide and other compound semiconductor materials
  - GaAs—Gallium arsenide
  - GaAlAs—Gallium aluminum arsenide
  - GaAs on Si—Gallium arsenide on silicon
  - GaP-Gallium phosphide
  - HgCdTe—Mercuric cadmium telluride
  - InAs—Indium arsenide
  - InP—Indium phosphide
  - InSb—Indium antimony
  - LiNbO3—Lithium niobate
  - SOS—Silicon on sapphire

The number in the Minimum Linewidth column represents the minimum linewidth at the critical mask layers as drawn. This number is stated in microns and is defined in Dataquest's fab survey as being available in production volumes.

The Wafer Size column represents the wafer diameter expressed colloquially in inches. However, for wafers greater than 3 inches in diameter, the colloquial expression is inaccurate. When calculating square inches, the following approximations are used:

Stated Diameter	Approximate Diameter
4 inches (100mm)	3.938 inches
5 inches (125mm)	4.922 inches
6 inches (150mm)	5.906 inches
8 inches (200mm)	7.87 inches

Wafer Start Capacity is defined in the fab survey as the equipment-limited wafer start capacity per four-week period. Start capacity is not limited by current staffing or the number of shifts operating, it is limited only by the installed equipment in the fab and the complexity of the process it runs.

The Clean Room Class column represents the level of cleanliness in the cleanest part of the clean room. This area represents the true environment to which the wafer is exposed.

The Merchant or Captive column categorizes each fab line on the tables as one of these two types. Definitions of the various categories are as follows:

- A Merchant fab line is a fab line that produces devices that end up available on the merchant market.
- A Captive fab line does not sell any of its devices on the merchant market. All production is consumed by the owner of the fab line.

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Table 1
Asia/Pacific-ROW Existing Pilot and Production Fab Lines
(Including Fabs Going into Operation During 1992)

Company	City	Fab Name	Products Produced	Process Technology	Est. Minimum Line Width (Microns)	Wafer Diameter	Est. Max. Wafer Capacity (4wk/Month)	Room (Gross) (Square Feet)	Class Clean Room	Merchant or Captive	Country
ADVANCED MICROELECTRONICS PRODUCT	HSIN CHU	FAB 1	NA	CMOS	2.00	4	10,000	0	NA	M	TAIWAN
AMALGAMATED WIRELESS	SYDNEY	NA	ASIC	CMOS	1.50	6	7,000	0	NA	M	AUSTRALIA
BEIJING NO.2	BEIJING	NA	INTERFACE IC	BIP TTL	5.00	3	10,000	0	NA	C	CHINA
BEIJING NO.3	BEIJING	NA	LOG TRANS LIN MEM WATCH	CMOS MOS	5.00	3	15,000	0	NA	C	CHINA
BEIJING NO.5	BEIJING	NA	OP AMP LOG PWR TRAN	NA	5.00	3	10,000	0	NA	C	CHINA
BEIJING NO.878	BEIJING	NA	DIS	NA	5.00	3	8,000	0	NA	C	CHINA
BEIJING TUBE FACTORY	BEIJING	NA	DIS	NA	5.00	4	10,000	0	NA	C	CHINA
BEL	BANGALORE	NA	DIS	NA	4.00	4	10,000	0	NA	M	INDIA
BELLING IC CO.	SHANGHAI	NA	DIS	CMOS	2.40	0	0	0	NA	C	CHINA
BHARAT ELECTRONICS	BANGALORE	N/M		NA	0.00	0	0	0	NA	M	INDIA
CHARTERED SEMICONDUCTOR	SINGAPORE	Fab 1	ASIC LIN EEPROM	CMOS MOS	1.20	6	15,000	20,000	10	M	SINGAPORE
CONTINENTAL DEVICES	DELHI	NA	DIS DIODE TRAN PWR SCR	NA	0.00	3	10,000	0	NA	M	INDIA
DAEWOO	GURO-DONG, SEOUL	BIPOLAR LINE	LIN	BIP	3.00	4	9,000	0	NA	M	SOUTH KOREA
DAEWOO	GURO-DONG, SEOUL	MOS LINE	CUSTOM	CMOS MOS	1.70	4	9,000	0	NA	M	SOUTH KOREA
DONG GUANG PLANT	BEIJING	NA	LOG MPU	BIP TTL	5.00	3	5,000	0	NA	C	CHINA
ELECT. COMPONENTS INDIA	HYDERABAD	NA	DIS CONSUMER ICs	BIP	0.00	3	15,000	0	NA	M	INDIA
EPISIL TECHNOLOGIES INC.	HSIN CHU	NA	LIN	BICMOS	3.00	5	12,000	5,380	10	M	TAIWAN
FINE MICROELECTRONICS	HSIN CHU	NA	OPTO TRAN	NA	0.00	3	10,000	0	NA	M	TAIWAN
FUCHOU	FUCHOU	NA	NA	NA	5.00	3	4,000	0	NA	M	CHINA
GENERAL INSTRUMENTS	HSI TIEN CITY	NA	PWR DIS	BIP	0.00	3	12,000	0	10,0	M	TAIWAN
GOLDSTAR	CHONGJU-CITY, CHOONGBUK	PHASE 1	1Mb DRAM 4Mb DRAM	CMOS MOS	0.80	6	30,000	0	NA	M	SOUTH KOREA
GOLDSTAR	CHONGJU-CITY, CHOONGBUK	PHASE 2	4Mb DRAM	MOS CMOS M2 POLY3	0.70	6	30,000	0	NA	M	SOUTH KOREA
GOLDSTAR	GUMI-CITY, KYUNGBUK	GUMI BIPOLAR	LIN	BIP TTL	3.00	4	25,000	0	NA	M	SOUTH KOREA
GOLDSTAR	GUMI-CITY, KYUNGBUK	GUMI MOS	SRAM DRAM	CMOS MOS	1.50	5	15,000	0	NA	M	SOUTH KOREA

(Continued)

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Table 1 (Continued)
Asia/Pacific-ROW Existing Pilot and Production Fab Lines
(Including Fabs Going into Operation During 1992)

Company	City	Fab Name	Products Produced	Process Technology	Est. Minimum Line Width (Microns)	Wafer Diameter	Est. Max. Wafer Capacity (4wk/Month)	Room (Gross) (Square Feet)	Class Clean Room	Merchant or Captive	Country
HARBIN FACTORY	HARBIN	NA	TRAN	NA	5.00	3	10,000	0	NA	C	CHINA
HOLTEK	HSIN CHU	NA	ASIC LIN	CMOS	2.00	5	10,000	0	NA	M	TAIWAN
HUA KO ELECTRONICS	TAI PO	NA	MPU LIN ASIC LOG SRAM ROM	CMOS MOS	0.00	4	8,000	0	NA	M	HONG KONG
HUALON MICROELECTRONICS	HSIN CHU	FAB 1	ROM TELECOM CONSUMER MPU	CMOS MOS	1.00	5	30,000	0	10	M	TAIWAN
HYUNDAI	ICHUN, KYUNGKI-DO	FAB I-A	PLD EEPROM 16K SRAM	CMOS MOS	1.20	5	15,000	0	NA	M	SOUTH KOREA
HYUNDAI	ICHUN, KYUNGKI-DO	FAB I-B	256K DRAM 256K SRAM	MOS CMOS	1.00	5	8,000	0	NA	M	SOUTH KOREA
HYUNDAI	ICHUN, KYUNGKI-DO	FAB II	1Mb DRAM 1Mb SRAM	CMOS MOS	0.80	6	25,000	0	NA	M	SOUTH KOREA
HYUNDAI	ICHUN, KYUNGKI-DO	FAB III - A	4Mb DRAM	CMOS MOS	0.80	6	20,000	0	NA	M	SOUTH KOREA
HYUNDAI	ICHUN, KYUNGKI-DO	FAB III - B	4Mb DRAM 16Mb DRAM	CMOS	0.60	6	20,000	0	NA	M	SOUTH KOREA
INDIAN TELEPHONE	BANGALORE	NA	DIS	BIP	0.00	3	12,000	0	NA	C	INDIA
INTEL	JERUSALEM	FAB 8	MPU	CMOS	1.00	6	21,000	24,000	10	M	ISRAEL
JINAN NO.1	JINAN	NA	LOG OP AMP	NA	5.00	3	10,000	0	NA	C	CHINA
JINAN NO.2	JINAN	NA	1K SRAM 4K DRAM	MOS	5.00	3	8,000	0	NA	C	CHINA
KOREAN ELECTRONIC CO.	GUMI-CITY, KYUNGBUK	BIPOLAR LINE 1	LIN	BIP	2.50	4	20,000	0	NA	M	SOUTH KOREA
KOREAN ELECTRONIC CO.	GUMI-CITY, KYUNGBUK	BIPOLAR LINE 2	CUSTOM	BIP	1.50	5	10,000	0	NA	M	SOUTH KOREA
LIAONING FACTORY	JINZHOU	NA	TRAN	NA	5.00	3	12,000	0	NA	C	CHINA
MACRONIX INC.	HSIN CHU	FAB 1	EPROM FLASH 4Mb ROM	MOS	0.80	6	8,000	53,800	1	M	TAIWAN
MIN MACHINERY INDUSTRY	NA	NA	LOG PWR TRAN	MOS	5.00	3	5,000	0	NA	C	CHINA
MOSEL-VITELIC CORPORATION	TAI PO, N.T.	FAB 1	LIN 256K DRAM 16K SRAM	CMOS	1.50	4	14,000	10,000	10	M	HONG KONG
MOTOROLA	SEREMBAN	ISMF	PWR TRAN DIS SST	BIP	0.00	4	8,000	6,000	NA	M	MALAYSIA
NAINA SEMICONDUCTORS	HALDWANI	NA	DIODES	NA	0.00	0	0	0	NA	M	INDIA

(Continued)

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Table 1 (Continued)
Asia/Pacific-ROW Existing Pilot and Production Fab Lines
(Including Fabs Going into Operation During 1992)

Company	City	Fab Name	Products Produced	Process Technology	Est. Minimum Line Width (Microns)	Wafer Diameter	Est. Max. Wafer Capacity (4wk/ Month)	Room (Gross) (Square Feet)	Class Clean Room	Merchant or Captive	Country
NATIONAL SEMICONDUCTOR	MIGDAL HAEMEK	NA	MPU MCU MPR DSP ARRAYS CUSTOM	CMOS M2 POLY1	0.70	6	5,500	18,000	10	M	ISRAEL
PHILIPS	SHANGHAI	NA	LIN DIGITAL IC FOR T.V.	CMOS BIP	0.00	5	10,000	0		M	CHINA
PHOTRONICS	NA	NA	OPTO	NA	0.00	3	10,000	0	NA	M	TAIWAN
QIANMEN SEMICONDUCTOR FACTORY	BEIJING	NA	DIG WATCH IC	NA	5.00	3	10,000	0	NA	C	CHINA
RAMAX	MELBOURNE	NA	FERRAM	CMOS GaAs	0.00	0	0	0	NA	M	AUSTRALIA
RCL SEMICONDUCTORS	TAI PO	NA	MEM MPU LOG LIN TRAN	CMOS	0.00	4	4,000	0	NA	M	HONG KONG
RECTRON LTD.	TAIPEI	NO. 1	DIS	NA	0.00	2	90,000	0	NA	M	TAIWAN
SAMSUNG	BUCHON-CITY, KYUNGKI-DO	BIPOLAR LINE	LIN	BIP	3.00	4	25,000	0	NA	M	SOUTH KOREA
SAMSUNG	BUCHON-CITY, KYUNGKI-DO	MOS LINE	MPU MCU LOG	CMOS MOS	2.00	5	20,000	0	NA	M	SOUTH KOREA
SAMSUNG	KIHEUNG-UP, KYUNGKI-DO	MOS 1	64K DRAM	MOS CMOS	1.50	4	35,000	0	NA	M	SOUTH KOREA
SAMSUNG	KIHEUNG-UP, KYUNGKI-DO	MOS 2	256K DRAM	CMOS MOS	1.20	6	35,000	0	NA	M	SOUTH KOREA
SAMSUNG	KIHEUNG-UP, KYUNGKI-DO	MOS 3	1Mb DRAM	MOS CMOS	0.80	6	35,000	0	NA	M	SOUTH KOREA
SAMSUNG	KIHEUNG-UP, KYUNGKI-DO	MOS 4	4Mb DRAM	CMOS	0.60	6	30,000	0	NA	M	SOUTH KOREA
SAMSUNG	KIHEUNG-UP, KYUNGKI-DO	MOS 5	16Mb DRAM	CMOS	0.50	8	6,000	0	NA	M	SOUTH KOREA
SGS-THOMSON	ANG MO KIO	BIPOLAR LINEAR	OP AMP TELECOM	BIP MOS	0.00	5	20,000	0	NA	M	SINGAPORE
SGS-THOMSON	ANG MO KIO	BIPOLAR POWER	PWR TRAN	BIP MOS	0.00	5	20,000	0	NA	M	SINGAPORE
SGS-THOMSON	ANG MO KIO	NMOS & CMOS	NA	CMOS	0.00	5	20,000	0	NA	M	SINGAPORE
SHANGHAI MICRO. R&D CENTER	SHANGHAI	NA	NA	NA	0.00	0	0	0			CHINA
SHANGHAI NO.5	SHANGHAI	NA	8080 MPU LOG MEM LIN DIS	CMOS	5.00	3	10,000	0	NA	C	CHINA
SHANGHAI NO.8331	SHANGHAI	NA	OP AMP PWR TRAN	BIP TTL	5.00	3	4,000	0	NA	C	CHINA

(Continued)

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Table 1 (Continued)
Asia/Pacific-ROW Existing Pilot and Production Fab Lines
(Including Fabs Going into Operation During 1992)

Company	City	Fab Name	Products Produced	Process Technology	Est. Minimum Line Width (Microns)	Wafer Diameter	Est. Max. Wafer Capacity (4wk/ Month)	Room (Gross) (Square Feet)	Class Clean Room	Merchant or Captive	Country
SHANGHAI PHILIPS NO.7	SHANGHAI	NA	OP AMP PWR TRAN DIS	BIP TTL CMOS	5.00	3	10,000	5,380	NA	M	CHINA
SHINDENGEN	NA	NA	TRAN DIODES	NA	0.00	0	0	0	NA	M	THAILAND
SID MICROELECTRONICS	CONTAGEM	NA	LIN PWR TRAN SST PWR ICs	BIP	30.00	3	12,000	15,000	NA	M	BRAZIL
SID MICROELECTRONICS	CONTAGEM	NA	PWR ICs	CMOS	2.00	4	13,000	15,000	NA	M	BRAZIL
SOUTH AFRICAN MICROELECTRONICS	PRETORIA	NA	A/D D/A TELECOM	BIP	5.00	3	10,000	0	NA	M	SOUTH AFRICA
SOUTH AFRICAN MICROELECTRONICS	PRETORIA	NA	A/D D/A TELECOM	CMOS	3.00	4	10,000	0	NA	M	SOUTH AFRICA
SPIC ELECTRONICS	GUINDY, MADRAS	NA	PHOTO VOLTAIC DIS	NA	3.00	3	15,000	0	NA	M	INDIA
SUZHOU PLANT	SUZHOU	NA	LOG OPTO CONSUMER	BIP TTL MOS	0.00	3	0	0	NA	C	CHINA
TI/ACER	HSIN CHU	FAB 1	4Mb DRAM	CMOS	0.80	6	25,000	45,000	NA	M	TAIWAN
TIAN GUANG FACTORY	SHAOXING	NA	LOG	BIP ECL TTL	5.00	4	14,000	0	NA	C	CHINA
TIANJIN NO.1	TIANJIN	NA	AUDIO IC	CMOS	5.00	3	10,000	0	NA	C	CHINA
TSMC	HSIN CHU	FAB 1	MEM MICRO LOG	CMOS M2 2POLY	1.00	6	14,000	7,637	10	M	TAIWAN
TSMC	HSIN CHU	FAB 2-A	SRAM EPROM LOG LIN	CMOS	0.80	6	25,000	40,000	1	M	TAIWAN
TSMC	HSIN CHU	FAB 2-B	SRAM	CMOS	0.80	6	4,000	40,000	NA	M	TAIWAN
UNITED MICROELECTRONICS	HSIN CHU	FAB 1	SRAM MCU LIN	CMOS MOS M2	1.50	4	45,000	0	NA	M	TAIWAN
UNITED MICROELECTRONICS	HSIN CHU	FAB 2-A	4Mb ROM EPROM	CMOS MOS M2	0.60	6	18,000	30,000	1	M	TAIWAN
UNITED MICROELECTRONICS	HSIN CHU	FAB 2-B	1Mb SRAM 4Mb ROM EPROM	CMOS	0.60	6	3,000	15,000	NA	M	TAIWAN
WINBOND	HSIN CHU	FAB 1	SRAM ROM MPU	CMOS MOS	1.00	5	20,000	0	10	M	TAIWAN
WINBOND	HSIN CHU	FAB 2	SRAM MPU	CMOS M2	0.80	6	8,000	0	1	M	TAIWAN
WUXI MICROELECTRONICS CORPORATION	WUXI JIANH SU	NA	TRAN DIODES LIN LOG MEM	MOS	5.00	4	15,000	0	NA	M	CHINA
YANHE RADIO FACTORY	XIAN	NA	LIN LOG	NA	5.00	3	7,000	0	NA	C	CHINA

NA = Not available
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Table 2
Asia/Pacific-Rest of World Future Pilot and Production Fab Lines
Planned Facilities by Year

Company	City	Fab Name	Products	Process Technology	Facility Type	Target Date Facility to Begin Operation	Est. Minimum Line Geometry (microns)	Wafer Size (Inches)	Est. Wafer Start Capacity (4 Wk/ Month)	Clean Room Square Feet	Country
Production Begins: 1993											
GOLDSTAR	CHONGJU-CITY, CHOONGBUK	PHASE 3	16Mb DRAM 4Mb SRAM	CMOS	F	NA	0.50	8	45,000	0	SOUTH KOREA
MOSel/VITELIC CORPORATION	HSIN CHU	FAB 1	4Mb DRAM	CMOS MOS	F	08/01/93	0.60	6	13,000	22,000	TAIWAN
NBC CHINA	BEIJING	NA	TELECOM CONSUMER ICS	CMOS	F	NA	2.00	6	0	0	CHINA
SEMICONDUCTOR COMPLEX	NAGAR-CHANDIGARH	NA	LSI	NA	F	11/01/91	3.00	6	0	0	INDIA
TECH SEMICONDUCTOR SINGAPORE LTD.	NA	NA	16Mb DRAM	CMOS	F	03/01/93	0.60	8	10,000	0	SINGAPORE
WUXI MICROELECTRONICS CORPORATION	WUXI	NA	TELECOM ICS	MOS	F	02/01/91	3.00	5	25,000	0	CHINA
Production Begins: 1994											
HITACHI	PENANG	NA	1Mb DRAM 4Mb DRAM	CMOS	F	NA	0.00	6	0	0	MALAYSIA
HUA YUE MICROELECTRONICS CO. LTD.	SHAOXING	NA	NA	CMOS	F	05/01/94	1.00	6	7,000	0	CHINA
MOSel/VITELIC CORPORATION	HSIN CHU	FAB 2	16Mb DRAM	CMOS MOS	F	NA	0.50	8	20,000	22,000	TAIWAN
SAMSUNG	KIHEUNG-UP, KYUNGKI-DO	FAB 6	4Mb 16Mb DRAM	CMOS	F	06/01/93	0.60	8	20,000	0	SOUTH KOREA
SYNTEK	HSIN CHU	NA	NA	NA	F	NA	0.00	6	10,000	0	TAIWAN
UNITED MICROELECTRONICS	HSIN CHU	FAB 3	SRAM	NA	F	NA	0.00	8	30,000	0	TAIWAN

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European Fab Database

October 19, 1992

Source: Dataquest

Market Statistics

Semiconductor Equipment, Manufacturing, and Materials

SEMM-SVC-MS-9203

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European Fab Database

October 19, 1992

Source: Dataquest

Market Statistics

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Semiconductor Equipment, Manufacturing, and Materials
SEMM-SVC-MS-9203

File behind the *Market Statistics* tab inside the binder labeled Semiconductor Equipment, Manufacturing, and Materials

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European Fab Database

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Note: All tables show estimated data.

European Fab Database

Background

The material in this document applies to the European portion of Dataquest's Semiconductor Equipment, Manufacturing, and Materials service wafer fab database. Information pertaining to Eastern Europe and Israel has also been included in this document because of the close ties between these markets. The wafer fab database is updated on an ongoing basis, employing both primary and secondary research methodologies. The tables included in this document highlight both production and pilot line wafer fabs.

Research Methodology

Dataquest takes a three-pronged approach to wafer fab database research. Information is gained through extensive annual primary research. This survey work is further supplemented with comprehensive secondary research conducted on an ongoing basis. The database is updated daily, which allows Dataquest to be able to provide a snapshot of the marketplace at any time. The information gathered through primary and secondary research is then further supplemented and cross-checked with Dataquest's various other information sources.

General Definitions

Fab line: A fab line is a processing line in a clean room that is equipped to do all front-end wafer processing. Occasionally there are two separate product-specific fab lines or two different wafer sizes in a clean room. In this situation, a clean room will be documented as two fab lines if the equipment is dedicated to each wafer size or product line. There can be many fab lines at one location.

Front-end wafer processing: Front-end wafer processing is defined as all steps involved with semiconductor processing, beginning with initial oxide and ending at wafer probe.

Production fab: A production fab is defined as a wafer fab capable of front-end processing more than 1,250 wafers per week (type = F).

Pilot fab: A pilot fab is defined as a wafer fab capable of front-end processing less than 1,250 wafers per week (type = P).

Definition of Table Columns

The Products Produced column contains information for seven product categories. The information in this column can be very detailed, depending on its availability. The nomenclature used within the seven product groups of the fab database is as follows, with definitions where warranted:

- Analog
  - LIN—Linear/analog devices
  - A/D D/A—Analog-to-digital, digital-to-analog converters
  - AUTOMOTIVE—Dedicated to automobile applications
  - CODEC—Coder/decoder
  - INTERFACE—Interface IC
  - MESFET (GaAs)—Metal Schottky field-effect transistor
  - MODFET (GaAs)
  - MDIODE (GaAs)—Microwave diode
  - MFET (GaAs)—Microwave field-effect transistor
  - MODEM—Modulator/demodulator
  - MMIC—Monolithic microwave IC
  - OP AMP—Operational amplifier
  - PWR IC—Power IC
  - REG—Voltage regulator
  - SMART PWR—Smart power
  - SWITCHES—Switching device
  - TELECOM—Telecommunications chips
- Memory
  - MEM—Memory
  - RAM—Random-access memory

- DRAM—Dynamic RAM
- SRAM 4 TR.—Static RAM uses a 4-transistor cell design
- SRAM 6 TR.—Static RAM uses a 6-transistor cell design
- VRAM—Video RAM
- ROM—Read-only memory
- PROM—Programmable ROM
- EPROM—Ultraviolet erasable PROM
- EEPROM or E2—Electrically erasable PROM
- FERRAM—Ferroelectric RAM
- FLASH—Flash memory
- NVMEM—Nonvolatile memory (ROM, PROM, EPROM, EEPROM, FERRAM)
- FIFO—First-in/first-out memory
- SPMEM—Other specialty memory (such as dual-port, shift-register, color lookup)

• Micrologic

- ASSP—Application-specific standard product
- BIT—Bit slice (subset of MPU functions)
- DSP—Digital signal processor
- MCU—Microcontroller unit
- MPR—Microperipheral
- MPRCOM—MPR digital communication (ISDN, LAN, UART, modem)
- MPU—Microprocessor unit
- LISP—32-bit list instruction set processor for AI applications
- RISC—Reduced-instruction-set computation 32-bit MPU

• Standard logic

- LOG—Standard logic

• ASIC logic

- ASIC—Application-specific IC
- ARRAYS—Gate arrays
- CBIC—Cell-based IC
- CUSTOM—Full-custom IC (single user)
- PLD—Programmable logic device

• Discrete

- DIS—Discrete
- DIODE
- FET—Field-effect transistor
- GTO—Gate turn-off thyristor
- HEMT (GaAs)—High-electron-mobility transistor
- MOSFET—MOS-based field-effect transistor
- PWR TRAN—Power transistor
- RECTIFIER
- RF—Radio frequency
- SCR—Schottky rectifier
- SENSORS
- SST—Small-signal transistor
- THYRISTOR
- TRAN—Transistor
- ZENER DIODE

• Optoelectronic

- OPTO—Optoelectronic

• CCD—Charge-coupled device (imaging)

- COUPLERS—Photocouplers
- IED—Infrared-emitting diode
- IMAGE SENSOR
- LASER (GaP)—Semiconductor laser or laser IC
- LED—Light-emitting diode
- PDIODE—Photo diode
- PTRAN—Photo transistor
- SAW—Surface acoustic wave device
- SIT IMAGE SENSOR—Static induction transistor image sensor

The Process Technology column lists four major types of technologies. This column also lists a few uncommon technologies along with

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available information on levels of metal, type of well, and logic structure. Definitions of the nomenclature used in the Process Technology column are as follows:

- MOS (silicon-based)
  - CMOS—Complementary metal-oxide semiconductor
  - MOS—n-channel metal-oxide semiconductor (NMOS) and p-channel metal-oxide semiconductor (PMOS) (More than 90 percent of the MOS fabs use n-channel MOS.)
  - M1—Single-level metal
  - M2—Double-level metal
  - M3—Triple-level metal
  - N-WELL
  - P-WELL
  - POLY1—Single-level polysilicon
  - POLY2—Double-level polysilicon
  - POLY3—Triple-level polysilicon
- BiCMOS (silicon-based)
  - BiCMOS—Bipolar and CMOS combined on a chip
  - BIMOS—Bipolar and MOS combined on a chip
  - ECL I/O—ECL input/output
  - TTL I/O—TTL input/output
- Bipolar (silicon-based)
  - BIP—Bipolar
  - ECL—Emitter-coupled logic
  - TTL—Transistor-transistor logic
  - STTL—Schottky TTL
- Gallium arsenide and other compound semiconductor materials
  - GaAs—Gallium arsenide
  - GaAlAs—Gallium aluminum arsenide
  - GaAs on Si—Gallium arsenide on silicon
  - GaP-Gallium phosphide
  - HgCdTe—Mercuric cadmium telluride
  - InAs—Indium arsenide
  - InP—Indium phosphide
  - InSb—Indium antimony
  - LiNbO3—Lithium niobate
  - SOS—Silicon on sapphire

The number in the Minimum Linewidth column represents the minimum linewidth at the critical mask layers as drawn. This number is stated in microns and is defined in Dataquest's fab survey as being available in production volumes.

The Wafer Size column represents the wafer diameter expressed colloquially in inches. However, for wafers greater than 3 inches in diameter, the colloquial expression is inaccurate. When calculating square inches, the following approximations are used:

Stated Diameter	Approximate Diameter
4 inches (100mm)	3.938 inches
5 inches (125mm)	4.922 inches
6 inches (150mm)	5.906 inches
8 inches (200mm)	7.87 inches

Wafer Start Capacity is defined in the fab survey as the equipment-limited wafer start capacity per four-week period. Start capacity is not limited by current staffing or the number of shifts operating, it is limited only by the installed equipment in the fab and the complexity of the process it runs.

The Clean Room Class column represents the level of cleanliness in the cleanest part of the clean room. This area represents the true environment to which the wafer is exposed.

The Merchant or Captive column categorizes each fab line on the tables as one of these two types. Definitions of the various categories are as follows:

- A Merchant fab line is a fab line that produces devices that end up available on the merchant market.
- A Captive fab line does not sell any of its devices on the merchant market. All production is consumed by the owner of the fab line.

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Table 1
European Existing Pilot and Production Fab Lines
(Including Fabs Going into Operation During 1992)

Company	City	Fab Name	Products Produced	Process Technology	Est. Minimum Line Width (Microns)	Wafer Diameter	Est. Max. Wafer Capacity (4wk/Month)	Clean Room (Square Feet)	Class Clean Room	Merchant or Captive	Country
ABB SEMICONDUCTOR	LENSBURG	NA	DIS	BIP	0	4	0	0		M	SWITZERLAND
ABB-HAFO AB	JARFALLA	NA	ASIC LIN	BIP CMOS	1.50	4	3,000	12,900	1	M	SWEDEN
ABB-IXYS SEMICONDUCTOR	LAMPERTHEIM	ABB-IXYS	DIS DIODE	BIP	5.00	4	10,000	8,000	100	M	GERMANY
AEG AG (DAIMLER BENZ)	ULM	ULM RSCH	3D ICs mm-WAVE OPTO	GaAs MOS	0	0	0	0	NA	M	GERMANY
ANALOG DEVICES	LIMERICK	NA	LIN AD/DA TELECOM	CMOS BICMOS	1.00	4	20,000	30,000	10	M	IRELAND
ANSALDO TRASPORTI	GENOA	LINITA	PWR DIS	BIP 1M	2.00	4	6,000	0	10	M	ITALY
ASCOM MICROELECTRONICS	BEVAIX	NA	ARRAYS CUSTOM	BIP	6.00	4	4,000	21,520	10	M	SWITZERLAND
AT&T MICROELECTRONICS	MADRID	NA	CBIC CUSTOM	CMOS M2	1.00	6	8,400	30,000	1	M	SPAIN
ATMOS/ELPOL	WARSAW	NA	ASIC	NA	2.00	4	0	0	NA	M	POLAND
AUSTRIA MIKROSYSTEME GmbH	UNTERPREMSTATTEN	NA	ASIC	CMOS BICMOS	0.80	4	15,000	32,000	NA	M	AUSTRIA
BANEASA S.A. (IPRS)	BUCHAREST	NA	THYRISTOR DIODE LIN	BIP	0	0	0	0	NA	M	ROMANIA
BT&D TECHNOLOGIES	IPSWICH, SUFFOLK	NA	OPTO LASER		1.00	2	320	35,500	10,000		ENGLAND
DIGITAL EQUIPMENT CORPORATION	SOUTH QUEENSFERRY	NA	MPU FPU LOG ALPHA	CMOS M3 2POLY	0.75	6	3,000	28,000	1	C	SCOTLAND
ELMOS GmbH	DORTMUND	NA	ASIC	CMOS	1.50	4	4,000	15,000	1	M	GERMANY
EM MICROELECTRONICS-MARIN S.A.	NEUCHATEL	FAB 3		NA	2.00	6	4,200	18,292	10	M	SWITZERLAND
ERICSSON	KALMAR	NA	PWR DIS	BIP	0	4	25,000	92,000	NA	M	SWEDEN
ES2 EUROPEAN SILICON STRUCTURES S.A.	ROUSSET CEDEX	ES2/MTD	CBIC ARRAYS CUSTOM MIL STD 883	CMOS M2	0.80	5	1,500	12,912	2	M	FRANCE
FUJITSU	NEWTON AYCLIFFE	PHASE 1	4Mb DRAM ASIC	CMOS	0.80	6	5,600	45,000	1	M	ENGLAND
GEC PLESSEY SEMICONDUCTOR	LINCOLN	NA	LIN MPU ARRAYS SRAM CUST	CMOS MOS	1.50	4	13,000	12,000	10	M	ENGLAND
GEC PLESSEY SEMICONDUCTOR	LINCOLN	NA	THYRISTOR	BIP SOS	0	4	0	0	NA	M	ENGLAND
GEC PLESSEY SEMICONDUCTOR	ROBOROUGH	NA	ASIC DSP TELECOM	CMOS NMOS M3	0.70	6	6,000	19,906	1	M	ENGLAND
GEC PLESSEY SEMICONDUCTOR	SWINDON	NA	DIODES DIS LIN	BIP	5.00	5	12,000	29,000	NA	M	ENGLAND
GEC PLESSEY SEMICONDUCTOR	SWINDON	NA	LIN	BIP	3.00	4	14,000	0	NA	M	ENGLAND
GENERAL INSTRUMENTS	CRICKLADE	NA	DIS	BIP	0	4	10,000	0	NA	M	ENGLAND
HITACHI	LANDSHUT	NA	4Mb DRAM 1Mb SRAM	NA	0.80	8	16,000	0	NA	M	GERMANY
HMT	BRUGG	NA	CONSUMER ICs	MOS	0	3	15,000	15,000	NA	M	SWITZERLAND
HUGHES MICROELECTRONICS	GLENROTHES	NA	ARRAYS CBIC EPROM CUSTOM	CMOS MOS	3.00	4	6,400	28,000	100	M	SCOTLAND
IBM	CORBEIL-ESSONNES	NA	ARRAYS LIN CUSTOM	BIP	2.00	5	40,000	50,000	NA	C	FRANCE
IBM	CORBEIL-ESSONNES	NA	256K DRAM 64K SRAM	CMOS MOS	1.00	5	25,000	25,000	NA	C	FRANCE
IBM	CORBEIL-ESSONNES	NA	1Mb DRAM	CMOS	0	8	7,000	0	NA	C	FRANCE
IBM	HANNOVER	NA	DIS	BIP	0	4	20,000	0	NA	C	GERMANY
IBM	SINDELFINGEN	NA	PWR DIS HYBRID	BIP	0	4	20,000	0	NA	C	GERMANY
IBM	SINDELFINGEN	NA	ARRAYS	BIP	2.00	5	15,000	20,000	NA	C	GERMANY

(Continued)

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Table 1 (Continued)
European Existing Pilot and Production Fab Lines
(Including Fabs Going into Operation During 1992)

Company	City	Fab Name	Products Produced	Process Technology	Est. Minimum Line Width (Microns)	Wafer Diameter	Est. Max. Wafer Capacity (4wk/Month)	Clean Room (Square Feet)	Class Clean Room	Merchant or Captive	Country
IBM	SINDELFINGEN	NA	1Mb DRAM 4Mb DRAM	CMOS	0.80	8	20,000	45,000	NA	C	GERMANY
IBM	SINDELFINGEN	NA	256K DRAM SRAM DSP MPU	MOS	1.50	5	25,000	20,000	NA	C	GERMANY
IBM	SINDELFINGEN	NA	CUSTOM	BIP	1.50	5	15,000	20,000	NA	C	GERMANY
IBM/SIEMENS	CORBEIL-ESSONNES	NA	16 Mb DRAM	CMOS	0.80	8	12,000	0		M	FRANCE
ICCE	BANEASA	NA	OPTO LIN	BIP	0	0	0	0	NA		ROMANIA
ICL	NA	NA	16K DRAM, 64K DRAM	NA	0	0	0	0	NA	M	BULGARIA
IMEC	LEUVEN	NA	NA	CMOS M2	0.70	0	0	0		R	BELGIUM
INST. SCIENCE & TECH.	TRENTO	NA	CCD	CMOS	0	4	10,000	0	NA	R	ITALY
INTEL	JERUSALEM	FAB 8	386 MPU 286 MPU	CMOS	0.80	6	21,000	24,000	10	M	ISRAEL
INTL. RECTIFIER	TURIN	BORGARO	RECTIFIER THYRISTOR	NA	0	4	15,000	13,000	100	M	ITALY
INTL. RECTIFIER	TURIN	VENARIA	RECTIFIER THYRISTOR	NA	0	4	10,000	0	NA	M	ITALY
ISKRA	TRBOVLJE	NA	DIS	BIP	0	3	5,000	0	NA	M	YUGOSLAVIA
ISOCOM	HARTLEPOOL	NA	OPTO	GaAs	0	0	0	0	NA	M	ENGLAND
ITALTEL	ROME	NA	NA	GaAs	0	0	0	0	NA	M	ITALY
ITT	FREIBURG	NA	PWR TRAN DIS	BIP MOS	5.00	4	42,000	0	100	M	GERMANY
ITT	FREIBURG	NA	DSP NVMEM CUSTOM	CMOS MOS	1.20	5	21,500	0	10	M	GERMANY
ITT	FREIBURG	NA	DIS CUSTOM	BIP	5.00	4	16,500	0	10	M	GERMANY
LUCAS	SUTTON COLDFIELD	NA	PWR DIS	GaAs	0	0	0	54,000	NA	M	ENGLAND
MATRA MHS S.A.	NANTES	FAB 1	256K SRAM MCU RISC MPI ASIC LIN	CMOS BICMOS M2	0.70	5	10,500	21,500	10	M	FRANCE
MICROELECT.-MARIN	MARIN	NA	CUSTOM	NA	0	4	10,000	0	NA	M	SWITZERLAND
MICROELECTRONICA S.A.	BANEASA	NA	MPU 16K DRAM	MOS	0	0	0	0	NA	M	ROMANIA
MICROELECTRONICS—IME LTD.	SOFIA	NA	LIN	CMOS BICMOS MOS	2.00	1	2,000	0		M	BULGARIA
MICROELECTRONICS—IME LTD.	SOFIA	NA	LIN	CMOS BICMOS MOS	2.00	5	9,000	0		M	BULGARIA
MICRONAS INC.	ESPOO	NA	LIN CBIC CUSTOM	CMOS M2	2.00	4	4,000	12,912	100	C	FINLAND
MIETEC ALCATEL	OUDENAARDE	FAB 1	CUSTOM CBIC ANA	MOS CMOS BICMOS	1.00	4	15,000	21,600	10	M	BELGIUM
MOTOROLA	EAST KILBRIDE	MOS 1	MCU LOG	CMOS MOS M1	3.00	4	43,200	25,600	100	M	SCOTLAND
MOTOROLA	EAST KILBRIDE	MOS 9	SRAM 1Mb DRAM MPU	CMOS M2	0.80	6	22,000	34,000	10	M	SCOTLAND
MOTOROLA	TOULOUSE	BIPOLAR 4	TELECOM OP AMP REG AUTO	BIP	2.00	4	25,000	22,000	100	M	FRANCE
MOTOROLA	TOULOUSE	TOULOUSE POWER	PWR TRAN	BIP	10.00	5	12,000	8,700	100	M	FRANCE
MOTOROLA	TOULOUSE	TOULOUSE RECTIFIER	DIS	BIP	0	4	3,600	5,800	NA	M	FRANCE
MTG (THESYS GmbH)	ERFURT	NA	ASIC	CMOS BICMOS	0	6	0	0	NA	C	GERMANY

(Continued)

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Table 1 (Continued)
European Existing Pilot and Production Fab Lines
(Including Fabs Going into Operation During 1992)

Company	City	Fab Name	Products Produced	Process Technology	Est. Minimum Line Width (Microns)	Wafer Diameter	Est. Max. Wafer Capacity (4wk/Month)	Clean Room (Square Feet)	Class Clean Room	Merchant or Captive	Country
NATIONAL SEMICONDUCTOR	GREENOCK	4"	LOG LIN	CMOS M1	2.50	4	25,000	0	100	M	SCOTLAND
NATIONAL SEMICONDUCTOR	GREENOCK	6"	LAN	BIP M2	2.00	6	21,000	18,700	10	M	SCOTLAND
NATIONAL SEMICONDUCTOR	GREENOCK	LINEAR 4"	LIN	BIP M1 M2	5.00	4	37,000	10,000	10	M	SCOTLAND
NATIONAL SEMICONDUCTOR	MIGDAL HAEMEK	NA	MPU MCU MPR DSP ARRAYS CUSTOM	CMOS M2 POLY1	0.70	6	5,500	18,000	10	M	ISRAEL
NEC	LIVINGSTON, WEST LOTHIAN	PHASE 1	1Mb DRAM 4Mb DRAM	CMOS M2 M3	0.70	5	9,000	19,500	1	M	SCOTLAND
NEC	LIVINGSTON, WEST LOTHIAN	PHASE 2	4Mb DRAM 256K SRAM MCU ASIC	CMOS	0.80	6	9,000	19,500	NA	M	SCOTLAND
NUOVA MISTRAL S.P.A.	SERMONETA (LATINA)	NA	ZENER DIODE DIODES SST	NA	3.00	4	15,000	10,760	1,000	M	ITALY
PHILIPS	CAEN	NA	CONSUMER ICS	BIPOLAR	1.50	5	18,000	0	100	M	FRANCE
PHILIPS	HAMBURG	CONSUMER	CON	BIP	1.20	5	18,000	16,140	100	M	GERMANY
PHILIPS	HAMBURG	DISCRETE	DIS	BIP	2.00	4	22,000	21,520	100	M	GERMANY
PHILIPS	HAMBURG	NA	8-BIT MCU 16-BIT MCU EEPROM ASI	CMOS NMOS M1 M2	1.00	5	12,500	32,280	10	M	GERMANY
PHILIPS	HAZELGROVE, STOCKPORT CHESHIRE	BIPOLAR	TRAN DIODE RECTIFIER	BIP	10.00	4	45,000	19,368	100	M	ENGLAND
PHILIPS	HAZELGROVE, STOCKPORT CHESHIRE	POWERMOS	DIODE SMART PWR	MOS 1M	3.00	4	10,000	11,836	10	M	ENGLAND
PHILIPS	NIJMEGEN	NA	LOG	CMOS	3.00	4	26,000	23,456	100	M	NETHERLANDS
PHILIPS	NIJMEGEN	NA	SRAM CON	CMOS NMOS M2	0.80	6	8,400	0	1	M	NETHERLANDS
PHILIPS	NIJMEGEN	NA	DIS	MOS BICMOS BIP	1.50	5	20,000	39,338	100	M	NETHERLANDS
PHILIPS	NIJMEGEN	NA	PWR DIS DIODES	NA	0.70	4	0	12,912	10,000	M	NETHERLANDS
PHILIPS	STADSKANAAL	NA	RECTIFIER	BIP M3	0	4	70,000	32,280	NA	M	NETHERLANDS
PHILIPS RTC	CAEN	NA	TRAN	NA	5.00	5	12,000	12,589	10	M	FRANCE
ROBERT BOSCH	REUTLINGEN	RtW/FAW	LIN DIS CUSTOM	BIP BICMOS	3.00	4	20,000	0	100	C	GERMANY
SEAGATE MICROELECTRONICS	LIVINGSTON	NA	LIN	BIP M2	3.00	4	5,000	16,140	100	C	SCOTLAND
SEMEFAB	GLENROTHES	NA	LIN DIS OPTO	BIP CMOS MOS	4.00	4	2,000	0	10	M	SCOTLAND
SEMIKRON	NURNBERG	NA	DIS	BIP	0	5	10,000	0	NA	M	GERMANY
SGS-THOMSON	AGRATE (MILAN)	FAB 9	64K 256K 1Mb EPROM PLD LIN ARRA	CMOS M2	0.70	6	28,000	22,000	10/1	M	ITALY
SGS-THOMSON	CATANIA	NA	DIS	NA	3.00	5	34,000	0	100	M	ITALY
SGS-THOMSON	CATANIA	NA	LOG LIN CUSTOM	CMOS	3.00	4	21,000	0	100	M	ITALY
SGS-THOMSON	COSTALETTO	NA	MPU	CMOS	0	5	0	0	NA	M	ITALY
SGS-THOMSON	GRENOBLE	NA	LIN PWR IC CUSTOM	BIP CMOS	1.50	4	20,000	21,520	100	M	FRANCE
SGS-THOMSON	RENNES	NA	LIN	BIP M2	5.00	5	16,000	0	10	M	FRANCE

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Table 1 (Continued)
European Existing Pilot and Production Fab Lines
(Including Fabs Going into Operation During 1992)

Company	City	Fab Name	Products Produced	Process Technology	Est. Minimum Line Width (Microns)	Wafer Diameter	Est. Max. Wafer Capacity (4wk/Month)	Clean Room (Square Feet)	Class Clean Room	Merchant or Captive	Country
SGS-THOMSON	ROUSSET	MODULE 5	EPROM EEPROM MPU MCU	CMOS MOS	1.50	5	22,000	33,356	1	M	FRANCE
SGS-THOMSON	TOURS	MESA	DIS	NA	20.00	4	60,000	0	100	M	FRANCE
SGS-THOMSON	TOURS	PLANAR	DIS	NA	5.00	4	15,000	0	100	M	FRANCE
SIEMENS	REGENSBURG	MEGA 1	1Mb DRAM 4Mb DRAM	CMOS	0.80	6	28,000	48,500	10	M	GERMANY
SIEMENS	VILLACH	VILLACH 1	TELECOM	BIPOLAR	2.00	4	26,000	24,748	100	M	AUSTRIA
SIEMENS	VILLACH	VILLACH 2	LOG	MOS	0.80	5	20,000	26,685	10	M	AUSTRIA
TAG	ZURICH	NA	DIS	NA	0	3	10,000	0	NA	M	SWITZERLAND
TELEFUNKEN	ECHING	NA	LOG MPU MCU ARRAYS CUST	CMOS	3.00	4	24,000	3,000	100	M	GERMANY
TELEFUNKEN ELECTRONIC	HEILBRONN	NA	CUSTOM LIN DIS MCU	BIP MOS CMOS	1.00	4	25,000	43,000	10	M	GERMANY
TEXET	NICE	NA	DIS	NA	0	4	10,000	25,000	NA	M	FRANCE
TI	AVEZZANO	PHASE 1	4Mb DRAM ASSP CBIC	CMOS	0.05	6	9,200	78,000	1	M	ITALY
TI	BEDFORD	PWR FAB	PWR DIS	BIP	3.00	4	24,000	9,000	100	M	ENGLAND
TI	FREISING	FRSI	LIN ASSP LOG	BIP CMOS BICMOS	0.80	5	19,300	10,000	10	M	GERMANY
TI	FREISING	FRSI	CBIC LIN ASSP LOG	CMOS BICMOS	0.80	5	10,000	17,000	10	M	GERMANY
TOMI	TORUN	NA	DIS	NA	0	0	0	0	NA	M	POLAND
VAISALA	VANTAA	NA	LIN	CMOS	5.00	3	200	0	100	M	FINLAND
VEB HALBLEITERWERK	FRANKFURT (ODER)	NA	NA	NA	0	6	10,000	0	NA	C	GERMANY
VEB ROEHRENWERK	NEUHAUS AM RENNWEG	NA	TRAN	NA	0	0	0	0	NA	C	GERMANY
VEB WERK FUER FERNSEHELEKTRONIK	BERLIN-OBERSCHOENEWEIDE	NA	SENSOR CCD	NA	0	0	0	0	NA	C	GERMANY
WESTCODE SEMICONDUCTOR	CHIPPENHAM	NA	DIS	BIP	0	2	10,000	0	NA	C	ENGLAND
ZETEX	OLDHAM	NA	DIS DIODE LIN	BIP MOS	1.50	4	10,000	26,000	100	M	ENGLAND

NA = Not available
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Table 2
European Future Pilot and Production Fab Lines
Planned Facilities by Year

Company	City	Fab Name	Products	Process Technology	Facility Type	Target Date Facility to Begin Operation	Est. Minimum Line Geometry (Microns)	Wafer Size (Inches)	Est. Wafer Start Capacity (4 Wk/ Month)	Clean Room Square Feet	Country
Production Begins: 1993											
INTEL	LEIXLIP, COUNTY KILDARE	FAB 10	486 MPU 586 MPU	BICMOS	F	NA	0.50	8	16,000	50,000	IRELAND
MIETEC ALCATEL	OUDENAARDE	FAB 2	ASIC	CMOS M2 POLY2	FAT		0.50	6	20,000	21,600	BELGIUM
NATIONAL SEMICONDUCTOR	GREENOCK	LINEAR	LIN	BIP	F	NA	0	6	0	0	SCOTLAND
SGS-THOMSON	CROLLES	PHASE 1	ASIC	CMOS BICMOS	RP	06-03-93	0.50	8	2,000	0	FRANCE
Production Begins: 1994											
FUJITSU	NEWTON AYCLIFFE	PHASE 2	16Mb DRAM	CMOS	F	NA	0.50	6	0	8,000	ENGLAND
MITSUBISHI	ALSDORF	NA	4Mb DRAM 16Mb DRAM	CMOS	F	NA	0.80	6	22,000	0	GERMANY

NA = Not Available
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CD and Wafer Inspection Equipment Markets

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CD and Wafer Inspection Equipment Markets

SUMMARY

In today's semiconductor industry, line geometries are shrinking, while device complexity, processing steps, wafer size, and mask levels continue to increase. In response to demands for faster measurements with greater resolution, new generations of tools are being developed to meet the requirements of advanced device fabrication. Measurement and inspection equipment is currently undergoing a transition from operator-intensive tools to automated, machine-intensive systems, as the semiconductor industry attempts to overcome the limitations of the human operator.

This study is Dataquest's market analysis of the critical dimension (CD) and wafer inspection equipment markets. In particular, the study focuses on three categories of equipment: optical CD tools, which include automated linewidth and overlay measurement equipment; wafer inspection stations that are used for detecting process-related defects; and joint CD/inspection systems that combine CD measurement capability with wafer inspection. All three types of equipment are based on microscope stations that, in the past, have relied upon operators to perform measurement and inspection tasks. These equipment markets have undergone significant changes in the last few years, as new systems for fully automated measurement and inspection operations have been introduced.

In 1987, the world market for CD and wafer inspection equipment was $94.0 million, of which $39.5 million (42.1 percent) was for optical CD measurement equipment, $24.5 million (26.1 percent) for wafer inspection stations, and $29.9 million (31.8 percent) for systems that combine both measurement and inspection capabilities on the same tool. Table 1 presents the worldwide markets for optical CD equipment, wafer inspection stations, and joint CD/inspection systems for 1982 through 1987.

All three market segments exhibited moderate to healthy dollar growth in 1986 and 1987. The emerging market segment of joint CD/inspection systems has been dominated by the presence of KLA Instruments and its 2020 system, priced at close to $1 million. This system has received attention not only for its price tag, but for its fully automated measurement and inspection capabilities as well. Semiconductor manufacturers in the United States, Japan, and Europe are exploring the applications and economics of these costly joint CD/inspection systems. In the meantime, other equipment companies are developing and introducing new products for this emerging market segment.

Growth, however, in the market segments of optical CD equipment and wafer inspection stations seems contrary to the mood and general business climate of the semiconductor equipment industry during the recession years. In part, the growth in these markets during 1986 and 1987 can be attributed to yen appreciation in Japan, in particular, in the wafer inspection equipment category. However, a far more significant factor affecting all regions of the world has been the increase in the average selling price (ASP) of equipment over the last several years. This is because new measurement and inspection technologies have been developed to keep pace with the shrinking geometries of integrated circuits. New technology advancements typically carry a higher price tag. Thus, it is no surprise that dollar growth in 1986 and 1987 is directly attributable to those companies offering advanced technology products with improved automation capability for submicron measurement and inspection.

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CD and Wafer Inspection Equipment Markets

Table 1

Worldwide Markets for CD and Wafer Inspection Equipment, 1982-1987
(Millions of Dollars)

	1982	1983	1984	1985	1986	1987	CAGR 1982-1987
Optical CD Equipment	$13.4	$22.5	$32.6	$20.1	$28.7	$39.5	24.1%
Wafer Inspection Stations	11.4	16.7	27.1	20.5	21.8	24.5	16.5%
Joint CD/Inspection Systems	0.0	0.7	3.1	13.9	20.3	29.9	155.6%*
Total	$24.9	$40.0	$62.8	$54.4	$70.7	$94.0	30.5%
Growth		54%	72%	(21%)	30%	33%	

Note: Numbers may not add to totals shown due to rounding.
*CAGR for joint CD/inspection systems is taken from 1983 through 1987.

Source: Dataquest
March 1988

Figure 1 presents a six-year trend in unit demand and ASP for optical CD equipment and wafer inspection stations. As shown in Figure 1, the ASP of optical CD measurement and wafer inspection stations has risen appreciably, while unit demand for both categories of equipment has continued to fall during the last three recession years.

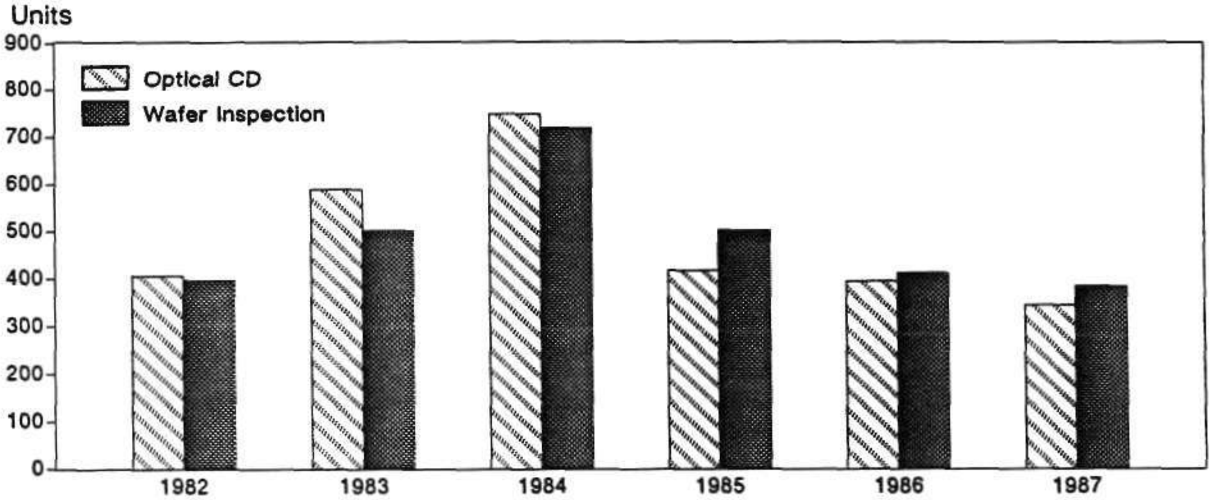
The substantial decline in unit demand for optical CD and wafer inspection equipment in 1985 was clearly a result of the excess capacity within the semiconductor industry. The need for new process control tools--linewidth measurement and wafer inspection equipment, in particular--is tied strongly to the current production level within the fab. With capacity utilization running at 62 percent in 1985, and little or no new technological developments in optical CD and wafer inspection stations, semiconductor manufacturers slashed spending in these equipment categories. Most equipment manufacturers of optical CD and wafer inspection systems continued to experience a decline in unit demand during 1986 and 1987. The growing portion within each market segment was represented by those systems that provided submicron measurement capability and improved equipment automation features.

CD and Wafer Inspection Equipment Markets

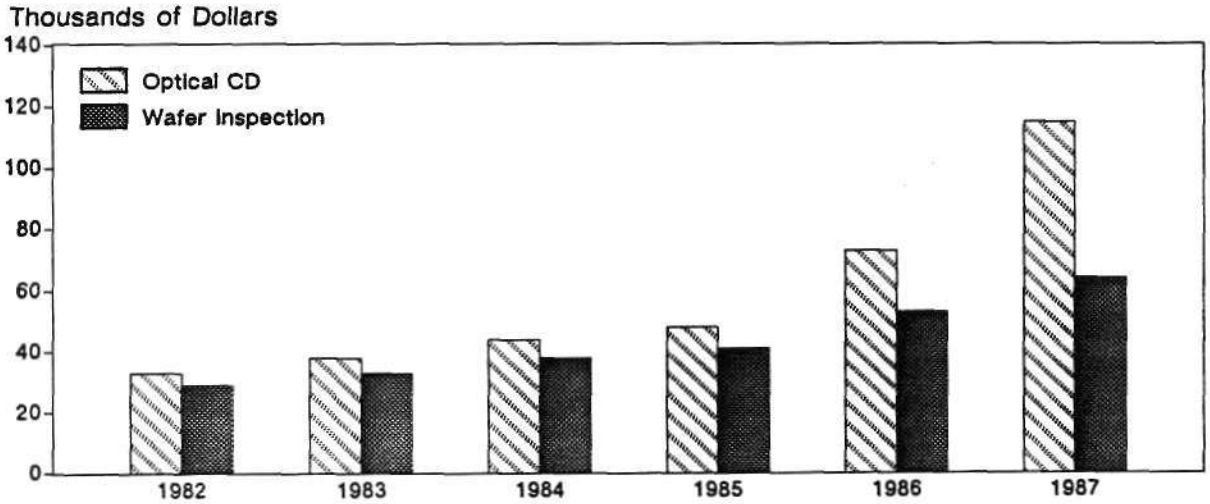
Figure 1

Optical CD Equipment and Wafer Inspection Stations
Worldwide Unit Demand and ASP, 1982–1987

Unit Demand



Average Selling Price



Source: Dataquest
March 1988

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CD and Wafer Inspection Equipment Markets

OVERVIEW

Critical dimension and wafer inspection systems represent segments within the larger equipment category that Dataquest defines as process control equipment. Process control is a broad category that includes equipment for mask and wafer inspection, film thickness measurement, linewidth and overlay measurement, resistivity mapping, process monitoring, surface analysis, and analytical quality control. This is a highly fragmented market with dozens of companies selling into many noncompetitive niches. Dataquest has chosen to focus on CD and wafer inspection systems, because these tools are used in the production environment to provide data, analysis, and feedback on equipment operation and the manufacturing process. The ability to acquire, measure, and analyze information in a timely manner becomes essential, as the semiconductor industry enters a new manufacturing phase in which attention is being focused on the automation of manufacturing processes. While total or "lights-out" factory automation in the semiconductor industry is still years away, automated CD and wafer inspection systems are fundamental components of manufacturing strategy today and will be necessary if lights-out automation is to be achieved.

Critical Dimension

A critical dimension of a semiconductor device refers to a line, element, or feature that must be manufactured and controlled to very tight specifications. In the design of advanced semiconductor devices, design tolerances of critical features are specified at 1/10 the size of the critical dimension. In the case of a 1.0-micron line geometry, that means that fabrication equipment, materials, and processing technology must reproducibly produce a feature that is 1.0 micron, with a deviation of plus or minus 0.1 micron, in order for the manufacturing process to be in control. CD measurement equipment must have very high precision, which means that repetitive measurements are reproducible within a very small range of deviation. The accuracy of a linewidth measurement system describes the nearness of a measurement to its accepted or true value, typically determined by comparison with in-house standards, usually a wafer that is known to be "good." A critical dimension can refer to the dimension of a linewidth in a device pattern at a given mask level, as well as to a measure of the allowable tolerance in the overlay of patterns from multiple mask levels. Typically, CD measurement systems available today perform both linewidth and overlay measurements.

Over the last several years, the field of CD measurement has diversified into a multitude of technologies. Conventional CD tools have been based on white-light microscopy systems. Today, however, this equipment is enhanced with fluorescent measurement capability and image-processing systems. In addition, laser-based measurement systems, confocal scanning laser microscopy, and coherence probe imaging technologies have been developed to perform submicron measurements. Scanning electron microscope (SEM) tools, traditionally relegated to the analytical lab, have been redesigned to meet the needs of submicron manufacturing in a production environment.

CD and Wafer Inspection Equipment Markets

Wafer Inspection

Wafer inspection refers to the inspection of patterned wafers for process defects by visual and image-processing techniques. Traditionally, this equipment has been designed as a microscope station at which an operator visually inspects wafers under magnification for the presence of defects, which range from contaminating particles to defective circuit patterns. As wafer inspection tools have matured, additional features have been added, including automatic wafer handling, automatic and programmable stage movement, autoalignment, autofocus, and keypad data entry systems. In conventional wafer inspection systems today, almost everything but human vision is automated. Recently, a new generation of automatic wafer inspection stations was introduced. These sophisticated systems utilize holographic spatial frequency filtering technology and advanced image-processing techniques to perform automatic defect detection. In some instances, wafer inspection systems assist in defect classification as well.

Wafer inspection equipment discussed in this study focuses on systems that are used for the detection of process-related defects. Market analysis of this equipment segment does not include standalone microscopes or the laser-based surface analyzers that are used to detect and measure particles, scratches, and deformities at the wafer surface.

Reticle Qualification

Reticle qualification systems are used during the setup and process qualification stage of lithographic processing. Typically, every time a reticle or mask is changed on a lithography tool, the reticle qualification procedure is performed to verify reticle quality and optimal lithographic equipment operation. Reticle qualification systems do not compete directly with the wafer inspection stations that are used for defect detection during the production process; thus, "ret qual" systems are considered a separate category from wafer inspection. This distinction becomes somewhat cloudy, because some systems, such as KLA Instruments' 2020 system, are used in both wafer inspection and reticle qualification applications. Reticle qualification systems are discussed briefly in this study, because these systems perform a function that is complementary to wafer inspection.

Joint CD/Inspection Systems

Over the last several years, a new category of measurement and inspection equipment has emerged—systems that are designed for both CD measurement and inspection capability. Dataquest refers to this category of equipment as joint CD/inspection systems. In 1983, Optical Specialties, Inc., introduced the first system designed as a microscope-based inspection station with automatic CD measurement capability. An operator, however, was still required to perform defect detection and classification. In 1984, KLA Instruments introduced its 2020 system, a tool that combines automatic CD measurement with automatic inspection capability. For the first time, the subjective judgement of the operator was removed from the wafer inspection process. The KLA 2020 has received attention, not only on the basis of its advanced technology and automated performance, but also because of its price tag, currently $895,000. The KLA 2020 heralded the beginning of a new era in advanced measurement and image-processing technology for the semiconductor industry. The purchase of joint CD/inspection systems now represents a substantial capital investment for semiconductor manufacturers and a significant growth opportunity for equipment manufacturers. In the last year alone, Dataquest noted that several companies were developing new products in this equipment category, and we expect more to follow in the years to come.

For more information on the different measurement technologies of CD and wafer inspection systems, please refer to the service section, "CD and Wafer Inspection Equipment—Technology and Trends."

COMPANY ACTIVITIES

Table 2 contains a list of companies active in the CD and wafer inspection equipment markets. This list, organized by region in which company headquarters are based, summarizes company products by equipment category: optical and e-beam-based CD equipment, wafer inspection stations, reticle qualification systems, and joint CD/inspection systems. While not the primary focus of our market analysis, the categories of e-beam-based CD equipment and reticle qualification systems are included in Table 2 and in the discussion of company activities, because they represent competitive, and, in some cases, complementary technologies and products. In addition to listing new product developments and announcements, Table 2 identifies four companies that are no longer active in these market segments.

In the following discussion of company activities and products, the measurement capability of CD equipment is discussed. The reader is cautioned that specifications of linewidth measurement capability for any model of equipment can vary, depending upon the type, thickness, and combination of semiconductor materials being measured, as well as whether the measurement is being performed in an R&D or a production environment. No attempt has been made to correlate and verify measurement conditions and specifications of the various models of CD measurement equipment discussed in this study.

Prometrix, a manufacturer of linewidth measurement systems based on electrical probing techniques, is not listed in Table 2 because its equipment does not fall into any of the identified product categories. The company, however, is briefly discussed in the following section on U.S. companies.

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Table 2

CD and Wafer Inspection Equipment Companies by Product Category

	CD Optical	CD e-Beam	Wafer Inspect	Reticle Qualification	Joint CD/Inspect
U.S. Companies					
Amray		X			
Estek (Aeronca)			X		
Insystems			X		
ITP Incorporated	X				
IVS Inc.	X		U/D		
KLA Instruments	X, N/P	X	X	X	X
Nanometrics	X	X			
Opal Inc.		N/P			U/D
Optical Specialties, Inc.	X		X		X
Reichert-McBain*	X				
SiSCAN Systems	X				
Waterloo Scientific	N/P				
Japanese Companies					
ABT (Akashi Beam Technology)		X			
Canon			X		
Dainippon Screen	N/P				
Hitachi	X	X			
Holon		X			
JEOL		X			
Lasertec				X	
Nidek	N/P		X		
Nikon	X		X		
Ryokosha	X				
Sony				X	
European Companies					
Bio-Rad Lasersharp Ltd.	X				
Cambridge Instruments	X	X		X	
Heidelberg Instruments	X		U/D		
Vickers Instruments	X	X			
Wild Leitz	X		X		
Zeiss			X		

(Continued)

Table 2 (Continued)

CD and Wafer Inspection Equipment Companies by Product Category

	CD Optical	CD e-Beam	Wafer Inspect	Reticle Qualification	Joint CD/Inspect
Departures					
Contrex					X
Machine Intelligence					X
Optoscan	X				
Karl Suss			X		

N/P = New product announcement
U/D = Equipment currently under development
*Acquisition by Optical Specialties Inc. from Cambridge Instruments announced in December 1987

Source: Dataquest
March 1988

U.S. Companies

Amray

Amray (Bedford, Massachusetts) manufactures the Amray 1500, a SEM-based CD measurement system. The Amray 1500 was designed for in-process measurement operations. The system has a throughput of approximately six wafers per hour at five measurement sites per wafer. The Amray 1500 is approximately four years old and is priced at $350,000.

Estek (Aeronca)

Estek, through its acquisition of Aeronca Electronics in late 1986, markets the AE-1000 automated wafer inspection system in the United States. Estek's AE-1000 system is manufactured by Canon of Japan and is the same as Canon's VIR-600 model. The AE-1000 can operate in 100 percent inspection or random sampling mode. Prior to inspection under the microscope, wafers are passed under a white-light source for visual inspection of gross defects and flaws in the wafer surface. The price of the AE-1000 is approximately $80,000, though price increases are expected due to the high rate of yen appreciation. Aeronca Electronics began to market the Canon wafer inspection system approximately three years ago. The Estek division responsible for Aeronca products is located in Charlotte, North Carolina.

CD and Wafer Inspection Equipment Markets

Insystems

Insystems (San Jose, California) manufactures a fully automated, full-wafer, submicron defect detection system that utilizes holography and spatial frequency filtering technology. The Model 8600 was designed for in-process patterned wafer inspection and can inspect an entire wafer surface for defects in less than 30 minutes. This is in comparison with the several hours required for inspection by conventional optical- or SEM-based inspection tools. This reduction in measurement time is achieved because the Model 8600 relies on parallel optical processing rather than a serial analysis of the wafer on a die-by-die basis. Defect classification is still an operator-dependent task.

The Model 8600, with up to 150mm wafer capability, can detect submicron defects in high-density, repetitive areas in single- and multiple-process levels in photoresist, oxide, polysilicon, metal, and other films, such as nitride, PSG, and polyimide. The Model 8600 is priced at $1.065 million. Insystems first introduced the system in March 1987 at SEMICON/Europa. The U.S. introduction was at SEMICON/West the following May. The Model 8600 was in beta site during 1986, and Insystems shipped its first two systems in fourth quarter 1987.

Insystems, founded in 1981, is a privately held company. Insystem's first product was the Model 8405 automatic photomask inspection system. The first unit, at a price of $800,000, was shipped to Motorola in April 1986. Insystems views the Model 8405 as an interim product and plans to focus on wafer inspection as its primary market.

ITP Incorporated

ITP Incorporated (Sunnyvale, California) manufactures a product line of optical CD measurement equipment including the System 85, Auto CD 88, and System 802. The System 85 is a video-based charge-coupled device (CCD) camera system capable of measuring lines and contacts smaller than 0.5 micron with 2 percent precision. This was ITP's first CD measurement system to combine a CCD camera and personal computer with the company's patented autofocus system. The System 85 is priced at approximately $45,000 to $50,000. The company's Auto CD 88 system, like its predecessor the Auto CD 87, combines the capability of the System 85 with wafer flat and feature location enhancements as well as robotic wafer-handling capability. The Auto CD 88 is priced at $75,000. ITP has been using CCD cameras in its CD measurement systems for approximately three years. ITP also manufactures the System 802 CD measurement system. This tool, also designed with autofocus, is approximately four years old and is priced at $130,000. ITP has been a privately held company since its founding in 1968.

CD and Wafer Inspection Equipment Markets

IVS Inc.

IVS Inc. (Concord, Massachusetts) manufactures a family of CD and registration alignment measurement equipment. The AccuVision products incorporate digital image processing and proprietary software algorithms with an optical microscope system to provide submicron measurement capability. The signal-to-noise ratio is improved by employing various digital enhancement techniques to remove random noise elements introduced by optical and electronic components.

IVS first introduced its AccuVision family of digital image-processing tools in May 1986. The AccuVision family currently includes the ACV-1, ACV-2, ACV-3, and ACV-4, which range in price from $80,000 to $300,000. The AccuVision systems are modular in hardware and software design, and each member of the AccuVision systems can be upgraded to the next system level, without price penalty. The ACV-4, introduced in May 1987, is a fully automatic, cassette-to-cassette system. It can measure linewidth geometries down to 0.3 micron, with .005-micron repeatability. Typical wafer throughput is on the order of 30 wafers per hour at five sites per wafer.

In addition to linewidth and registration alignment measurement and image enhancement routines, IVS provides a Digital Compare software package that can be used to highlight the presence of defects. To implement this function, the operator identifies a given area of the wafer as a "golden" image. Then the system, with its pattern recognition algorithms, performs a comparison analysis of selected portions of the wafer with the "golden" image. The difference between the two digitized signals is presented on a color monitor—areas in red represent what is present on the wafer but should not be, while areas in green identify what is missing on the wafer but should be there.

IVS is developing an automated wafer defect inspection system. The company plans to introduce this system in 1988.

IVS, founded in 1980, began its operations as a manufacturer of digital image processors for scientific applications. The company began to shift its focus to the semiconductor wafer metrology market in 1984 and received its first round of venture funding in early 1985.

KLA Instruments

KLA Instruments (Santa Clara, California) is a major manufacturer of automated image analysis systems for the semiconductor industry. The company's Wafer Inspection Division (WISARD) was formed in 1983; in 1984, it introduced the KLA 2020 Wafer Inspector, the industry's first fully automated wafer inspection system. The KLA 2020 is an in-process wafer inspection system that integrates CD, registration overlay, and area measurements with defect monitoring and macro inspection. The price of the system is $895,000.

Typical wafer throughput for the 2020 on CD measurement is on the order of 90 wafers per hour at five sites per wafer. The KLA 2020 performs a linewidth measurement in a 1.5-second time interval, which includes the time to move to a new position, the time for the system to settle and stop, and, finally, the time for the system to acquire the linewidth image. KLA states that measurements from the 2020 exhibit strong linear correlation with calibrating SEM tools down to 1.0 micron, with a three-nines to four-nines correlation coefficient. Customer applications, however, have included repeatable linewidth measurement down to 0.6 micron.

The KLA 2020 also has automatic defect inspection capability. After the wafer cassettes are loaded, inspection proceeds automatically under the direction of the system computer. The KLA 2020 has defect measurement sensitivity down to 0.5 micron in both repeating and random geometry inspection modes.

The first KLA 2020 system was shipped in early 1985. Dataquest estimates that, at the end of 1987, there were approximately 62 KLA 2020s in the installed base, with about 80 percent of the units in the production environment and 20 percent in R&D facilities. Of those tools used in the production environment, approximately 65 percent are used for defect inspection, while the remaining 35 percent are used for metrology measurements in the lithography area.

In May 1985, the company introduced a major enhancement to the 2020, the Design Reference Generator (DRG). The DRG allows the 2020 to compare a processing level on the silicon wafer with the design data base of the mask or reticle used to expose the wafer. This is an important application in the identification of repeating defects. The price of the DRG is approximately $350,000.

In May 1986, KLA introduced a computer subsystem, the KLA Utility Terminal (KLAUT), which is used with the 2020 to collect, process, and format wafer inspection data into graphics displays for statistical analysis.

In May 1987, KLA introduced the KLA Stepper Set-Up (KLASS), a software enhancement for the 2020. The KLASS software, which loads on the KLAUT, is an applications package for optimizing stepper setup parameters. The KLASS software can optimize the correct focus and exposure settings for a stepper in approximately 4 minutes and produces a picture of the stepper control screen on the KLAUT terminal in order to guide the operator in changing new focus and exposure settings. The KLASS software package is priced at $20,000. The second software enhancement for the KLA 2020 was introduced in September 1987. The Product Wafer Detect Audit (PWDA) assists the user in identifying the cause of defects. It sells for approximately $30,000.

Since early 1987, KLA has offered the KLA 2005, a metrology-only version of the 2020. This system, which has no defect inspection capability, has been targeted specifically at the lithography area of the fab. The 2005 is priced at approximately $700,000, which includes a KLAUT computer and the KLASS software applications package. Several 2005 systems that were sold in 1987 were upgraded later to full 2020 systems. The price of the upgrade is approximately $300,000.

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CD and Wafer Inspection Equipment Markets

In September 1987, KLA introduced two new wafer inspection systems, the KLA 2028 and the KLA 2030. The KLA 2028 automatic wafer defect inspection system retains the same macro defect detection capability as the KLA 2020; however, the new 2028 is capable of micro defect detection at rates of speed approximately 4 times (for random geometry inspection) to 15 times (for repeating array inspection) faster than those of the KLA 2020. The KLA 2028, a dedicated defect inspection system, is priced at $895,000. The KLA 2030 Automatic Wafer Defect Inspection and Metrology system combines the metrology capability of the KLA 2020 with the enhanced defect detection capability of the new 2028. The price of the KLA 2030 is $1.095 million. Current owners of the KLA 2020 can retrofit their systems to full 2030 performance capability at a cost of approximately $300,000. For customers with 2020 systems on order, backlog conversion to the 2028 will be performed at no charge, and conversion to the 2030 will be priced at $200,000. First shipments of the KLA 2028 and 2030 are expected in March 1988.

KLA Instruments is developing a coherence probe microscope system for CD measurement beyond the limit of conventional white-light optical systems. The coherence probe microscope utilizes a Linnick microscope, which is essentially a Michelson interferometer with the addition of two microscope objectives. The technique of coherence probe imaging (CPI) produces images by applying electronic algorithms to a particular set of interference images taken from the Linnick interference microscope. The coherence probe microscope system also provides three-dimensional detail of line geometry measurements. This system, known as the KLA 5000, has a measurement resolution of 0.7 micron and wafer throughput is 40 to 45 wafers per hour at five sites per wafer. The system is priced at approximately $380,000. In March 1988, KLA introduced the KLA 5000 at SEMICON/Europa in Zurich, Switzerland, and presented preliminary results of the KLA 5000's operations at the SPIE meeting in Santa Clara, California. KLA Instruments currently has a patent pending on the coherence probe microscope.

In addition to the manufacture of optical CD/inspection systems, KLA distributes the KLA/Holon 2711, a low-voltage, e-beam, submicron metrology system designed for automated CD and registration measurements. Its primary applications are in the characterization of process parameters in the initial stages of process development and in process control monitoring as device volumes increase. Wafer throughput is greater than 15 wafers per hour at five sites per wafer, and the system can handle 100mm through 200mm wafers. This nondestructive measurement system can measure linewidths down to 0.1 micron, with a precision less than or equal to 0.05 micron (3 sigma) for automatic CD measurement. The price of the 2711, depending on options, is less than $500,000. The KLA/Holon 2711 is the first product to be introduced under an agreement announced in November 1986 by KLA and Holon Co., Ltd., of Japan. KLA is the exclusive distributor of the 2711 in the United States and Europe.

KLA Instruments was founded in 1976 and has been a publicly traded company since October 1980. Over the years, KLA has successfully developed a family of advanced inspection systems for use in various segments of the semiconductor industry. The company is structured into three operating divisions: the Reticle and Photomask Inspection Division (RAPID), the Wafer Inspection Division (WISARD), and the

Automated Test Systems Division (ATS). A new division recently was established to focus on supplying inspection systems to the printed circuit board industry; first deliveries are scheduled for 1988.

Nanometrics

Nanometrics (Sunnyvale, California) manufactures optical linewidth measurement equipment for the semiconductor industry. Its first Nanoline system was shipped in 1978, and total installations of Nanometrics' optical linewidth measurement systems number on the order of 1,000 units. The Model 50, introduced in 1986, replaced its predecessors, the Nanoline V and VA.

The Model 50 measurement technology is based on a narrow optical slit that is mechanically stepped across a magnified image of the wafer feature. The light passing through the slit is measured by a photomultiplier tube (PMT) to form a high-resolution reflectance profile. The profile is stored on the system computer and analyzed to determine the linewidth of the wafer feature. The primary changes between the Model 50 and the Nanoline V and VA include improved autofocus algorithms, faster measurement times, better system measurement linearity, and improved equipment uptime. The linewidth measurement capability of the Model 50 is approximately 0.7 to 0.8 micron in a production environment. The price of this system is about $45,000.

The Model 50 optical linewidth measurement system, like its predecessors in the Nanoline family of equipment, does not have wafer-handling capability. Recently, however, Nanometrics developed the NanoStation-1, which is an optional wafer-loading station for the Model 50. This option now transforms the Model 50 into a fully automatic linewidth measurement system, with wafer throughput on the order of 25 wafers per hour at five sites per wafer. The price of the Model 50 with the NanoStation-1 is $80,000 to $85,000. This wafer handling option for the Model 50 was introduced at the end of 1987.

In 1986, Nanometrics introduced the Model 51 Fluorescence Submicron Linewidth Measurement System. The Model 51 uses the same technology (i.e., a scanning PMT) as the Model 50; however, the system optics were designed for fluorescence linewidth measurement. Fluorescence-based systems provide high-quality images, because the fluorescence signal is generated by the material itself and, as such, is completely incoherent. While this incoherent signal is weak, an important advantage is that it does not produce the ringing or interference effect evident in coherent source systems. Images show a very high contrast, since the fluorescing photoresist features appear against a black (nonfluorescing) substrate background. Nanometrics claims linewidth measurement capability on the Model 51 down to 0.4 micron in the fluorescence measurement mode. Several units of the Model 51 were shipped in 1987. The price is approximately $45,000.

Nanometrics is developing the Model 400 Linewidth and Registration Measurement Station. This fully automated, cassette-to-cassette tool provides both bright field and fluorescence measurement capability for CD and overlay registration measurement. The Model 400 is based on a different technology from that of the Nanoline and Models 50/51 systems. While the Nanoline and Models 50/51 systems utilize a photomultiplier scanning slit detection system, the Model 400 incorporates a proprietary CCD camera developed by Nanometrics. The CCD camera is particularly well suited for collecting the weak signals associated with fluorescence measurements. Nanometrics displayed a post-engineering prototype system of the Model 400 at the SEMICON/West show in May 1987. The price of the Model 400 is expected to be on the order of $150,000. Shipments are expected to begin in 1988.

In addition to optical linewidth measurement systems, Nanometrics manufactures a fully automated SEM system for linewidth measurement and defect inspection. The Model 100 was designed as an in-line SEM system, with minimum linewidth measurement of 200 angstroms. Wafer throughput is currently about 12 wafers per hour at five sites per wafer; however, the company expects throughput to be increased to approximately 20 wafers per hour, with certain system modifications. The Model 100 was introduced in May 1986, and shipments began in fourth quarter 1986. It is priced at approximately $420,000. The Model 100 is the successor to Nanometrics' CWIKSCAN product line of scanning electron microscopes.

Nanometrics was founded in 1975 and has been a publicly traded company since late 1984. Nanometrics has a wholly owned subsidiary, Nanometrics Japan Ltd., located in Narita, Japan. In addition to the company's optical and SEM-based linewidth measurement systems, other Nanometrics' products include film thickness measurement equipment for the semiconductor industry and ultraviolet, visible, and infrared spectrophotometers for analytical applications. Nanometrics also markets a molecular beam epitaxy system, the model EV100, manufactured by Eiko Engineering of Japan. Nanometrics' majority-owned subsidiary, Loma Park Associates, manufactures a tooling system used in the production of multilayer printed circuit boards.

Opal Inc.

Opal Inc. (Billerica, Massachusetts) is a new entrant in the wafer metrology and inspection systems market. Opal was established in December 1986 by Optrotech Ltd. and several other investors including Adler & Company and TA Associates, a large international venture capital firm. Optrotech, a manufacturer of inspection equipment for the printed circuit board industry, has a 31.5 percent interest in the $4.6 million investment, while the investor group led by TA Associates has a majority interest of 58 percent. The remaining investment was funded by Opal management.

Optrotech began development of an e-beam-based CD system in late 1985, and established Opal Inc. as a separate business operation to finish product development and implement manufacturing, sales, and marketing operations. Opal Inc., in turn, established a wholly owned subsidiary, Opal Technologies Ltd. (Nes Ziona, Israel), that will conduct the research and development effort. The CD measurement system, known as Opal 702, was designed for automatic submicron metrology of wafers in the production environment; however, the company plans to incorporate wafer inspection capability on the system as well. The company claims that the 702 exhibits an impressive throughput rate that is comparable with the rate of most optical-based systems: 30 wafers per hour at five sites per wafer. In March 1988, Opal presented preliminary information on the metrology operations of the Opal 702 system at the SPIE meeting in Santa Clara, California.

CD and Wafer Inspection Equipment Markets

Optical Specialties, Inc.

Optical Specialties, Inc. (OSI; Fremont, California) manufactures a family of products for CD measurement and wafer inspection. The company introduced its first wafer inspection stations in 1980. Since that time, OSI's wafer inspection products have included the single-cassette MV-7, the four-cassette MV-10, and the fully programmable MV-15 inspection stations. These tools have ranged in price from $25,000 to $50,000. In 1986, OSI introduced the MV-360. The system features a robotic wafer-handling system that is characterized by a very low contaminant count, as verified by VLSI Standards, a contamination analysis firm in the Silicon Valley. The MV-360 can handle 3-inch to 150mm wafers and is priced at approximately $65,000.

OSI introduced its first linewidth measurement system, the VLS-I Video Linewidth System in 1983. This optical tool provides linewidth measurement on wafers and photomasks and verifies pattern overlay registration on wafers. Equipment specifications quote 0.5-micron minimum measurement capability. The VLS-I is priced at $47,000.

In late 1983, OSI began shipments of its first two systems that provide integrated wafer inspection and linewidth measurement capability. These tools, the MV-207 and the MV-215, combine the VLS-I linewidth measurement system with the MV-7 and MV-15 wafer inspection stations. The MV-207 and MV-215 are priced at $65,000 and $100,000, respectively. The MV-PLUS wafer inspection and CD measurement station was introduced in 1984. This system provides fully automated measurement capability in addition to programmable wafer inspection and is priced at approximately $180,000. In May 1987, OSI announced an applications software package for the MV-PLUS, the Metrology Analysis Program I (MAP-I). This software package receives measurement data from OSI's MV-PLUS and uses it to optimize stepper/aligner operating parameters. The MV-360CD, introduced in May 1987, supplements the wafer inspection station of the MV-360 with CD measurement capability. The price of the MV-360CD is approximately $120,000.

In May 1987, OSI announced its new, fully automatic CD and defect inspection system, the Micropatterning Process Control System. The new system is designed to perform a variety of tasks without operator intervention. The tool automatically receives wafers from robotic material-handling equipment, reads the wafer's identification code (via an alphanumeric optical character reader), creates a wafer pattern array map, performs macroscopic defect inspection and classification, reads the photo mask layer identifier (optical character verification), measures registration and linewidths, detects and classifies microscopic defects, and displays macro or micro images and test data. The OSI system uses pattern recognition and proprietary software algorithms for defect inspection and classification. The Micropatterning Process Control System was designed for use in the production environment as well as for the setup and qualification of new processes. The equipment can handle 100mm through 200mm wafers. The system is expected to go into beta site during the first part of 1988. The system's target selling price will be approximately $500,000. OSI has received funding for this project through R&D Funding, a venture-funding arm of Prudential-Bache.

CD and Wafer Inspection Equipment Markets

In December 1987, Cambridge Instruments agreed to acquire a 40 percent equity interest in Optical Specialties, Inc., in exchange for the transfer of its Reichert-McBain division to OSI. The Microcheck, Polycheck, and Polycheck VLSI products of Cambridge and Reichert-McBain will now be incorporated into the OSI product line of CD and wafer inspection systems for the semiconductor industry.

OSI was founded in 1978 as an engineering consulting firm for the semiconductor industry and has been a publicly traded company since 1985.

Prometrix

Prometrix (Santa Clara, California) manufactures a linewidth measurement system based on electrical probing techniques. The LithoMap EM-1 (successor to the LithoMap 20) provides extremely fast and accurate linewidth measurement capability. However, it is limited to conductive layers and requires special test wafers. The EM-1, priced at approximately $210,000, is targeted at process setup and qualification of lithography and etch processing. This system does not compete directly in the market with CD measurement equipment used in the production environment.

Reichert-McBain

Reichert-McBain (Chatsworth, California), part of the Cambridge Instruments' organization until December 1987, manufactures optical systems for manual and automated measurement of CDs. In 1986, the company introduced its Wafer MAP Automatic Optical Measurement System for linewidth and overlay measurement. This system, priced at approximately $150,000 to $180,000, was sold in 1986 through early 1987. The product is no longer available, having been replaced by Cambridge Instruments' new Polycheck VLSI system for wafer metrology and inspection. Reichert-McBain also manufactured a system that is complementary to Wafer MAP, the MAP System II Intelligent Measuring System for line and edge measurement in nonsemiconductor industry applications. The price of the MAP product ranged from $80,000 to $120,000. Dataquest estimates that there are approximately 70 systems of the MAP family of products in the installed base, of which one-third are Wafer MAP systems for the semiconductor industry.

The Reichert-McBain facility in Chatsworth, California, is responsible for design, development, and manufacture of the Microcheck, Polycheck, and Polycheck VLSI products of Cambridge Instruments. (See the Cambridge Instruments entry under the section of this service section entitled "European Companies" for more information on these systems.) In addition to its semiconductor products, Reichert-McBain manufactures general application microscopes and industrial 3-D optical inspection stations. In December 1987, Cambridge Instruments agreed to acquire a 40 percent equity interest in Optical Specialties, Inc., in exchange for the transfer of the Reichert-McBain division to OSI. The Microcheck, Polycheck, and Polycheck VLSI products will now be incorporated into the OSI product line of CD and wafer inspection systems for the semiconductor industry. Reichert-McBain became part of the Cambridge Instruments' organization in May 1986 as part of the merger between Cambridge Instruments and Reichert-McBain, R. Jung GmbH (Heidelberg, West Germany), C. Reichert Optische Werke (Vienna, Austria), and Reichert Scientific Instruments (Buffalo, New York).

CD and Wafer Inspection Equipment Markets

SiSCAN Systems

SiSCAN Systems (Campbell, California) manufactures a CD measurement and line profilometry system based on the technology of confocal scanning laser microscopy (CSLM). SiSCAN introduced the SiSCAN-IIA in May 1987. The SiSCAN-IIA, like its predecessor the SiSCAN-I, focuses on three-dimensional measurement of linewidths, contact areas, and layer registration. The SiSCAN II-A is designed to measure submicron circuit features in a Class 10 clean room environment. System enhancements include a smaller footprint, a new focus mechanism, and improvements in the speed of stage movements. In addition, the SiSCAN-IIA features an automatic robotic wafer-handling system. Wafer throughput is greater than 20 wafers per hour at five sites per wafer, and linewidths can be measured down to 0.3 micron, with 0.005-micron repeatability. The price of the SiSCAN-IIA is $350,000. Dataquest believes that the first two units were shipped in fourth quarter 1987. Enhanced computer capability and pattern recognition for the SiSCAN-IIA will be available in summer 1988, and the company will retrofit existing systems for a modest price.

The SiSCAN-IIM, priced at $270,000, is the manual version of the SiSCAN-IIA. Dataquest estimates that a total of four to five systems were shipped in 1987 to both U.S. and European customers. The company's first product, the SiSCAN-I, was introduced in May 1986. It is priced at approximately $240,000. Dataquest estimates that at the end of 1987, SiSCAN had a total installed base on the order of 18 systems.

All SiSCAN confocal scanning laser systems, to date, have utilized an argon ion laser (488nm wavelength) as the illumination source. The company now offers a helium cadmium laser that emits light at 325nm. The shorter wavelength offers several advantages over 488nm illumination, including improved resolution and depth of focus. In addition, many photoresists have lower transmission profiles at shorter wavelengths and, thus, appear more opaque at 325nm than at 488nm. This means that interference effects will be attenuated significantly. Thus, the 325nm source reduces the amount of reflected and scattered light that makes linewidth measurement more difficult at 488nm. SiSCAN Systems expects to ship its first system with a 325nm laser source in early 1988.

SiSCAN is developing the technology for heavy-mass metrology. Heavy mass refers to sample substrates that are significantly heavier than wafers. Examples include masks, reticles, and erasable optical discs. The scanning mechanism for all SiSCAN tools consists of precise translation of the sample stage in a plane beneath a fixed laser beam and optical components. Heavy-mass metrology requires that existing x-y translation stages for wafers be adapted for heavier sample substrates.

SiSCAN Systems was founded in 1982 and has received a total of $10 million in venture funding.

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Waterloo Scientific

Waterloo Scientific (Waterloo, Ontario) manufactures an automatic CD measurement system based on confocal laser scanning microscopy. The system (WSI-1000CD) is priced at approximately $300,000, which includes robotic material-handling capability. A prototype system was first introduced in May 1987, and Dataquest expects deliveries to begin in 1988.

Waterloo Scientific is a small, privately owned, Canadian firm. The company was formed in 1983. Its main products are laser scanning microscopes. In addition to its automatic CD measurement tool, Waterloo Scientific has a second laser scanning microscope system, the WSI 100, which features optical beam induced current (OBIC) measurement for semiconductor material and device characterization. An OBIC signal is produced when a light beam is focused on the surface of a p-n junction. When viewing the OBIC image, it is possible to observe real-time internal current flow by varying the TTL input signal.

Japanese Companies

ABT

ABT (Akashi Beam Technology; Tokyo, Japan) manufactures a family of transmission and scanning electron microscopes for analytical applications. The CC-CD system, in particular, is a cassette-to-cassette SEM-based tool that was designed for linewidth measurement of integrated circuit patterns. The CC-CD system is priced at $375,000. International Scientific Instruments (Milpitas, California) and ISI Korea, Inc., (Seoul, Korea) are wholly owned subsidiaries of Akashi Beam Technology of Japan.

Canon

Canon (Tokyo, Japan) manufactures the VIR-600 Series of wafer inspection stations for the semiconductor industry. The VIR-600 can operate in 100 percent inspection or random sampling modes. Prior to inspection under the microscope, wafers are passed under a white-light source for visual inspection of gross defects and flaws in the wafer surface. For approximately the last three years, Canon has had a marketing agreement with Aeronca (acquired by Estek in 1986) to supply the company with VIR-600 wafer inspection systems for marketing and sale in the United States.

Canon introduced a new model, the VIR-630, at SEMICON/Japan in December 1987. The new VIR-630 differs from the 600 in that the individual wafer transport time has been reduced by a factor of 3, down to approximately 3 seconds. The price of the VIR-630 is approximately ¥11 million ($76,000), and sales to Japanese semiconductor manufacturers began in summer 1987. The VIR-600 system was first introduced in 1982. It is currently priced at approximately ¥8 million ($55,000) in Japan.

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In addition to its wafer inspection stations, Canon manufactures a laser-based system that measures particulate contamination on the wafer surface. The model name of this tool is The Standard. This system does not compete directly in the same market segment as the other wafer inspection equipment discussed in this study.

Canon is a major manufacturer of semiconductor processing equipment including projection aligners, steppers, and contact/proximity aligners, as well as automatic photoresist processing equipment.

Dainippon Screen

Dainippon Screen (Kyoto, Japan) introduced an optical linewidth measurement system at SEMICON/Japan in December 1987. The SLM 601, which is still under development, has a minimum linewidth measurement capability of 0.8 micron. Automatic wafer handling will be a future option. Deliveries of the SLM 601 are expected to begin in April 1988. Dainippon Screen also manufactures automatic film thickness measurement systems and tools for trench depth measurement.

Hitachi

Hitachi Deco (Hitachi Electronics Engineering Co., Ltd.; Tokyo, Japan) manufactures the Lithography Accuracy Measuring Unit (LAMU) system for CD measurements. The LAMU-600 has nominal linewidth measurement of 0.8 micron, and 0.03-micron repeatability for overlay measurement. The LAMU-600, a production-oriented CD measurement system, is priced at ¥43 million ($300,000) in Japan. As yet, there has been no marketing of the LAMU-600 in the United States. This is because the LAMU-600 requires extensive software for interfacing with stepper and other lithography systems. At this time, Hitachi is still investigating the necessary software system capability that would be required to market the LAMU-600 effectively to the U.S. semiconductor industry.

In addition to the LAMU measurement system, Hitachi Deco manufactures the HILIS-200 and IS-1000 products, which are used to inspect the surface of wafers for particulate and defect contamination. Hitachi Deco introduced the IS-1000 at SEMICON/Japan in December 1987. The IS-1000 is the newest generation of the company's HILIS-200 inspection system. Both of these tools utilize a highly sensitive detector to detect ultrafine foreign particles that adhere to the surface of a wafer. This is done by directing a laser beam over the wafer surface and detecting scattered light from the particles. The IS-1000 has a detection limit of 0.8 micron (first layer) to 2.0 microns (second or third layer, aluminum layer) on patterned wafers, compared with the HILIS-200 detection limit of 2.0 to 3.0 microns. The IS-1000 detection and measurement rate is on the order of 6 to 7 minutes per wafer, and, as such, the system has been designed for R&D, analytical, and process qualification operations. The HILIS-200 operates at twice the speed of the IS-1000, and is used extensively in the production environment. The HILIS-200 is priced at ¥50 million ($350,000), while the new IS-1000 is approximately ¥90 million ($625,000). Deliveries to Japanese customers are expected to begin in April 1988.

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Hitachi's HILIS-200 and IS-1000 systems do not compete directly in the same market segment as the other wafer inspection equipment discussed in this study.

Hitachi Denshi (a different Hitachi equipment company from Hitachi Deco) manufactures the S-6000 Critical Dimension Measurement SEM system. This tool, priced at ¥90 million ($625,000), is three years old. In that time, Hitach Denshi has established itself as the leader in CD SEM tools with over 90 percent of its systems currently being used in a production environment. Wafer throughput for the S-6000 is on the order of eight wafers per hour at five sites per wafer. Dataquest estimates that more than 100 S-6000 systems are in the installed base, of which Japanese customers represent more than 80 percent of shipments.

Holon

Holon (Tokyo, Japan) manufactures a low-voltage, e-beam, submicron metrology system designed for automated CD and registration measurements. The system's primary applications are in the characterization of process parameters in the initial stages of process development and in process control monitoring, as device volumes increase. This nondestructive measurement system can measure linewidths down to 0.1 micron, with a precision that is less than or equal to 0.05 micron (3 sigma) for automatic CD measurement. Wafer throughput is greater than 15 wafers per hour at five sites per wafer. The ESPA-11, first introduced approximately two-and-a-half years ago, is priced at ¥90 million ($625,000) in Japan. This price includes an extended service warranty.

In November 1986, Holon and KLA Instruments announced an agreement by which KLA would have exclusive distribution rights to the ESPA-11 in the United States and Europe. KLA markets the ESPA-11 under the name KLA/Holon 2711. Dataquest believes that Holon has shipped several systems to KLA Instruments in the United States and two systems to Japanese semiconductor manufacturers. Holon was formed by several ex-JEOL engineers. NKK, the Japanese steel manufacturer, has a 20 percent equity position in the company.

JEOL

JEOL (Tokyo, Japan) manufactures a series of SEM systems. The JEPAS-1200 has been geared toward CD measurement in the production environment. Wafer throughput is on the order of 10 wafers per hour at five sites per wafer, and the system is priced at approximately $450,000. In addition to manufacturing SEM microscope systems, JEOL is a major manufacturer of maskmaking and direct-write e-beam lithography equipment. JEOL's U.S. offices are in Peabody, Massachusetts.

Lasertec

Lasertec (Yokohama, Japan), formerly NJS Corporation, manufactures an automatic reticle qualification system known as the model 3WD36 Automatic Wafer Inspection System. This system was designed with high-resolution objective lenses and confocal laser optics, which allow wafers to be inspected for defects down to 0.5 micron. The high-speed inspection system converts the images of two adjacent dies to video signals that are compared with each other to detect the presence of defects. Defect coordinates, which are stored in the system computer, can be recalled by the operator for directing wafer stage movement during defect confirmation and classification. Dataquest believes that Lasertec shipped its first system in the latter half of 1987. The 3WD36 is priced at approximately ¥78 million ($540,000) in Japan.

In addition to its automatic wafer inspection system, Lasertec manufactures the 1LM11 Laser Scanning Microscope and the 2LM11 Color Laser Scanning Microscope, each with CD measurement capability. The 1LM11 Laser Scanning Microscope utilizes confocal optics to provide a high-quality image capable of 0.3-micron measurement. The 1LM11 is best suited for the R&D environment or the area of quality and process control applications, as the 1LM11 has no automatic wafer-handling capability.

The 2LM11 Color Scanning Laser Microscope, also designed with confocal optics, utilizes beam output from both helium-neon and argon ion lasers to produce a real-time high-quality color image. The system, which includes a CD measurement system, has measurement capability of 0.3 micron and an optional OBIC display. An (OBIC) is produced when a light beam is focused on the surface of a p-n junction. When viewing the OBIC image, it is possible to observe real-time internal current flow by varying the TTL input signal. Applications for both the 1LM11 and 2LM11 systems outside the semiconductor industry include the study of metal surfaces, ceramics, polymers, synthetic textiles, and biological/biomedical specimens.

Lasertec's 3WD36, 1LM11, and 2LM11 products do not compete directly in the same market segment as the other wafer inspection and CD measurement equipment discussed in this study.

In addition to these products, Lasertec is also a major manufacturer of automatic mask/reticle inspection systems for the semiconductor industry.

Nidek

Nidek (Gamagori, Aichi, Japan) manufactures four models of wafer inspection equipment: the IM-8A, IM-8B, IM-6, and IM-9. All four models are based on the traditional operator-dependent microscope station for the detection and classification of defects on patterned wafers. The IM-8A and IM-8B models include autofocus, automatic alignment, and automatic wafer handling. The difference between the 8A and 8B models is the configuration of input and output cassettes. The 8A and 8B are both priced at ¥8 million (approximately $55,000). The IM-6 and IM-9 were new systems for Nidek in 1987 and are priced at ¥2.5 million ($18,000) and ¥6.0 million ($42,000), respectively. Nidek competes with Canon and Nikon in Japan's wafer inspection market.

At SEMICON/Japan in December 1987, Nidek introduced a new optical linewidth measurement system that marks the company's entry into this equipment category. The model CD-10 is priced at approximately ¥5 million ($35,000). Deliveries will begin in 1988. In addition to wafer inspection systems and CD measurement tools, Nidek manufactures wafer-flatness measurement equipment.

CD and Wafer Inspection Equipment Markets

Nikon

Nikon (Nippon Kogaku K.K.; Tokyo, Japan) manufactures both CD and wafer defect inspection stations for the semiconductor processing environment. Nikon's linewidth measurement systems include the LAMPAS-M2, -M3, and -HD systems, and the company manufactures a line of wafer defect inspection stations, the Optistation 1, 1A, 2, and 2A systems.

The Incident-Light Micro-Pattern Analyzer LAMPAS-M3 was introduced in Japan in 1983. It utilizes Nikon's patented scanning laser design for pattern-edge detection to determine CD and registration overlay measurements on wafers and masks. The linewidth is determined by scanning a precisely focused laser beam over the circuit pattern edges and then using a high-resolution laser interferometer to measure the distance between the edge detection pulses. The M3 has been designed with a helium-neon laser (628nm) as its source, with a laser spot size of 1 micron x 5 microns and a laser spot scan distance of 100 microns.

The LAMPAS-M3 minimum linewidth measurement capability has been specified at 0.8 micron on a hard chrome mask, with repeatability of 0.05 micron or better. Wafer throughput is greater than 30 wafers per hour at five sites per wafer. The price of the LAMPAS-M3 is approximately $165,000. The M3 was first introduced in the United States in 1984 but has not received wide acceptance. Dataquest estimates that more than 80 percent of the LAMPAS-M3 installations, to date, were in Japan.

The predecessor of the LAMPAS-M3 was the LAMPAS-M2 system. The LAMPAS-M2 was introduced in Japan at the end of 1978. The first system was shipped to a customer in Japan in 1979, and the last sale of this measurement system was in February 1984. Dataquest estimates that approximately 70 units were shipped, with about 95 percent of these units going to Japanese customers. The price of the LAMPAS-M2 was approximately $110,000.

Nikon's newest CD measurement system, the LAMPAS-HD, was introduced in September 1987. As with the other LAMPAS tools, the HD employs a laser-based edge detection method; however, the HD utilizes a helium-cadmium laser with a 325nm wavelength, which improves linewidth measurement capability. In addition, the laser spot size has been reduced to 0.4 micron x 0.4 micron, and the laser spot scan distance is 30 microns, rather than the 100-micron range of the M3.

The LAMPAS-HD system is a fully automated CD measurement tool and is capable of measuring linewidths down to 0.6 micron on silicon wafers with 1.0-micron-thick photoresist lines. Nikon cites linewidth measurement capability of 0.5 micron and repeatability specifications of less than 0.024 micron on chrome masks. While wafer throughput specifications are not yet available, the HD is expected to demonstrate the same wafer throughput as the M3, or faster. Shipment to Japanese customers began in October 1987. The price for the LAMPAS-HD in Japan is approximately ¥60 million. The price in the United States has not yet been fixed but is expected to be less than $500,000.

CD and Wafer Inspection Equipment Markets

In addition to its LAMPAS family of CD measurement systems, Nikon manufactures the Optistation line of wafer inspection stations. The Optistation 1 was introduced in 1982, the Optistation 2 in 1984, and the 2A in 1985. In 1987, Nikon introduced the Optistation 1A. The difference between the Optistation 1 and 2 series is that the Optistation 2 series of wafer inspection systems can be interfaced directly in-line with track and lithography equipment. Not all semiconductor manufacturers require this capability, so Nikon offers the Optistation 1 series, which does not have the interface feature. The Optistations 1 and 2 are 3-inch- to 125mm compatible, while the models 1A and 2A are 100mm to 150mm compatible. The Optistation systems in the United States are typically configured as four-cassette systems with one-cassette input and three-cassette output for rework, accept, and reject. In Japan, the typical system configuration includes only accept and reject output cassettes, since Japanese manufacturers often do not perform rework on processed material. The Optistation capabilities were expanded when SMIF compatibility was announced in May 1986. The Optistation systems range in price from $50,000 to $70,000. While the Optistation is primarily a wafer defect inspection system, an optional linewidth measurement module is available at a cost of $35,000.

In addition to producing LAMPAS and Optistation wafer measurement and inspection equipment, Nikon is a major manufacturer of wafer steppers and mask metrology tools for the semiconductor industry. Nikon Precision Incorporated (San Bruno, California) was formed in 1982 as a subsidiary of Nippon Kogaku K.K. of Japan in order to support Nikon's sales, marketing, service, and technical support operations in North America. Nikon is a world leader in the production of high-quality optics for cameras, microscopes, medical, and scientific instrumentation.

Ryokosha

Ryokosha (Tokyo, Japan) manufactures a video-based linewidth measurement system for the semiconductor industry. The MF-68 system consists of a telecomparator, video camera, and computer system with autofocus and variable threshold selection. The MF-68 has been manufactured for approximately 15 years and was jointly developed by Hitachi and Ryokosha. It began as a manual measurement tool and gradually has become more automated. The MF-68K, approximately one year old, is the latest generation of the MF-68 systems, and it contains 100 programmable routines for linewidth measurement. The MF-68K is priced at approximately ¥10 million ($70,000), while the MF-68 is priced at about ¥7 million ($49,000). Essentially all of Ryokosha's sales of linewidth measurement systems have been in Japan; only a small fraction of the company's installed base is in export markets.

Sony

Sony (Atsugi-City, Kanagawa, Japan) developed the ARQUS-20 Automatic Reticle Qualification System in 1979. The ARQUS-20 utilizes a proprietary defect detection algorithm to perform a die-to-die comparison of the wafer image in order to detect the presence of defects. The defect specification on the ARQUS-20 is 0.8 micron at an 11-minute-per-square-centimeter scanning rate. Sony's ARQUS-20 is priced at approximately ¥80 million ($560,000) in Japan. The ARQUS-20 became a commercial product in 1985 and is represented by Marubeni. Dataquest believes that only two systems have been shipped to date, both to Sony's Kokubu semiconductor manufacturing plant on Kyushu.

CD and Wafer Inspection Equipment Markets

European Companies

Bio–Rad Lasersharp Ltd.

Bio–Rad Lasersharp Ltd., (Abingdon, Oxfordshire, England) manufactures a scanning laser microscope system, the SOM 150. The imaging modes of the SOM include optical beam induced current, confocal, and differential phase contrast (DPC). An optional CD/linewidth measurement package is also available. Major applications for this system include material characterization and preproduction qualification in semiconductor processing. The system was first introduced in Europe in early 1986 and made its U.S. debut at SEMICON/East in September 1986. The system, which does not include automated wafer handling, is priced at $95,000. Dataquest believes that approximately 12 to 14 units are in the installed base worldwide. The company was formed by Bio–Rad Laboratories when it acquired the manufacturing and marketing rights to the Lasersharp scanning laser microscope from IBT Dubilier.

While the Bio–Rad Lasersharp tool does not compete directly with other commercial confocal microscope measurement systems discussed in this study, the company is mentioned because of possible future development of a system for the semiconductor production environment.

Cambridge Instruments

Cambridge Instruments (Cambridge, England) manufactures a family of products for the wafer metrology and inspection market. These include optical CD and defect inspection systems, a SEM–based system for CD measurement, and an optical system for image–to–data base comparison of reticles, masks, and wafers.

Cambridge offers three different systems for optical CD measurement: the Microcheck 1, the Polycheck, and the Polycheck VLSI. The Microcheck 1 and Polycheck systems were introduced at SEMICON/West in May 1987. The Microcheck 1, priced at $60,000, is a manual system that employs fully automatic measurement of CDs and overlay. The Microcheck 1 is well suited for R&D and pilot–line manufacturing. The Polycheck system provides CD measurement capability down to 0.5 micron, macro measurements of large dimensions, and additional defect inspection capabilities. The Polycheck is priced at $115,000. Both the Microcheck 1 and Polycheck systems were designed for use in cross–industry applications including the measurement of CDs in magnetic head manufacturing and other computer peripheral operations. Dataquest believes that all deliveries of Microcheck 1 and Polycheck systems through the end of 1987 have gone to nonsemiconductor manufacturing operations.

The Polycheck VLSI, introduced in September 1987, was designed as a fully automatic CD measurement and inspection station for the semiconductor production environment. The tool features a four–cassette robotic wafer–handling system with up to 200mm wafer capability. Wafer inspection is accomplished through the use of preprogrammed inspection sequences, and an operator performs defect detection and classification operations. Typical measurement repeatability is approximately

0.008 micron (1 sigma), and measurement capability is down to 0.5 micron. The Polycheck VLSI is an enhanced version of the basic Polycheck system, which, in turn, was based on the Wafer MAP product of Reichert-McBain. The price of the Polycheck VLSI is on the order of $200,000. Dataquest believes that deliveries will begin in first quarter 1988.

Reichert-McBain, part of the Cambridge Instruments' organization until December 1987, is responsible for design, development, and manufacture of the Microcheck, Polycheck, and Polycheck VLSI products. In December 1987, Cambridge Instruments agreed to acquire a 40 percent equity interest in OSI in exchange for the transfer of the Reichert-McBain division to OSI. The Microcheck, Polycheck, and Polycheck VLSI products will now be incorporated into the OSI product line of CD and wafer inspection systems for the semiconductor industry.

The Scanline system from Cambridge Instruments is an automated e-beam comparator dedicated to submicron linewidth measurement. While this system is based on SEM technology, the Scanline design has been optimized for CD measurement, rather than for imaging. The system has minimum feature-size measurement down to 0.1 micron, with repeatability of 30 to 50 angstroms. Wafer throughput is at a minimum of 12 wafers per hour at five sites per wafer. Wafer-size capability ranges from 2-inches to 150mm, with an option available for 200mm wafers. The system is priced at approximately $300,000 with pattern recognition capability. The Scanline is currently under final development, and Dataquest believes that deliveries will begin in 1988.

The Chipcheck system from Cambridge is an image-to-data base comparator for reticles, masks, and wafers, and is used in process qualification operations. The system, introduced in 1984, automatically detects and classifies defects or deviations from the original CAD design and corresponding masks, reticles, or processed wafers. This image-to-data base comparative analysis is particularly useful for detecting repeating defects on multi-die reticles and can readily identify standard defects including rat bites, bridges, dirt, and pinholes. The tool primarily is used in mask and reticle inspection; however, Dataquest believes that several customers use the system for wafer inspection as well. In the wafer inspection mode, the Chipcheck system compares photoresist images on the silicon wafer directly with the original design data in the CAD data base. The minimum defect detection limit is 0.5 micron. The Chipcheck system is priced at approximately $750,000, and Dataquest estimates that there were approximately 15 systems in the installed base at the end of 1987. CD measurement capability is available as an option.

Cambridge Instruments was founded in 1881 by Horace Darwin, youngest son of the famous naturalist, Charles Darwin. In May 1986, the Cambridge Instruments organization merged with R. Jung GmbH (Heidelberg, West Germany), C. Reichert Optische Werke (Vienna, Austria), Reichert Scientific Instruments (formerly American Optical Company and Spencer Lens Company, located in Buffalo, New York), and Reichert-McBain. Today, Cambridge Instruments' semiconductor products include optical and e-beam metrology equipment, CAD data base and wafer inspection systems, scanning electron microscopes, direct-write e-beam lithography equipment, MOCVD reactors, epitaxial reactors, and single-crystal pullers. Three other major markets for the company are scientific instruments, ophthalmic and medical instruments, and components for industrial process control and automation.

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CD and Wafer Inspection Equipment Markets

Heidelberg Instruments

Heidelberg Instruments (Heidelberg, West Germany) manufactures the Line Profile Measurement (LPM) system. The LPM is a confocal laser scanning microscope designed for fully automatic linewidth measurement and line profilometry. The system is designed with telecentric optics that allows a laser beam to be scanned over the wafer surface, which is held fixed in the x-y plane. The LPM measures linewidths down to 0.3 micron, with .005-micron repeatability. One of the advantages of confocal scanning laser microscopy is the ability to measure the vertical profile of a circuit feature. The LPM can measure lineheight down to 0.05 micron, with .005-micron repeatability. Typical wafer throughput is on the order of 20 to 25 wafers per hour at five sites per wafer.

The LPM was first introduced at SEMICON/Europa in March 1987, and the first system was shipped to Siemens in late May. Dataquest estimates that a total of five systems was shipped in 1987, with systems going to both European and U.S. semiconductor manufacturers. The price of the LPM in Europe is DM 550,000, while the price in the United States is approximately $340,000.

Heidelberg Instruments is developing an automatic defect inspection system for the wafer inspection market. The system will be designed with die-to-die and die-to-data base inspection modes. The company plans to introduce the system in fourth quarter 1988.

Heidelberg Instruments was formed in 1984 by five researchers from Heidelberg University and four industrial partners. Investors in Heidelberg Instruments include Wild Leitz, a West German manufacturer of wafer and mask metrology and inspection equipment for the semiconductor industry. Other products from Heidelberg Instruments include laser scanning microscope systems for biological, chemical, and medical applications.

Vickers Instruments

Vickers Instruments (York, England) manufactures the Quaestor CD-07A, a fully automatic, optical linewidth and overlay measurement system. This system has been designed specifically for the production environment, with major emphasis placed on fully automatic operation and reliable linewidth measurement in production operation. The CD-07A utilizes an image-shearing technique to measure linewidth geometries down to 0.7 micron. The system has a wafer throughput rate of 25 wafers per hour at five measurement sites per wafer. The CD-07A was introduced in 1986, and deliveries began in 1987. Dataquest estimates that more than 35 systems were shipped in 1987 to semiconductor manufacturers in the United States, Europe, and Japan. The price of the Quaestor CD-07A is approximately $230,000.

Vickers Instruments also manufactures e-beam-based CD measurement systems. In May 1987, Vickers introduced the Nanolab SR Series at SEMICON/West. The Nanolab SR Series is an automatic, nondestructive, submicron CD and inspection system. The tool utilizes SEM technology and is designed to operate in the production environment. The wafer throughput rate is greater than 15 wafers per hour at five sites per wafer. The linewidth measurement range is from 0.1 micron to 10.0 microns. Inspection capability is based on visual observations made by an operator. The first shipment of the Nanolab SR was in late 1986, and Dataquest estimates that the installed base of systems was approximately 15 systems at the end of 1987. This system is priced at $500,000.

Vickers also offers a sister tool to the Nanolab SR Series. This system, the Nanolab DL3206 SEM, is based on the same SEM technology as the Nanolab SR tool. The difference in the two systems is that the Nanolab DL3206 SEM is designed for use in process development and troubleshooting, such as in the early stages of setting up a production line. In contrast, the Nanolab SR Series is designed for in-line processing in a production environment. The price of the DL3206 system is $280,000.

Vickers Instruments is an operating business unit of Vickers plc. Manufacturing of the Quaestor system occurs at the company's headquarters in York, England. The U.S. corporate office is located in Woburn, Massachusetts, while the Canadian office is located in Nepan, a suburb of Ottawa, Ontario. The Nepan office is where e-beam instrument design, development, and manufacturing takes place. Vickers Instruments is represented by Union Optical in Japan. Vickers plc, Vickers Instruments' parent company, is a multinational corporation with diverse interests that range from marine engineering, infant medical-care systems, and the Rolls-Royce automobile operations.

Wild Leitz

Wild Leitz (Wetzlar, West Germany) manufactures microscopes and measurement and inspection systems for front-end and assembly operations within the semiconductor industry. The company's CD measurement systems employed in the production environment are the MPV-CD 2 and the LTS-M systems. The MPV-CD 2 is a standalone optical CD tool priced at approximately $70,000. It was introduced in the late 1970s. The LTS-M, introduced in 1984, incorporates the MPV-CD 2 system, pattern recognition, and an IBM PC system with the automatic wafer-handling capability of the Leitz Transport System (LTS). The LTS-M is priced at approximately $175,000. Wild Leitz introduced its four-cassette wafer inspection station, the Leitz Inspection Station (LIS) in 1982. This inspection station ranges in price from $50,000 to $100,000. The company also offers a one-cassette version of the LIS wafer inspection system known as the LTS.

In addition to its CD and wafer inspection equipment, Wild Leitz manufactures the MPV-SP 2, a film thickness measurement system; the MVG Automatic, a mask comparator system used for image overlay and CD measurements; and a scanning acoustic microscope system with applications in materials research, failure analysis, and device development. Wild Leitz is also a major supplier of optical microscopes and components to OEMs.

Leitz IMS Company (Billerica, Massachusetts) was formed as a partnership between Wild Leitz of West Germany and Image Micro Systems, Inc., of the United States. The LMS-2000 Laser Metrology System provides CDs and pattern-dimensional integrity data with nanometer accuracy and repeatability over an 8 x 8-square-inch area. The LMS-2000 can support the output of several e-beam mask generating systems. Shipments of the LMS-2000 system began in 1987. The price of the tool is approximately $1 million.

The name of the company, Wild Leitz, reflects its two parent corporations: Wild Heerbrugg of Switzerland and Ernst Leitz Wetzlar GmbH of West Germany. In the late 1970s, the Leitz family sold a minority interest, and later a majority share, of the Leitz business to Wild. Today, Wild Leitz represents a large conglomerate of business activities centered on optical imaging systems. Major business operations include microelectronics, medical and microscopic diagnostics, and industrial metrology technology. A fourth group in Wild Leitz is involved in providing venture funding for new companies including Heidelberg Instruments, a manufacturer of confocal scanning laser microscopy systems for the semiconductor industry.

Zeiss

Zeiss (Oberkochen, West Germany) manufactures the Wafer Inspection Station (WIS). The WIS was introduced in March 1985 at SEMICON/Europa as a basic manual inspection station. Enhancements to the WIS system include a motorized stage, new microscope design, automatic wafer handling and vacuum transport, and computer-controlled operation. In addition, a film thickness measurement option for the WIS was introduced at SEMICON/East in September 1987. The price of the WIS is approximately $110,000 but will vary, depending upon options. Manufacture of the WIS system occurs at Zeiss facilities in Gottingen and Oberkochen, West Germany. Shipments of the WIS system, to date, have been to European and Canadian semiconductor manufacturing companies.

Departures

Contrex

Contrex spent six years in the development of a submicron automated measurement and wafer inspection system, the Wafervision 3000. This system, priced at approximately $600,000 to $800,000, was expected to compete with the KLA 2020. Contrex ceased operations in 1986, after being unable to secure additional funding.

Machine Intelligence

Machine Intelligence undertook preliminary development of an automated CD and wafer inspection station. The company closed its facilities in 1987, after being unable to obtain sufficient venture funding for further product design and development. Technology developed by Machine Intelligence for bank note inspection was sold to a European currency-printing equipment manufacturer when the corporation was dissolved.

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Optoscan

Optoscan, founded in 1983, spent four years in the development of a laser-based linewidth and overlay measurement system, the model 2010. This system, priced at approximately $240,000, utilized a 325nm laser source and was expected to achieve 0.5-micron measurement capability. General Signal acquired Optoscan in 1985 and closed the subsidiary in 1987, after an unsuccessful effort to market the 2010 system.

Karl Suss

While Karl Suss (Munich, West Germany) has not officially announced its departure from the wafer inspection equipment market, the company is no longer actively marketing its IP-125 wafer inspection station. The IP-125 wafer inspection system was sold between 1982 and 1984 in Europe and was priced at approximately $40,000.

MARKET ANALYSIS

The following sections of our study present historical market information and analysis for optical CD equipment, wafer inspection stations, and joint CD/inspection systems from 1982 through 1987. This information includes worldwide market estimates by company, unit demand, and ASP trends as well as a discussion of the market leaders by region for each of the three market segments. Models of equipment in each segment are identified by vendor and ASP. (ASPs reflect 1987 prices across all regions of the world, unless otherwise noted. The yen/dollar exchange rate in 1987 was 144.) In addition to these three equipment segments, the e-beam-based CD equipment and reticle qualification systems are discussed briefly with regard to their competitive impact. The forecast of optical CD equipment, wafer inspection stations, and joint CD/inspection systems is contained in the final section of this study.

Optical CD Equipment Market

World Market

In 1987, the worldwide market for optical CD equipment was $39.5 million, up 38 percent from the 1986 level of $28.7 million. Table 3 presents historical worldwide sales for companies participating in this market segment from 1982 through 1987.

CD and Wafer Inspection Equipment Markets

Table 3

Worldwide Optical CD Equipment Market, 1982–1987
(Millions of Dollars)

Company	1982	1983	1984	1985	1986	1987	1987 % Share
Heidelberg Instruments	0	0	0	0	0	$ 1.6	4.0%
Hitachi	0	0	0	0	$ 4.1	6.0	15.2
IVS, Inc.	0	0	0	0	0.5	1.5	3.8
Nanometrics	$ 4.0	$ 7.0	$ 6.7	$ 2.3	1.5	1.7	4.3
Nikon	1.9	2.4	4.7	3.0	2.3	5.2	13.2
Optical Specialties, Inc.	0	1.9	4.7	3.1	2.2	1.3	3.3
Reichert-McBain	0	0	0	0	3.0	0.3	0.8
Ryokosha	1.1	1.6	2.2	1.4	1.5	1.4	3.5
SiSCAN Systems	0	0	0	0	1.9	3.0	7.6
Vickers Instruments	0	0	0	0	0	8.3	21.0
Wild Leitz	1.6	2.8	4.4	4.4	4.8	3.6	9.1
Others	4.8	6.8	9.9	5.9	6.9	5.6	14.2
Total	$13.4	$22.5	$32.6	$20.1	$28.7	$39.5	100.0%
Growth		68%	45%	(38%)	43%	38%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

Vickers Instruments of the United Kingdom ranked first in market share of the optical CD equipment market, with the successful introduction of its new automatic CD measurement system, the Quaestor CD-07A. Hitachi, with its LAMU measurement system, and Nikon, with its LAMPAS tools, ranked second and third, respectively, in the world market. Together, these three companies had a combined share of 49.4 percent. In addition, the new confocal scanning laser microscopy systems of Heidelberg Instruments and SiSCAN Systems captured a combined share of 11.6 percent of the 1987 market. All five companies have introduced new systems within the last two years, and Dataquest believes that their success in the marketplace reflects new technology implementations and advanced automation capability. The prices of the CD measurement systems of these five companies range from $230,000 to $420,000, substantially higher than $115,000, the ASP across all equipment models in this market segment in 1987.

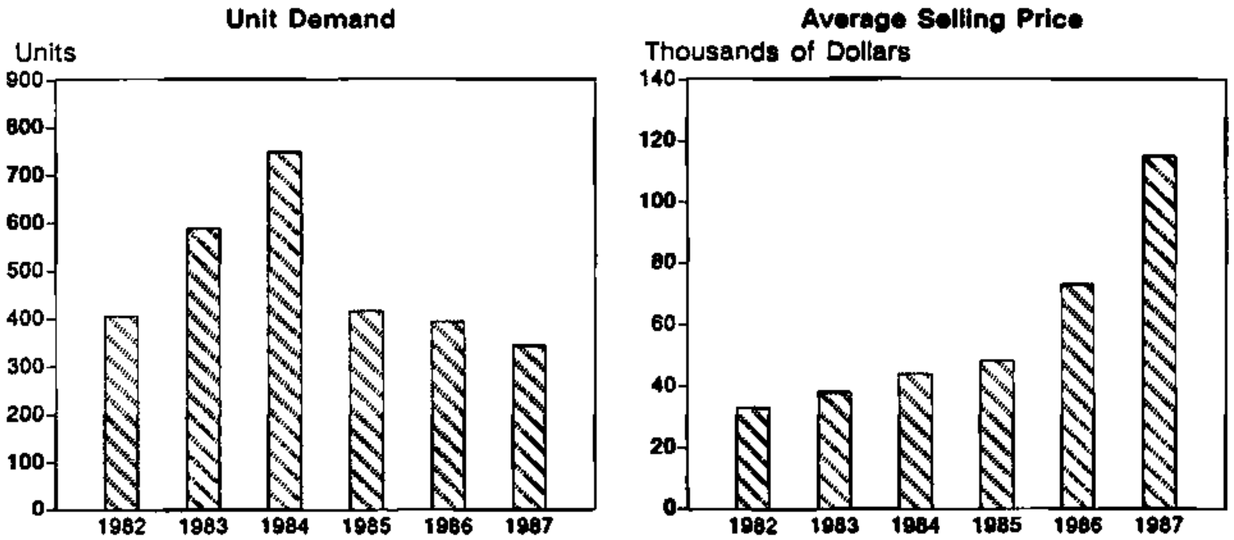
CD and Wafer Inspection Equipment Markets

In 1982, the market leaders in the CD equipment market consisted of Nanometrics, Nikon, and Wild Leitz. Dataquest estimates that these companies had a combined share of 56.0 percent of the $13.4 million market. In 1984, the boom year for the semiconductor equipment industry, market leaders in the CD equipment market were Nanometrics, Nikon, OSI, and Wild Leitz. These companies had combined sales of $20.5 million, or 62.9 percent of the 1984 market. Interestingly enough, Nikon has managed to maintain its market share of approximately 13 percent from 1982 through 1987. In addition, it was the only company among the 1982 and 1984 market leaders that was still ranked among the top three in 1987.

With the advent of new technologies and increased equipment automation, the ASP of optical CD equipment has risen considerably over the last five years. Figure 2 presents a summary of the worldwide unit demand and ASP of optical CD equipment from 1982 through 1987. As illustrated in Figure 2, the ASP of optical CD equipment has increased by a factor of 3.5 between 1982 and 1987, from approximately $33,000 to almost $115,000. At the same time, unit demand for CD measurement systems has declined every year for the last three years, and, in 1987, it stood at only 85 percent of its 1982 level.

Figure 2

Optical CD Equipment
Worldwide Unit Demand and ASP, 1982–1987



Source: Dataquest
March 1988

CD and Wafer Inspection Equipment Markets

Regional Markets

Table 4 presents the historical optical CD equipment market by regional consumption. In 1987, the United States and Japan had approximately equal share of the world optical CD equipment market, with 37.7 percent and 37.5 percent, respectively. European sales of optical CD equipment were 17.2 percent of the world market in 1987, while the ROW represented 7.6 percent.

Table 4

Optical CD Equipment
Regional Markets, 1982–1987
(Millions of Dollars)

Region	1982	1983	1984	1985	1986	1987	CAGR 1982-1987
United States	$ 6.2	$11.0	$16.6	$ 7.8	$11.3	$14.9	19.2%
Japan	4.8	7.3	10.4	6.7	10.5	14.8	25.3%
Europe	1.9	3.0	3.7	3.4	4.1	6.8	29.1%
ROW	0.6	1.2	1.8	2.2	2.7	3.0	38.0%
Total	$13.4	$22.5	$32.6	$20.1	$28.7	$39.5	24.1%
Growth		68%	45%	(38%)	43%	38%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

Many of the market leaders that emerged in 1987 are relatively new participants in the optical CD equipment market. Growth in the regional markets during 1987 is directly attributable to those new companies offering advanced technology products with improved automation capability.

In the United States, the top three participants in the optical CD equipment market in 1987 were Vickers Instruments, SiSCAN Systems, and IVS, Inc. Together, these three companies represented 57.7 percent, or $8.6 million, of the 1987 optical CD equipment market in the United States. Both SiSCAN Systems and IVS, Inc., sold their first systems in 1986, while Vickers started shipments in 1987. Wild Leitz, Nanometrics, and OSI were next in the ranking in this market segment in 1987 and had a combined share of approximately 23.5 percent. In 1984, Nanometrics and OSI were the major suppliers of optical CD measurement equipment to the U.S. semiconductor industry and had a combined share of 49.4 percent of the $16.6 million market. On a unit basis, Nanometrics and OSI have dominated the U.S. market over the past six years.

CD and Wafer Inspection Equipment Markets

In Japan, Hitachi and Nikon ranked first and second, respectively, in a market of $14.8 million in 1987. These two manufacturers had a combined market share of 71.0 percent. Ryokosha is the next largest supplier of optical CD equipment to the Japanese semiconductor industry, with 9.5 percent share of the 1987 market.

In Europe, the top three participants in 1987 were Vickers Instruments, Wild Leitz, and Heidelberg Instruments, with a combined share of 75.0 percent of the $6.8 million market. While Vickers Instruments and Heidelberg Instruments experienced their first sales in this market segment during 1987, Wild Leitz has been a major supplier of optical linewidth measurement and inspection systems since the early 1980s.

In 1987, no clear leader emerged in the $3.0 million optical CD equipment market in the ROW region.

Equipment Models and Average Selling Prices

Table 5 presents a summary of optical CD measurement equipment by manufacturer, model name, and ASP.

Table 5

Optical CD Equipment
Equipment Models and ASPs

Company	Model	ASP
Bio-Rad Lasersharp Ltd.	SOM 150	$ 95,000
Cambridge Instruments	Microcheck 1	$ 60,000
Dainippon Screen	SLM 601	N/A
Heidelberg Instruments	LPM	$340,000
Hitachi	LAMU-600	$300,000
ITP, Inc.	AUTO CD 88	$ 75,000
	System 802	$130,000
IVS, Inc.	Accuvision-1 (ACV-1)	$ 80,000
	ACV-2	$140,000
	ACV-3	$220,000
	ACV-4	$300,000
KLA Instruments	KLA 2005	$700,000
	KLA 5000	$380,000
Nanometrics	Model 50	$ 45,000
	Model 51	$ 45,000
	Model 400	$150,000
Nidek	CD-10	$ 35,000
Nikon	LAMPAS-M3	$165,000
	LAMPAS-HD	$420,000*
Optical Specialties, Inc.	VLS-I	$ 47,000

(Continued)

Table 5 (Continued)

Optical CD Equipment
Equipment Models and ASPs

Company	Model	ASP
Reichert-McBain	Wafer MAP	$165,000
Ryokosha	MF-68	$ 49,000
	MF-68K	$ 70,000
SiSCAN Systems	SiSCAN-I	$240,000
	SiSCAN-II M	$270,000
	SiSCAN-II A	$350,000
Vickers Instruments	Quaestor CD-07A	$230,000
Waterloo Scientific	WSI-1000CD	$300,000
Wild Leitz	MPV-CD 2	$ 70,000
	LTS-M	$175,000

N/A = Not Available
*Reflects price in Japan; at time of publication, price had not yet been fixed in the United States.

Source: Dataquest
March 1988

SEM-Based CD Systems

SEM-based CD systems provide better measurement resolution and depth of focus, compared with their optical counterparts. These systems, with measurement capability down to 0.1 micron, are already being used for linewidth and overlay measurement in R&D and pilot line operations. Many of the SEM manufacturers have perceived this as a growing market opportunity and are currently redesigning and retrofitting their existing SEM tools for operation in the production environment. So far, this has encompassed the addition of CD measurement software packages from optical-based systems, automatic wafer handling, and load locks to increase wafer throughput. The systems being designed specifically for IC metrology are low-voltage SEMs because of the concern about damage to the wafer at higher levels of electron irradiation. Compared with optical tools, the SEM CD tools still have relatively low throughput, on the order of 8 to 15 wafers per hour at five measurement sites per wafer. The slow throughput rate and the general lack of user-friendly controls are two factors that have impeded the acceptance of many SEM systems in the production environment.

CD and Wafer Inspection Equipment Markets

Table 6 identifies several companies currently providing SEM-based CD measurement systems. The table includes equipment model names and ASPs. Hitachi, with its S-6000 system, has established a leadership position in Japan, where semiconductor manufacturers have embraced SEM CD systems for submicron measurement.

Table 6

SEM-Based CD Systems
Equipment Models and ASPs

Company	Model	ASP
ABT (Akashi Beam Technology)	CC-CD	$375,000
Amray	Model 1500	$350,000
Cambridge Instruments	Scanline	$300,000
Hitachi	S-6000	$625,000
JEOL	JEPAS-1200	$450,000
KLA Instruments*	KLA/Holon 2711	$500,000
Nanometrics	Model 100	$420,000
Opal Inc.	Opal 702	N/A
Vickers Instruments	Nanolab SR Series	$500,000
	DL3206 SEM	$280,000

N/A = Not Available

*Holon's equivalent system, model ESPA-11, is priced at ¥90 million in Japan.

Source: Dataquest
March 1988

CD Measurement Equipment—An Evaluation of Four Factors

With a plethora of competing technologies to choose from, semiconductor manufacturers are faced with evaluating and differentiating CD measurement systems on the basis of the following four important factors:

- Measurement capability
- Wafer throughput
- Cost of the equipment
- Level of equipment automation

CD and Wafer Inspection Equipment Markets

Measurement Capability

Measurement capability is an essential issue, as manufacturers advance into the processing and measurement range of 1.25- to 0.75-micron geometries. This is the range at which traditional white-light CD measurement systems begin to "run out of steam." New technologies and techniques, such as confocal scanning laser microscopy, fluorescence measurement capability, enhanced video imaging processing, and coherence probe imaging tools, are being designed to compete with the traditional white-light measurement systems for measuring line geometries in the submicron range. SEM-based CD measurement systems provide an additional alternative to the variety of optical techniques that are available or are being developed today.

Wafer Throughput

In the production environment, equipment throughput must meet or exceed a rate that will accommodate the flow of material through the processing line. Optical CD measurement equipment typically has a throughput on the order of 25 to 30 wafers per hour at five linewidth measurements per wafer. In comparison, wafer throughput for e-beam-based systems is on the order of 8 to 15 wafers per hour at five sites per wafer. This is slower than the optical systems because, during the SEM CD measurement process, the wafer must be in a vacuum environment. Manufacturers have added load locks to improve throughput on the SEM CD tools. A significant exception for CD equipment throughput is KLA Instruments' 2020 system. This system has a throughput of approximately 90 wafers per hour at five linewidth measurement sites per wafer.

Cost of the Equipment

In 1987, optical CD measurement systems ranged in price from $50,000 for a traditional white-light microscopy tool to almost $900,000 for a joint CD/inspection system like the KLA 2020. SEM CD systems ranged in price from $300,000 to $600,000. This enormous breadth in the range of prices, coupled with varying measurement capability and throughput, has further complicated the purchasing issues and priorities for semiconductor manufacturers.

Equipment Automation

The fourth major factor in the evaluation of CD measurement systems is the level of equipment automation. All systems today provide some form of automated wafer handling in addition to automatic measurement algorithms. Some types of equipment, however, still require some additional amount of operator assistance and interaction beyond normal setup procedures. This reliance on an operator is considered unacceptable by many semiconductor manufacturers who want fully automated equipment performance. Dataquest believes that Vickers Instruments, in particular, was able to capture 21.0 percent of the world optical CD equipment market in 1987 because its Quaestor CD-07A system provides reliable automated performance in the production environment.

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CD and Wafer Inspection Equipment Markets

In addition to the automation of physical operations, semiconductor manufacturers also are very interested in measurement systems that can analyze the collected data for the optimization of equipment setup parameters. In particular, several systems have been developed for optimizing the performance of lithography equipment. KLA Instruments offers a software enhancement for the 2020 system, known as the KLA Stepper Set-Up, or KLASS. The KLASS software is an applications package for optimizing stepper setup parameters, including focus and exposure settings. In May 1987, OSI announced an applications software package known as the Metrology Analysis Program I (MAP-I). This software package receives measurement data from OSI's MV-PLUS and uses it to optimize stepper/aligner operating parameters. Perkin Elmer introduced the OMS 1 Overlay Measurement System at SEMICON/West in May 1987. This system provides fast, precise overlay measurements that are used to optimize the performance of the company's Micralign and Micrastep lithography tools. Dataquest expects analysis packages to be developed eventually in order to provide measurement, analysis, and feedback to equipment in a single closed-loop operation.

Wafer Inspection Equipment Market

World Market

In 1987, the worldwide market for wafer inspection stations was $24.5 million, up 13 percent from the 1986 level of $21.8 million. Table 7 presents historical worldwide sales for companies participating in this market segment from 1982 through 1987.

Table 7

Worldwide Wafer Inspection Stations Market, 1982–1987 (Millions of Dollars)

Company	1982	1983	1984	1985	1986	1987	1987 % Share
Canon	$ 0.8	$ 1.3	$ 2.0	$ 1.3	$ 1.4	$ 2.0	8.2%
Estek (Aeronca)	0	0	0	0.3	0.2	0.1	0.4
Insystems	0	0	0	0	0	2.1	8.7
Nidek	1.3	1.7	2.0	1.7	2.2	3.1	12.6
Nikon	1.3	3.2	5.8	4.4	6.4	8.1	33.0
Optical Specialties, Inc.	5.3	4.2	7.8	4.2	2.8	1.7	6.9
Karl Suss	0.1	0.2	0.2	0	0	0	0
Wild Leitz	0.6	2.3	4.3	4.7	3.5	2.8	11.4
Zeiss	0	0	0	0.9	2.4	1.8	7.3
Others	2.0	3.8	5.0	3.0	2.9	2.8	11.4
Total	$11.4	$16.7	$27.1	$20.5	$21.8	$24.5	100.0%
Growth		47%	62%	(25%)	7%	13%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

CD and Wafer Inspection Equipment Markets

Nikon, with its Optistation systems, had the largest share of the 1987 worldwide wafer inspection market with 33.0 percent of the $24.5 million market. Nidek, Wild Leitz, and Canon together had an additional 32.2 percent. All four companies manufacture microscope-based inspection stations that rely on operators to detect and classify defects on the wafer surface. Insystems, with its new system based on holographic, spatial frequency filtering technology, captured 8.7 percent of the world market with sales of $2.1 million in 1987. This system provides fully automatic detection of an entire wafer in less than 30 minutes. While the traditional microscope inspection stations are priced at approximately $60,000 to $70,000, the automatic wafer inspection system from Insystems is $1 million.

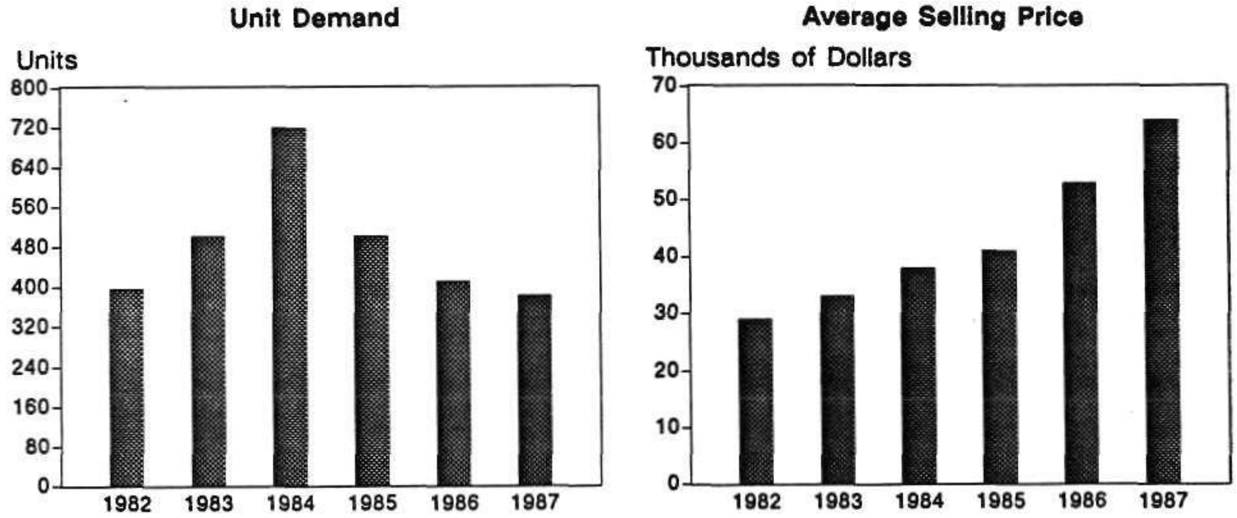
In contrast with 1987, the 1982 market was dominated by OSI, which had 46.5 percent share of the $11.4 million market. In 1984, the market leaders in wafer inspection equipment were OSI, Nikon, and Wild Leitz. These companies had combined sales of $17.9 million, or 66.1 percent, of the 1984 market. As in the optical CD equipment market, Nikon has maintained its presence as a market leader from 1982 through 1987.

Figure 3 presents a summary of the worldwide unit demand and ASP of wafer inspection stations. As with optical CD measurement equipment, worldwide unit demand for wafer inspection stations declined in 1985, 1986, and 1987. At the same time, the price of the equipment has been increasing from an average of $29,000 in 1982 to $64,000 in 1987. The increase in the ASP of wafer inspection stations has been more gradual than the ASP of optical CD equipment over the same time frame. This is because the technology of defect detection has remained virtually unchanged over this time period. An operator is still responsible for visually scanning a magnified image of the wafer surface to detect the presence of defects. As wafer inspection stations have matured, system enhancements have been directed toward automatic wafer handling, automatic and programmable stage movement, autoalignment, autofocus, and keypad data entry systems. Recently, a new generation of wafer inspection stations was introduced. These systems perform automatic defect detection and, in some instances, assist in defect classification as well. The technological advances of Insystems' holographic, spatial frequency filtering system and KLA's new 2028 automatic inspection station are reflected in price tags in the neighborhood of $1 million.

CD and Wafer Inspection Equipment Markets

Figure 3

Wafer Inspection Stations
Worldwide Unit Demand and ASP, 1982–1987



Source: Dataquest
March 1988

Regional Markets

Table 8 presents the historical wafer inspection equipment market by regional consumption. In 1987, Japan had the major share, with 42.7 percent of the $24.5 million world market. The United States ranked second, with 31.0 percent, while Europe represented 14.7 percent, and ROW had approximately 11.6 percent. Japan's major share of the wafer inspection market in 1986 and 1987, for the most part, is due to yen appreciation during those years. However, Dataquest believes that, since 1985, Japan also has purchased more wafer inspection stations on a unit basis than has the United States. This correlates with the general trend that Japan has purchased more wafer steppers on a cumulative basis than has the United States over the last three years.

In the United States, the top three participants in the wafer inspection market in 1987 were Nikon, OSI, and Wild Leitz. Together, they represented 61.8 percent of the $7.6 million market in 1987. These three companies have been the major suppliers of wafer inspection stations to the United States since 1983. In 1982, OSI dominated the U.S. market with more than 80 percent of the $6.1 million market.

In Japan, Nikon, Nidek, and Canon are the major suppliers of wafer inspection equipment. In 1987, they had a combined share of almost 82.9 percent of the $10.5 million market. These three companies have consistently represented in excess of 80 percent of the Japanese wafer inspection market since 1982.

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CD and Wafer Inspection Equipment Markets

Table 8

Wafer Inspection Stations
Regional Markets, 1982–1987
(Millions of Dollars)

Region	1982	1983	1984	1985	1986	1987	CAGR 1982-1987
United States	$ 6.1	$ 8.5	$14.2	$ 7.8	$ 7.5	$ 7.6	4.5%
Japan	4.0	6.0	9.1	7.2	8.6	10.5	21.3%
Europe	1.1	2.0	3.2	4.0	3.8	3.6	26.8%
ROW	0.2	0.3	0.6	1.5	1.9	2.9	70.7%
Total	$11.4	$16.7	$27.1	$20.5	$21.8	$24.5	16.5%
Growth		47%	62%	(25%)	7%	13%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

In Europe, the top three participants were Wild Leitz, Zeiss, and Nikon, with a combined share of 88.9 percent of the $3.6 million market in 1987. For Nikon, 1987 was the first year of sales in Europe, while Zeiss began to sell wafer inspection stations in Europe in 1985. Historically, Wild Leitz has been the market leader in wafer inspection in Europe since 1983.

In ROW, Nidek and Nikon were the major suppliers of wafer inspection stations, with a combined share of 55.2 percent of the $2.9 million market in 1987.

Equipment Models and Average Selling Prices

Table 9 presents a summary of wafer inspection stations by manufacturer, model name, and ASP.

Table 9

Wafer Inspection Stations
Equipment Models and ASPs

Company	Model	ASP
Estek (Aeronca)	AE-1000	$ 80,000
Canon	VIR-600	$ 55,000
	VIR-630	$ 76,000
Heidelberg Instruments	Under development	N/A
Insystems	Model 8600	$1,065,000
IVS Inc.	Under development	N/A
KLA Instruments	KLA 2028	$ 895,000
Nidek	IM-8A/-8B	$ 55,000
Nikon	Optistation 1	$ 50,000
	Optistation 1A	$ 55,000
	Optistation 2	$ 60,000
	Optistation 2A	$ 70,000
Optical Specialties, Inc.	MV-7	$ 25,000
	MV-10	$ 35,000
	MV-15	$ 50,000
	MV-360	$ 65,000
Wild Leitz	LTS	$ 60,000
	LIS	$ 75,000
Zeiss	WIS	$ 120,000

Source: Dataquest
March 1988

Reticle Qualification Systems

Reticle qualification systems represent a category of equipment that is used during the setup and process qualification stages of wafer fabrication. These systems do not compete directly with wafer inspection stations that are used to monitor wafers for the presence of defects in a production environment. There is, however, some overlap in product applications, because some equipment, such as KLA Instruments' family of 2020 systems, is used in both wafer inspection and reticle qualification applications. (Note that the majority of KLA's sales of reticle qualification systems are the KLA 200 Series products, manufactured by the company's RAPID division.) Table 10 identifies several manufacturers of reticle qualification systems by equipment model names and ASPs.

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Table 10

Reticle Qualification Systems
Equipment Models and ASPs

Company	Model	ASP
Cambridge Instruments	Chipcheck	$ 750,000
Lasertec	3WD36	$ 540,000
KLA Instruments	KLA 2020	$ 895,000
	KLA 2028	$ 895,000
	KLA 2030	$1,095,000
	KLA 200 Series	$ 670,000- $ 950,000
Sony	ARQUS-20	$ 560,000

Source: Dataquest
March 1988

Joint CD/Inspection Systems

World Market

In 1987, KLA Instruments had 92.3 percent share of the world market of $29.9 million for joint CD/inspection equipment. This category of equipment has been dominated strongly by KLA Instruments since it started to ship its 2020 system in 1985. OSI was the first equipment company to combine linewidth and overlay measurement capability with wafer inspection when it introduced its MV-207 and MV-215 systems in 1983. These tools combined the company's popular MV-7 and MV-15 microscope-based inspection stations with the CD measurement capability of its VLS-I system. While the MV-207 and MV-215 perform linewidth and overlay measurement in an automatic mode, an operator is still required to perform defect detection and classification. In 1984, KLA Instruments introduced the 2020 system, a tool that combines automatic CD measurement with automatic inspection capability. For the first time, the subjective judgement of the operator was removed from the wafer inspection process. OSI is developing a fully automated measurement and inspection system that will also free the operator from visual defect inspection. The company plans to market the system in 1988, and Dataquest expects other introductions in the joint CD/inspection equipment category to occur this year. Table 11 presents historical worldwide sales for the two companies that participated in this market segment from 1982 through 1987.

Figure 4 presents a summary of the worldwide unit demand and ASP of joint CD/inspection systems from 1982 through 1987. Over the last several years, the ASP of joint CD/inspection systems has skyrocketed, while unit demand has remained relatively constant. The increasing ASP of joint CD/inspection systems reflects the acceptance of KLA's 2020 system in the marketplace. The 2020 is priced at $895,000, which is substantially higher than the $77,000 ASP of joint CD/inspection systems in 1983.

CD and Wafer Inspection Equipment Markets

Table 11

Worldwide Joint CD/Inspection Systems Market, 1982-1987
(Millions of Dollars)

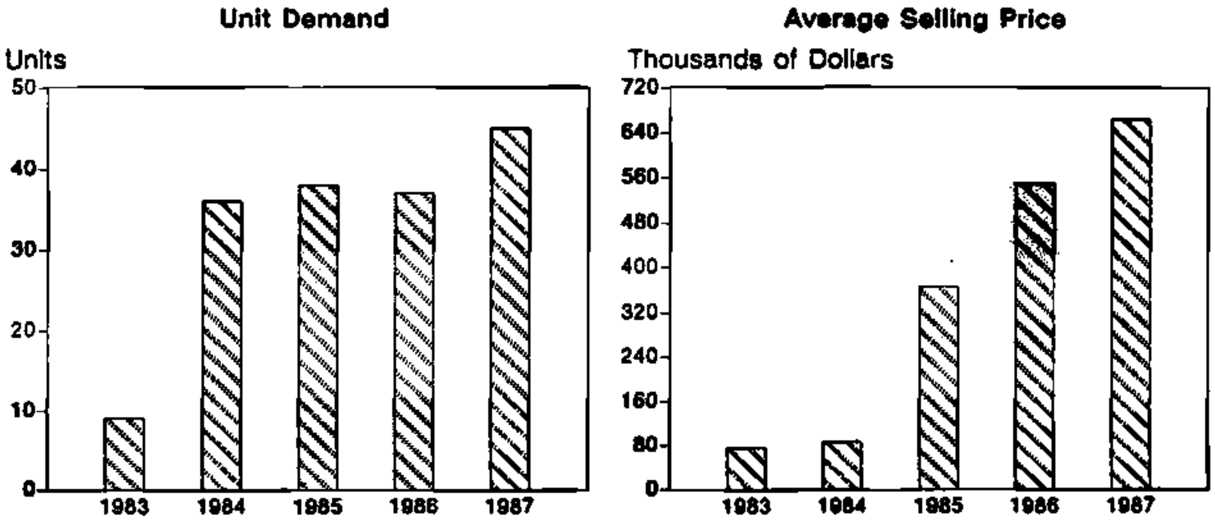
Company	1982	1983	1984	1985	1986	1987	1987 % Share
KLA Instruments	0	0	0	$11.2	$18.1	$27.6	92.3%
Optical Specialties, Inc.	0	$0.7	$3.1	2.7	2.2	2.3	7.7
Total	0	$0.7	$3.1	$13.9	$20.3	$29.9	100.0%
Growth			343%	348%	32%	30%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

Figure 4

Joint CD/Inspection Systems
Worldwide Unit Demand and ASP, 1983-1987



Source: Dataquest
March 1988

CD and Wafer Inspection Equipment Markets

Regional Markets

Table 12 presents the historical joint CD/inspection systems market by regional consumption. In 1987, the United States represented 45.8 percent of the $29.9 million market. Japan ranked second with 38.5 percent, while Europe ranked third with 12.4 percent. Semiconductor manufacturers in the ROW countries have not as yet purchased significant amounts of equipment in this category. On a dollar basis, KLA Instruments dominates the market in the United States, Japan, and Europe. On a unit basis, however, OSI has shipped almost twice as many systems as KLA Instruments from 1983 through 1987.

Table 12

Joint CD/Inspection Systems
Regional Markets, 1982-1987
(Millions of Dollars)

Region	1982	1983	1984	1985	1986	1987	CAGR 1983-1987
United States	0	$0.6	$2.7	$ 8.3	$10.5	$13.7	119%
Japan	0	0	0.1	3.8	7.2	11.5	N/A
Europe	0	0.1	0.3	1.6	2.6	3.7	147%
ROW	0	0	0	0.2	0	1.0	N/A
Total	0	$0.7	$3.1	$13.9	$20.3	$29.9	156%
Growth			343%	348%	32%	30%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

Equipment Models and Average Selling Prices

Table 13 presents a summary of joint CD/inspection systems by manufacturer, model name, and ASP. All products identified in Table 13 are optical-based systems, except for Opal's new SEM-based metrology tool, the 702. The company plans to incorporate wafer inspection capability on this system in the future.

Table 13

Joint CD/Inspection Systems Equipment Models and ASPs

Company	Model	ASP
Cambridge Instruments*	Polycheck	$ 115,000
	Polycheck VLSI	$ 200,000
KLA Instruments	KLA 2020	$ 895,000
	KLA 2030	$1,095,000
Opal Inc.	Opal 702	N/A
Optical Specialties, Inc.	MV-207	$ 65,000
	MV-215	$ 100,000
	MV-PLUS	$ 180,000
	MV-360CD	$ 120,000
	Micropatterning Process Control System	$ 500,000

N/A = Not Available
*Polycheck and Polycheck VLSI products transferred to Optical Specialties, Inc., as part of December 1987 acquisition of Reichert-McBain.

Source: Dataquest
March 1988

Optical CD, Wafer Inspection, and Joint CD/Inspection Equipment Market

World Market

The three categories of optical CD equipment, wafer inspection stations, and joint CD/inspection systems are closely related, because they represent process control equipment used directly in the production environment. In the case of the joint CD/inspection systems, applications and functionality overlap with those of equipment in the other two categories. Therefore, companies participating in one market segment are well placed to develop systems in one or both of the other categories. For example, Heidelberg Instruments and IVS Inc., both optical CD equipment manufacturers, are developing wafer inspection stations, while KLA Instruments, a major manufacturer of joint CD/inspection equipment, now offers systems that perform only automatic wafer inspection (the KLA 2028) or automatic linewidth and overlay measurements (the KLA 2005 and the new KLA 5000 system). Some manufacturers, such as Nikon and Wild Leitz, are already major participants in two segments, or, in the case of OSI, the company offers equipment in all three categories. Finally, several companies, such as KLA Instruments, Nanometrics, Hitachi, and Vickers Instruments, offer e-beam-based as well as optical CD measurement equipment in order to provide linewidth measurement capability that encompasses the entire range of submicron processing.

Table 14 presents historical worldwide sales for companies participating in the optical CD, wafer inspection, and joint CD/inspection equipment markets from 1982 through 1987. Dataquest believes that Table 14 provides an interesting perspective of company and product developments and indicates those companies that are well positioned for future market growth.

Table 14

Worldwide Market Share
Optical CD Equipment, Wafer Inspection Stations, and Joint CD/Inspection Systems, 1982-1987
(Millions of Dollars)

Company	1982	1983	1984	1985	1986	1987	1987 % Share
Canon	$ 0.8	$ 1.3	$ 2.0	$ 1.3	$ 1.4	$ 2.0	2.1%
Estek (Aeronca)	0	0	0	0.3	0.2	0.1	0.1
Heidelberg Instruments	0	0	0	0	0	1.6	1.7
Hitachi	0	0	0	0	4.1	6.0	6.4
Insystems	0	0	0	0	0	2.1	2.3
IVS, Inc.	0	0	0	0	0.5	1.5	1.6
KLA Instruments	0	0	0	11.2	18.1	27.6	29.4
Nanometrics	4.0	7.0	6.7	2.3	1.5	1.7	1.8
Nidek	1.3	1.7	2.0	1.7	2.2	3.1	3.3
Nikon	3.2	5.6	10.5	7.4	8.7	13.3	14.2
Optical Specialties, Inc.	5.3	6.8	15.6	10.0	7.2	5.3	5.6
Reichert-McBain	0	0	0	0	3.0	0.3	0.3
Ryokosha	1.1	1.6	2.2	1.4	1.5	1.4	1.5
SiSCAN Systems	0	0	0	0	1.9	3.0	3.2
Karl Suss	0.1	0.2	0.2	0	0	0	0
Vickers Instruments	0	0	0	0	0	8.3	8.8
Wild Leitz	2.2	5.1	8.7	9.1	8.3	6.4	6.8
Zeiss	0	0	0	0.9	2.4	1.8	1.9
Others	6.9	10.7	14.9	8.8	9.7	8.4	9.0
Total	$24.9	$40.0	$62.8	$54.4	$70.7	$94.0	100.0%
Growth		61%	57%	(13%)	30%	33%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

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CD and Wafer Inspection Equipment Markets

In 1987, the three leaders in the combined market of optical CD, wafer inspection, and joint CD/inspection systems were KLA Instruments, Nikon, and Vickers Instruments. They had a combined market share of 52.4 percent of the $94.0 million market. These three players, each headquartered in a different region of the world, have strength and breadth in a variety of areas. KLA Instruments, of the United States, is very strong in the joint CD/inspection systems market and recently introduced systems for automatic wafer inspection as well as automatic optical and e-beam CD measurement. In addition, KLA is the world's largest supplier of mask inspection systems to the semiconductor industry. Nikon, of Japan, has had a strong and consistent presence in the optical CD and wafer inspection equipment markets since the early 1980s and is also a major manufacturer of wafer steppers. Vickers Instruments, of the United Kingdom, ranked first in market share in the world optical CD equipment category in 1987. In addition to offering optical CD, Vickers offers a SEM-based CD measurement system for the semiconductor production environment.

While KLA Instruments, Nikon, and Vickers performed well in 1987, an additional 15 equipment companies competed for approximately 38.6 percent of the $94.0 million market. As new technologies and products are developed and new companies enter the marketplace, the optical CD, wafer inspection, and joint CD/inspection equipment markets will continue to be highly competitive segments within the semiconductor equipment industry.

Regional Markets

Table 15 presents the historical market for optical CD, wafer inspection, and joint CD/inspection systems by regional consumption. In 1987, Japan and the United States accounted for almost equal share of the $94.0 million market, with 39.3 percent and 38.5 percent, respectively. Europe ranked third with 14.9 percent, while the ROW represented 7.3 percent of the world market.

Table 15

Regional Markets
Optical CD Equipment, Wafer Inspection Stations, and Joint CD/Inspection Systems, 1982-1987
(Millions of Dollars)

Region	1982	1983	1984	1985	1986	1987	CAGR 1983-1987
United States	$12.3	$20.1	$33.5	$23.9	$29.3	$36.2	24.1%
Japan	8.8	13.4	19.8	17.5	26.2	36.9	33.2%
Europe	3.0	5.0	7.0	9.1	10.6	14.0	36.1%
ROW	0.8	1.5	2.4	3.9	4.6	6.9	53.9%
Total	$24.9	$40.0	$62.8	$54.4	$70.7	$94.0	30.5%
Growth		61%	57%	(13%)	30%	33%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

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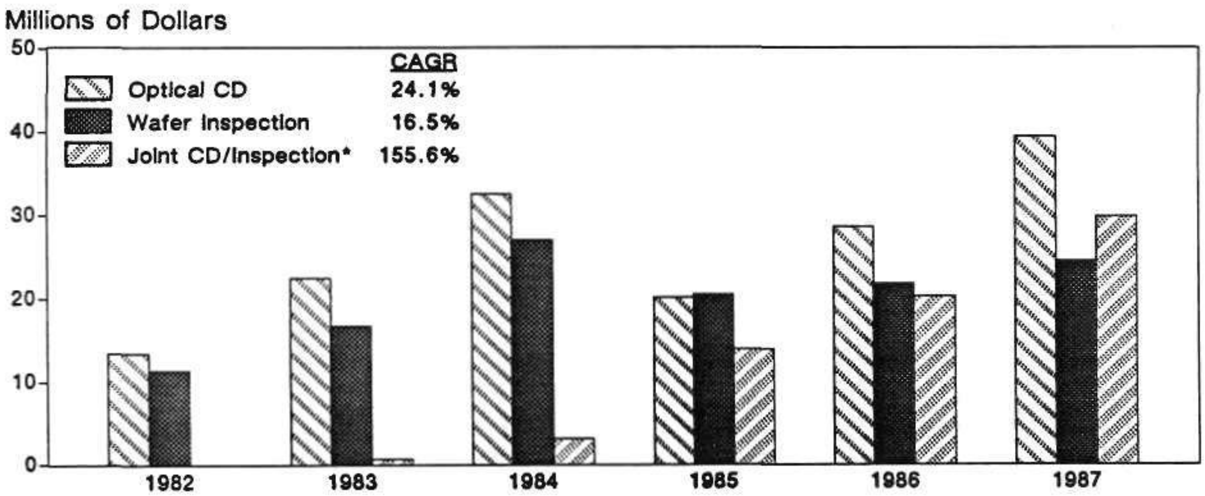
CD and Wafer Inspection Equipment Markets

Figure 5 presents a summary of the worldwide markets for optical CD equipment, wafer inspection stations, and joint CD/inspection systems for 1982 through 1987 (see Table 1 for tabulated data). As illustrated in Figure 5, the compound annual growth rate (CAGR) for the optical CD equipment and wafer inspection markets were 24.1 percent and 16.5 percent, respectively. The newly emerging market segment of joint CD/inspection equipment enjoyed a healthy 155.6 percent CAGR between 1983 and 1987. Overall, the combined market segments grew from $24.9 million in 1982 to $94.0 million in 1987 at a CAGR of 30.5 percent.

Figure 5

Worldwide Optical CD Equipment, Wafer Inspection Stations, and Joint CD/Inspection Systems Market, 1982–1987 (Millions of Dollars)



*CAGR for Joint CD/Inspection systems is from 1983 through 1987.

Source: Dataquest
March 1988

FORECAST

Table 16 presents Dataquest's forecast for the markets of optical CD equipment, wafer inspection stations, and joint CD/inspection systems from 1988 through 1992. Sales of optical CD equipment, wafer inspection stations, and joint CD/inspection systems are expected to reach $325 million in 1992. In particular, the emerging market for joint CD/inspection systems is anticipated to experience strong growth at a CAGR of 32.5 percent, reflecting a trend in the industry for multiple functionality and integrated applications on a single piece of capital equipment.

CD and Wafer Inspection Equipment Markets

Table 16

Forecast
Optical CD Equipment, Wafer Inspection Stations, and Joint CD/Inspection Systems, 1988–1992
(Millions of Dollars)

	Actual 1987	1988	1989	1990	1991	1992	CAGR 1987-1992
Optical CD Equipment	$39.5	$ 53	$ 61	$ 77	$ 99	$127	26.3%
Wafer Inspection Stations	24.5	36	41	50	62	76	25.4%
Joint CD/Inspection Systems	29.9	42	51	67	90	122	32.5%
Total	$94.0	$131	$153	$194	$251	$325	28.2%
Growth		39%	17%	27%	29%	29%	

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
March 1988

The optical CD equipment market is forecast to grow at a 26.3 percent CAGR. This will be driven by the acceptance of new technologies for submicron measurement. At this time, however, no measurement technology has emerged as a clear leader. Over the next several years, SEM-based CD tools for the production environment will also emerge as significant competition for optical systems in the submicron measurement range.

Wafer inspection stations are expected to experience growth of 25.4 percent, or sales of $76 million in 1992. Within the category of wafer inspection stations, Dataquest expects most of the growth to come from advanced image-processing systems that rely on software algorithms or technology-based defect detection. In many cases, this capability, combined with critical dimension measurement, will be available in a joint CD/inspection system.

Market growth in each of the three equipment categories will be driven by the need for automated measurement and inspection tools for the sub-1.5-micron production environment, since sub-1.5-micron processing represents the major thrust in new fab capacity and IC production over the next five years. In a recent analysis, Dataquest concluded that 20 percent of silicon square inches consumed in the United States in 1992 will be used in sub-1.0-micron production, while an additional 37 percent of silicon will be used in production of devices with geometries greater than 1.0 micron but less than 1.5 microns. (These percentages of silicon square inches for sub-1.5-micron processing translate to 49 percent of silicon wafer starts.) While this analysis considers semiconductor production only in the United States, we believe that the figure of 57 percent of silicon square inches for sub-1.5-micron processing will be indicative of semiconductor processing in all regions of the world.

Dataquest believes that market growth for optical CD equipment, wafer inspection stations, and joint CD/inspection systems will be the result of equipment that incorporates the following:

- New technology implementations for submicron measurement
- Advanced image-processing algorithms for defect detection and classification
- Fully automated equipment operation for the production environment

These three factors will contribute to a continuing trend toward higher ASPs for equipment in the future, since equipment with increasing levels of sophistication carries a correspondingly higher price tag. In general, semiconductor manufacturers would prefer to minimize the amount of measurement and inspection of wafers during the fabrication process, since each additional task lengthens the cycle time and may, in itself, expose the wafer to additional contamination. CD measurement and wafer inspection systems, however, will not disappear altogether, since these tools provide vital information for monitoring process control in the production environment. While a reduction in measurement and inspection operations may impact overall unit demand, Dataquest expects the CD measurement and wafer inspection equipment markets to continue to experience healthy growth in the years to come.

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Ion Implantation Equipment

OVERVIEW

Ion implantation has rapidly become one of the most important steps in the processing of semiconductor devices. This technology has arisen to satisfy the requirements for better control of device electrical characteristics and for better yields as device geometries have decreased to below 2 microns. For this report, Dataquest segments the ion implant market into three segments: medium-current implanters, high-current implanters, and high-voltage implanters.

In 1985, the market for medium-current implanters was $132 million. Of this, North American semiconductor manufacturers purchased $36 million, the Japanese purchased $72 million, Europeans purchased $16 million, and rest of world (ROW) companies purchased $8 million. Included in the sales for Japanese manufacturers are systems manufactured by TEL-Varian in Japan.

In 1985, the market for high-current implanters was $119 million. Of this, North American semiconductor manufacturers purchased $45 million, Japanese manufacturers purchased $49 million, European companies purchased $20 million, and ROW companies purchased $5 million. The sales numbers for Japanese manufacturers include sales by TEL-Varian and Sumitomo-Eaton.

The total worldwide consumption of medium- and high-current ion implanters in 1985 was $251 million, which represented a 19 percent decline from $309 million in 1984. Consumption in North America was $81 million, which was down 34 percent from $123 million in 1984. Consumption in Japan was $121 million, which was down 14 percent from $140 million in 1984. Consumption in Europe was $36 million, which was flat with 1984 consumption. Consumption in ROW countries was $13 million, which was 30 percent higher than 1983's $10 million.

The 1985 market share of the U.S.-based medium- and high-current system manufacturers accounted for 81 percent of the world market, roughly equal to 82 percent of the previous year. Japanese vendors had the rest of the world share. U.S. manufacturers lost share slightly in high-current markets and gained share slightly in medium-current markets.

Dataquest expects the worldwide medium- and high-current market to fall to $190 million in 1986. This represents a 24 percent decline from 1985. This decline will be the second year of negative growth for this equipment segment specifically and for capital spending in general. The ion implant segment has been hit particularly hard in this recession. Semiconductor manufacturers are burdened with greater than 50 percent overcapacity in several device segments. While in the past manufacturers were reluctant to implant several species on one implanter, preferring to dedicate implanters to processes, they have chosen to share implanters between processes and device types during this recession. Worldwide medium- and high-current implanter sales are expected to increase 32 percent in 1987 to $250 million.

TECHNOLOGY

Ion implantation is a method of introducing doping impurities into semiconductor materials. This technology has arisen in response to the need for precision and uniformity in both the amount of dopant and the doping geometries. Ion implantation is an alternative for diffusion doping, which is done in diffusion furnaces.

History

Ion implantation is an example of the application of an existing technology to semiconductor processing. The entrepreneurs who started this technology came out of various particle accelerator laboratories that were doing research in atomic physics at that time.

The first commercial ion implanter was produced by Accelerators, Incorporated (AI), in 1968. However, High Voltage Engineering, Inc. (HVE), had already established a five-year contract, beginning in 1965, with Corning Glass Company to provide ion implanters to Corning's Signetics subsidiary. During the late 1960s and early 1970s, commercial implanters were produced by HVE, Lintott Engineering, and Ortec.

Since its early formation, there have been considerable changes in the market structure. Table 1 gives a brief history of some of the significant events in this marketplace. In 1970, GCA acquired Ortec and, subsequently, abandoned the business in 1981. In 1971, some of the technologists at HVE left to form Extrion, which was subsequently bought by Varian in 1975. In 1978, some of the founders of Extrion left to form Nova with financial support from Cutler-Hammer. Eaton subsequently acquired Cutler-Hammer and has absorbed Nova under the Eaton logo. In 1980, Lintott was bought by Applied Materials. Applied Materials suspended production in 1983 in order to develop a new product for introduction in 1985. In 1980, Veeco bought AI. Throughout this period, several Japanese companies were developing their implant technology, and they now have a healthy share of the Japanese market.

Table 1

BRIEF CHRONOLOGY OF ION IMPLANTERS

1968	Accelerators, Incorporated (AI), was founded. It manufactured low-current postacceleration 80-400 KeV equipment.
1970	Ortec manufactured 200 KeV preacceleration equipment. Lintott (United Kingdom) used mass separator as a high-current ion implanter.
	GCA acquired the Ortec implanter operation.
1971	Extrion was founded by a group from High Voltage Engineering and funded by Glouchester Engineering. It manufactured low-current, 150, 200, and 400 KeV preacceleration equipment.
1974	Extrion manufactured a 100 KeV, dedicated implanter.
	Eltek was started by a group from AI to manufacture 100 KeV, dedicated implanters.
1975	Varian acquired Extrion.
	Cutler-Hammer acquired Eltek and made it part of Kasper.
	Extrion manufactured a medium-current, 200 KeV implanter.
	Extrion manufactured a high-current, 200 KeV implanter.
	Kasper manufactured a low-current, 200 KeV implanter.
1977	AI manufactured a medium-current preacceleration, 200 KeV implanter.
	Lintott manufactured a high-current, 200 KeV implanter.
1978	Nova was founded by a group from Extrion and funded by Cutler-Hammer. Eaton acquired Cutler-Hammer.
1980	Veeco acquired AI.
	Eaton/Nova manufactured a very high-current, 80 KeV implanter (pre-dep).

(Continued)

Table 1 (Continued)

BRIEF CHRONOLOGY OF ION IMPLANTERS

1980	Applied Materials acquired Lintott and named the new company, Applied Implant Technology (AIT).
	Extrion manufactured a very high-current, 80 KeV implanter (pre-dep).
1981	Extrion manufactured a very high-current, 120 KeV implanter (pre-dep).
	AIT manufactured a very high-current, 120 KeV implanter (pre-dep).
	GCA discontinued manufacturing implanters.
1982	AIT discontinued manufacturing operations to place efforts on a next-generation product.
1983	Eaton/Nova manufactured a very high-current, 160 KeV implanter (pre-dep).
1984	Veeco introduced a very high-current, 120 KeV implanter (pre-dep).
1985	Applied Materials introduced its Precision Implant 9000 with capability for 30 milliamps of beam current.
1986	Eaton and Varian introduced their new-generation high-current systems with capability for 20 milliamps of beam current.

Source: Sini Systems
Dataquest
December 1986

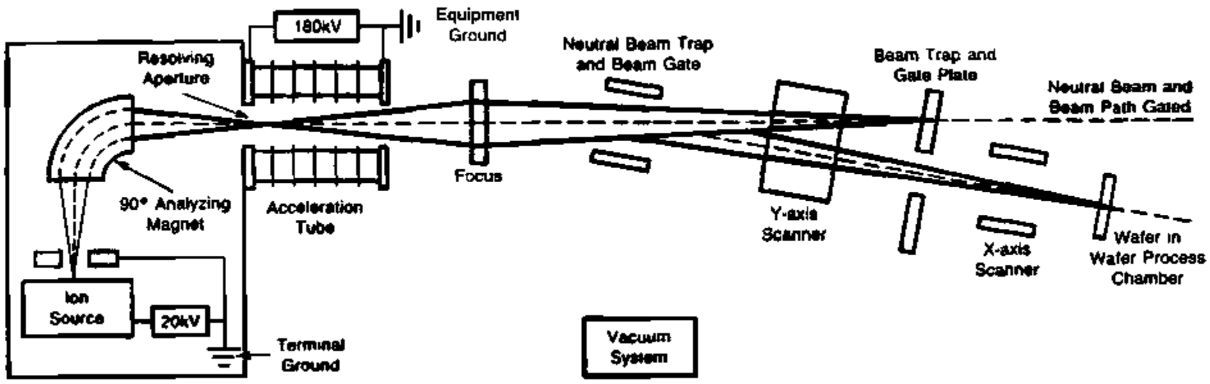
Machine Configuration

Figure 1 illustrates the basic configuration of an ion implanter. The basic elements are the source, the extractor, the analyzer magnet, the accelerator column, the scanning mechanism, the end station, and the monitoring instrumentation. In addition, implanters require a vacuum system to maintain a very high vacuum. The following section describes the basic operation.

Ion Implantation Equipment

Figure 1

TYPICAL ION IMPLANTER CONFIGURATION



Source: Semiconductor Integrated Circuit Techniques
Fairchild Corporation

Theory of Operation

The physical theories involved in ion implantation include the creation of charged particles, the acceleration of those charged species (ions) through an electrostatic field, and the uniform distribution of those ions over the target (usually silicon or gallium arsenide wafers). In order to create an unimpeded beam, a very high vacuum is required. Most ion implanters have several vacuum pumps situated along the beam line to achieve vacuums of 10^{-5} Torr and lower.

The species of choice is produced in the source, extracted, and preaccelerated toward the analyzer magnet. Since a given process requires a specific species with a predetermined charge, the analyzer magnet current is set to choose this ion. The magnetic current, and thus the magnetic field, will cause the ion with the correct charge-to-mass ratio to traverse the magnet with the correct trajectory in order to emerge from the other end of the magnet. Ions with improper charge-to-mass ratios will have improper curvatures and, thus, will be lost on the walls of the magnet.

After emerging from the analyzer magnet, the ion beam is post-accelerated toward the wafer. Some configurations vary from system to system, such as the use of focusing plates, scanning plates, beam gates, and neutral beam traps. These will be discussed in the following sections.

Ion Implantation Equipment

The ion beam, which comprises ions with the proper charge and energy, is scanned across the wafer, implanting the ions into the substrate at the required depth. These ions become the dopant that will give the semiconductor device the proper electrical characteristics. However, the ions do not occupy crystal lattice sites immediately after implantation. They must be activated by the annealing of the wafer. Typical annealing is at 1000°C for 30 minutes. However, recent developments in equipment such as rapid thermal processors are allowing annealing to be done in approximately 10 seconds. Annealing also repairs the damage to the crystal lattice that was caused by the beam.

Sources

There are three types of sources used in ion implantation--solid, liquid, and gaseous. Dataquest estimates that approximately 67 percent of the installed implanters use a gas source. High-current implanters (which will be discussed later) almost exclusively use the solid type. Liquid sources are not used in any commercially available production ion implanter so they are not discussed here.

Solid Sources

The most widely used solid source is the Freeman Source. The basic mechanism is the sublimation of the solid dopant--which may be in the form of pellets, lumps, or pressed charges--into vapor. The sublimation takes place at pressures of 10^{-5} to 10^{-6} Torr and depends on the vapor pressure of the solid dopant. This vapor is passed over a tungsten filament at 3000°C to 4000°C to create a plasma discharge. The ions from the plasma are then electrostatically extracted into the beam line. Historically, all dopants except boron, which has a low vapor pressure, were available in solid form. Recently, boron has also become available in solid form.

The advantages of solid dopants are safety, purity, and beam stability. Since they are not under pressure, there is less potential for them to leak into the atmosphere. Also, since gases come in metal containers, any residual water vapor in these containers, when combined with the dopants, can eventually cause corrosion of the source and beam line components. Solid sources obviate this problem. In addition, the presence of water vapor in the gas bottles can cause variations in the beam current. This type of variation is not present with solid sources.

Gas Sources

The use of gas sources is the most widespread and the best understood. The most widely used gas source is the Penning Diode. In this application, gas is introduced into the source chamber where a tungsten filament creates a plasma discharge. The plasma ions are then extracted into the beam line. All dopants are available in gaseous form.

The problems with beam line corrosion and current stability can be reduced by careful choice of the gas vendor, since refilling procedures can introduce impurities and water vapor into the bottles. However, there is growing concern in the semiconductor industry about the handling of hazardous materials. Although great care is taken to minimize danger to personnel in the event of a gas leak, Dataquest believes that there will be a steady shift to the use of all solid sources.

Beam Line

The beam line can have various configurations. Starting with the extractor, the beam can be preaccelerated or not. The extractor can provide adequate acceleration prior to the analyzer magnet. If the beam is preaccelerated, it is not usually postaccelerated. After acceleration, the beam may go through vertical and horizontal focusing plates. In most cases, the analyzing magnet provides beam focusing.

The next component is the scanning plates that are used in beam scanning and hybrid scanning methods, which will be discussed later. The scanning plates may be electrostatic or electromagnetic. By varying the electrical power to these plates, the ion beam is scanned across the wafer, depositing the beam uniformly.

It is at the scanning plates that a neutral offset can be added to the beam. To create the offset, the vertical or horizontal scanning plates bend the ion beam so that neutral particles continue straight ahead and miss the wafer. Such an offset is required to trap the neutral (uncharged) particles from the beam. These particles are produced when an ion collides with a residual gas molecule. Such collisions occur quite often and can account for 1 percent of the total ions in the beam. The new particles formed as a result of collisions will have nearly full energy but no charge. Since these uncharged particles would not be affected by a scanning mechanism, they would cause a nonuniformity at the center of the wafer as the other 99 percent of the beam scans across the wafer. The nonuniformity could be 10 to 100 percent, depending on the type of scanning method used.

The beam then goes through a beam aperture. The aperture helps eliminate unwanted particles from impinging on the wafer. These particles could be created by collisions with air molecules or with the hardware in the beam line. The aperture also shields the wafer from unwanted magnetic and electrostatic fields.

Scanning

We will discuss three types of beam scanning in this section; beam scanning (also known as x-y scan or electrostatic scan), hybrid scanning, and wafer scanning (also known as mechanical scan). Table 2 lists the types of scanning used in the major ion implanters in use today.

Table 2

SCANNING METHODS

Machine	Machine Type	Scan Type
AIT-IIIA	High	Hybrid
Nova NV-10 series	High	Wafer
Extrion 80-10	High	Hybrid
Extrion 120-10	High	Hybrid
Extrion 160-10	High	Hybrid
Extrion DF-3000	Medium	Beam
Extrion 350D	Medium	Beam
Eaton NV-3206	Medium	Beam
Applied Materials 9000	High	Wafer

Source: Solid State Technology
February 1985
Dataquest
December 1986

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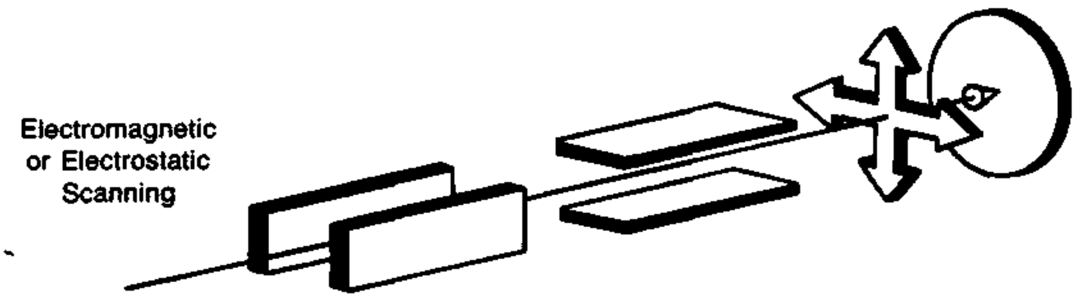
Ion Implantation Equipment

Beam Scanning

In the beam scan, the wafer is kept stationary and the beam is swept in vertical and horizontal planes by the electrostatic or electromagnet scanning plates, writing a single wafer at a time. This configuration is illustrated in Figure 2. Since the energy deposited on the wafer will heat the wafer, this approach is suitable for medium-current systems where wafer heating can be maintained to within acceptable levels. For high-current applications, in order to maintain photoresist on the wafer below critical temperatures (nominally 100°C), the beam energy must be spread over many wafers in a batch. For this reason, beam scanning is not used in high-current applications, and manufacturers have resorted to hybrid and mechanical scanning to spread the beam energy over the wafer in the batch.

Figure 2

BEAM SCANNING



Source: Yield Assurance Seminar
Prometrix Corporation 1984
Wayne O'Neill, Sini Systems

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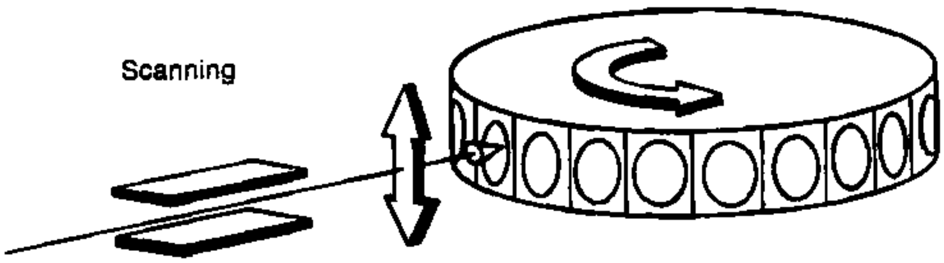
Hybrid Scanning

In hybrid scanning, the wafers are loaded onto a rotating drum or wheel. This is illustrated in Figure 3. The drum rotates rapidly moving the wafers across the beam path. As the drum or wheel rotates in one direction, the beam is scanned in the other, thus doping the whole wafer. Since the beam is scanned in both beam and hybrid scanning methods, neutrals will become a problem with respect to uniformity. It is for this reason that these two approaches use neutral beam traps as described above. Hybrid scanning enjoys the advantage of distributing the beam over a batch of wafers, thus allowing higher currents and energies to be used in implantation.

Figure 3

HYBRID SCANNING



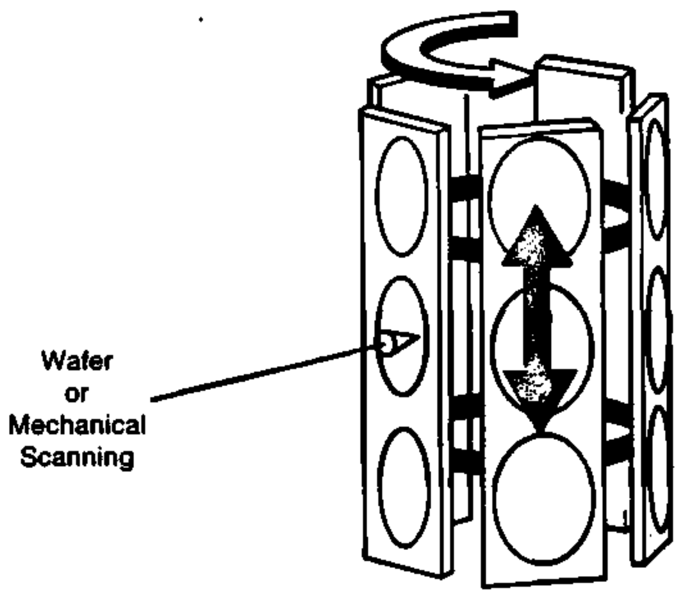
Source: Yield Assurance Seminar
Prometrix Corporation 1984
Wayne O'Neill, Sini Systems

Wafer Scanning

In wafer scanning, the wafers are also located on a rapidly spinning wheel or drum. This arrangement is illustrated in Figure 4. As the wheel or drum spins in one direction, it is also moved up and down to ensure that the entire wafer is covered with the beam. Since the beam is not scanned, this approach does not require the addition of a neutral beam trap. It also enjoys the advantage of distributing the beam over a batch of wafers, thus allowing higher currents and energies to be used in implantation.

Figure 4

WAFER SCANNING



Source: Yield Assurance Seminar
Prometrix Corporation 1984
Wayne O'Neill, Sini Systems

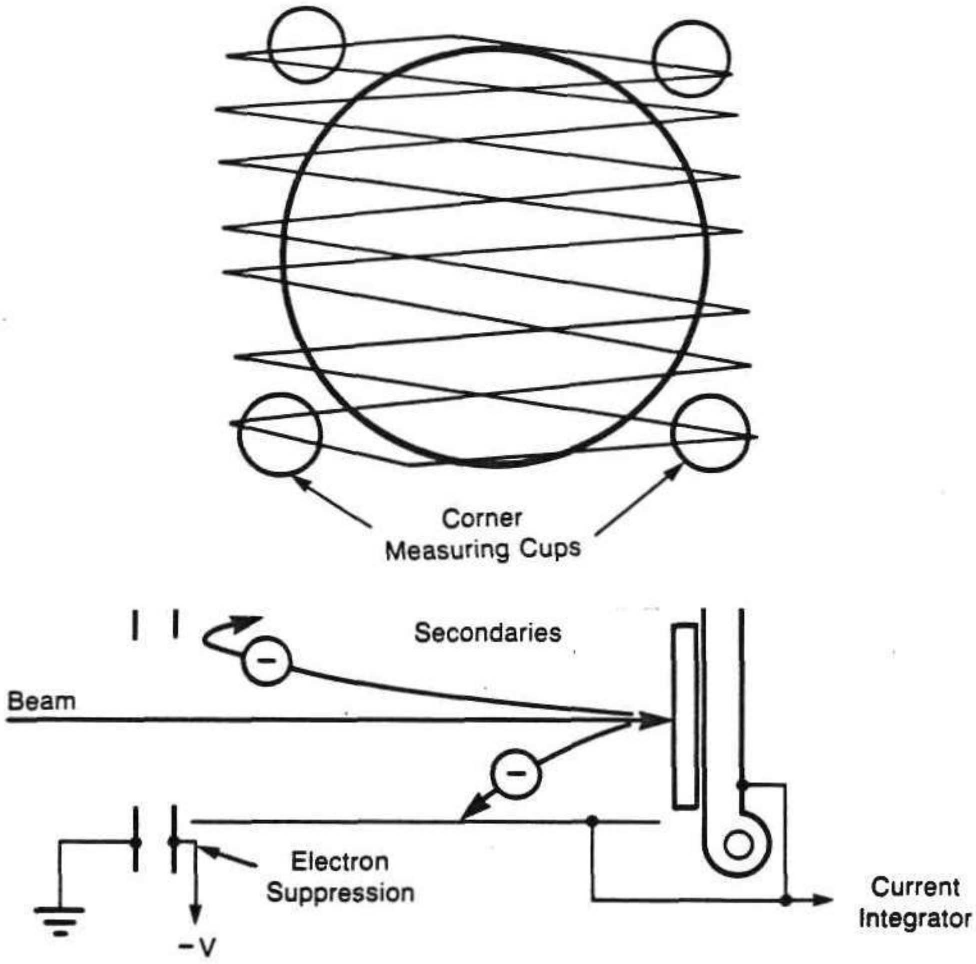
Monitoring and Control

The uniformity of dose across the wafer is a critical factor in the monitoring and control of the beam. The method used for monitoring the beam is the faraday cup, a current-collecting electrode that is situated in various configurations in the beam, depending on the monitoring requirements.

In the electrostatic scan systems, faraday cups are placed to measure the amount of over-travel of the beam. This arrangement is illustrated in Figure 5. The amount of over-scan is critical for dose uniformity.

Figure 5

FARADAY CUP



Source: Yield Assurance Seminar
Prometrix Corporation 1984
Wayne O'Neill, Sini Systems

In hybrid and wafer scan systems, a slit in the carousel or wheel respectively allows the beam to fall on a faraday cup behind the carousel or wheel on each revolution. This gives a measure of the amount of current per revolution. In the wafer scan systems, this signal is used to index the wheel up or down. Such indexing is necessary to compensate for differing radial velocities from center to periphery across the wheel.

For wafers with insulating films, large surface charges can accumulate during implantation. These charges can damage devices on the wafer and can cause variations in the beam diameter, contributing to severe nonuniformities. To alleviate this effect, electron flooding, the injection of low-energy electrons near the wafer, is used to neutralize the build-up of positive charge on the wafer surface. Electron flooding must be done in such a way as to not affect the dosimetry.

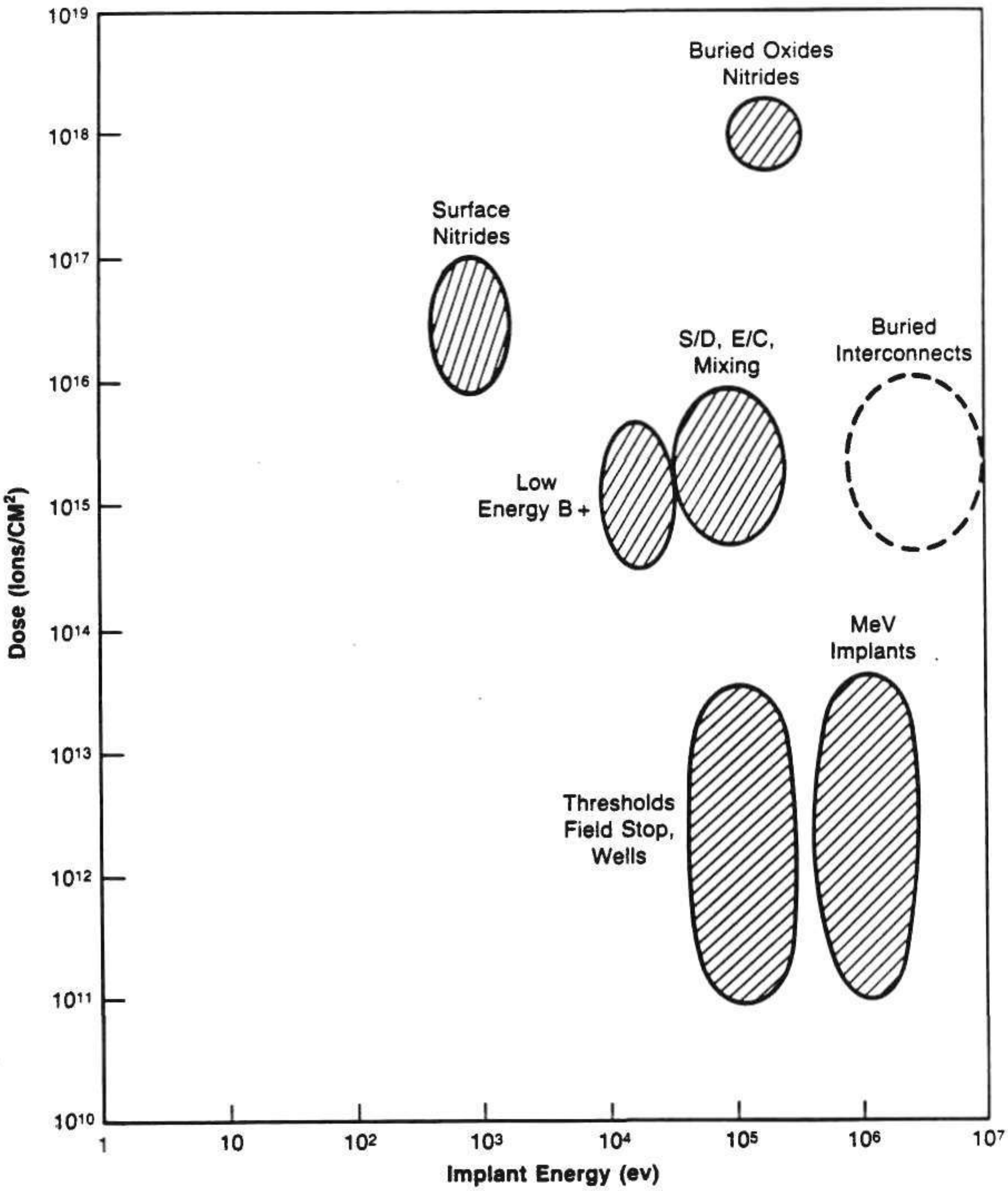
PROCESS

Ion implantation has grown as an alternative to diffusion. Diffusion is done in furnace tubes and consists of pre-deposition (pre-dep) and drive-in. In pre-dep, the dopant is deposited on the wafer surface. These pre-dep wafers are placed into the furnace for the drive-in process. At drive-in, the furnace temperature is raised to 1000 to 1200°C for one to two hours, depending on the required diffusion depth. Diffusion of the dopant occurs isotropically into the wafer, and will penetrate to regions beneath masked areas on the wafer. Because of this out-diffusion and the concomitant lack of control of junctions, the use of diffusion tubes for VLSI integrated circuit production is becoming inadequate. Ion implantation is preferred over diffusion because of better control of dopant distribution, superior uniformity, and better precision in controlling the actual dosage.

Since the advent of implantation for semiconductor manufacturing, processing has evolved along with system design. As different process requirements have unfolded, the current and voltage capability of implanters have changed to meet them. The success of MOS processing with its requirements for source/drain doping has been made feasible with the development of high-current implanters. Semiconductor manufacturers continue to find new implanter applications for their production processes. Figure 6 illustrates the regions of processing with respect to dose and energy.

Figure 6

PROCESS APPLICATIONS



Source: ASEE Seminar, 1985
Dipu Pramanic, Gould/AMI

Ion Implantation Equipment

Bipolar Processing

A typical bipolar device with the concomitant processes is shown in Figure 7. Since bipolar devices cannot be packed as densely as MOS devices, the line geometries are not as small. Therefore, junction dimensions are not as critical and the use of diffusion still prevails. However, the use of implant has accelerated in recent years and the number of implant steps has increased to an average of six per wafer.

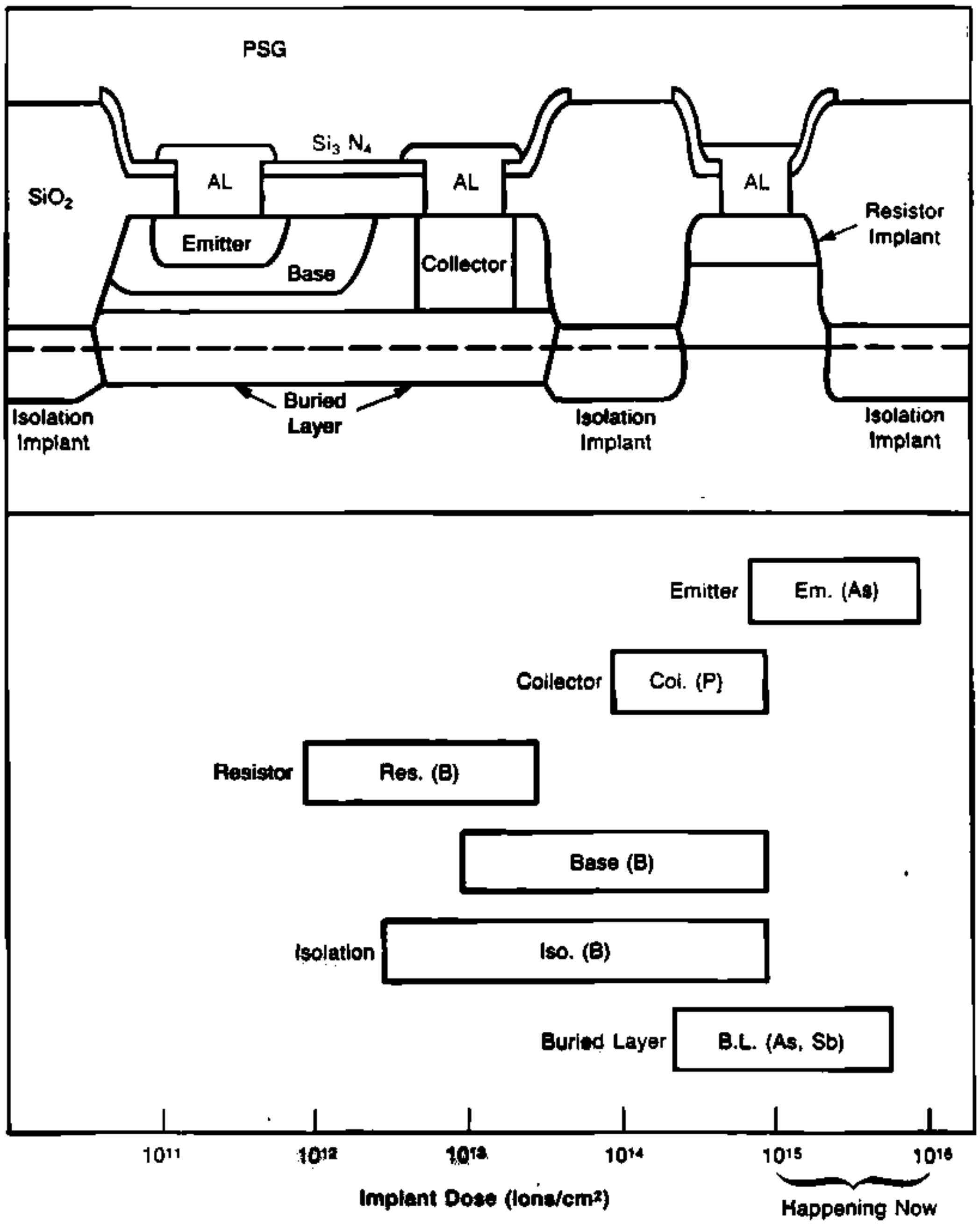
Historically, ion implant energies were not adequate to penetrate to the depths required for bipolar processing. As line geometries and junction depths decreased, they became amenable to implantation, which has also increased the average number of implants per wafer.

Medium-current implanters can be used economically for doses of less than 10^{14} ions per cm^2. At higher doses, the throughput of the implanter becomes too low to be cost-effective. For this reason, emitters, collectors, and buried collectors were universally done in diffusion furnaces. With the advent of high-current implanters, these structures are routinely done by implantation.

Since high-current implanters are also capable of medium-current applications, their application reaches into regions held by medium-current systems (i.e., for bases, isolation, and resistors). This utility also applies to MOS processing, which helps to explain the greater growth in sales for high-current than for medium-current implanters.

Figure 7

BIPOLAR PROCESSING



Source: Integrated Circuit Technologies for the 1980s, K.A. Pickar Signetics, February 1982

Implanted Resistors

Diffused resistors generally have poor tolerances and, since ion implantation controls impurities precisely, implants improve resistor tolerances. Ion implantation at low doses also may be used to create high-resistance, low-power resistors.

Phantom-Layer Deposition

Phantom-layer deposition is a backside implant that lowers high-starting resistivity and may be used to ensure good backside ohmic contact. It also eliminates the possibility that a manufacturer will create a diode on the backside of the silicon in the process of soldering the devices. This creation of a diode occurs because the material used in soldering is itself a dopant.

Buried-Layer Implant

Bipolar devices commonly use a buried layer, or highly doped layer, and then grow an epitaxial layer over it. The buried layer makes it possible to maintain a low-collector resistivity without degrading the breakdown voltage. The impurity types and profiles that are possible with ion implantation may help to reduce the auto-doping problem as well.

Base and Emitter Predepositions

Manufacturers use ion implantation to implant bases at 10^{13} ions/cm^2 to 10^{15} ions/cm^2 and emitters at 10^{15} ions/cm^2 to 10^{16} ions/cm^2 on critical-geometry bipolar devices.

Backside Gettering

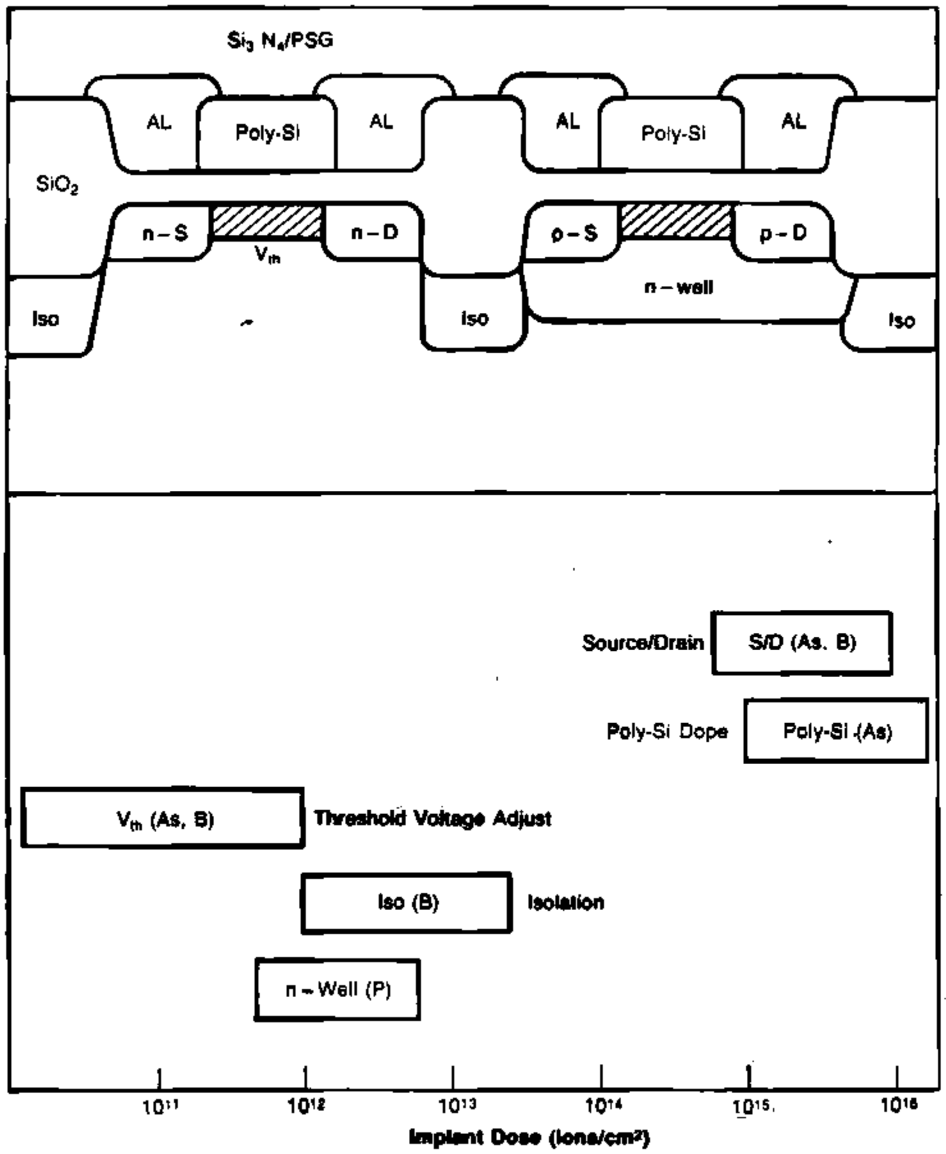
Manufacturers typically implant Argon ions at 10^{13} ions/cm^2 to 10^{15} ions/cm^2 into the backside of the wafer. The damage caused to the lattice by the ions provide gettering sites for the capture of metallic impurities in the substrate. Such impurities degrade the devices and lower the probe yields on the wafer.

MOS Processing

Figure 8 shows a typical MOS device (in this case, CMOS) with the concomitant energy/dose regions. Originally, implant was used universally for the threshold adjust and also had some usage in N-well and isolation doping. With the increased packing densities for MOS devices, requirements for implant extended into the source/drain and polysilicon doping applications. These high-dose applications require higher currents and are largely responsible for the rapid growth of high-current implanters. The evolution of MOS technology has been made possible by the pacing developments in implant systems.

Figure 8

MOS PROCESSING



Source: Integrated Circuit Technologies for the 1980s, K.A. Pickar Signetics, February 1982

Ion Implantation Equipment

MOS Threshold Adjustment

Short implants are used to control surface dopant concentrations and to adjust the threshold voltages of MOS devices. The more control a manufacturer has over the threshold of a device, the better the performance of the device. It is possible to have different thresholds for different transistors on the same chip. We observed one process that includes five threshold adjustments: two on the depletion device, two on the enhancement device, and one field threshold adjustment. Threshold adjustment was not possible before the advent of ion implantation.

Capacitor Implant

Some manufacturers apparently improve the performance of MOS devices by using an implant through the oxide of capacitors. The thinner the oxide, the larger the capacitance, and ion implantation helps the manufacturer achieve a high threshold and a high surface concentration.

Source and Drain Implant

Source and drain implant as a substitute for furnace predeposition on small-geometry, MOS devices is currently a very popular process. Manufacturers use 50 to 100 KeV energies at surface doses of 10^{15} ions/cm^2 to 10^{16} ions/cm^2.

P-Well in CMOS Devices

The P-well is implanted in N-type silicon to permit the fabrication of N-channel and P-channel devices on the same substrate. There are other variations on this application such as N-wells in P-type silicon and twin-tub implantations.

Emerging Applications

Semiconductor manufacturers are continually finding new applications for ion implantation. These new uses are first characterized in their labs and pilot lines and then transferred into production. The applications listed below are in various stages of acceptance in production processing.

ROM Programming

Vendors of application-specific ICs (ASICs) compete on the basis of delivery. For read-only memories, the codes are set early in the processing cycle by adjusting threshold voltage, formation of gates, or formation of through-hole contacts. Therefore, delivery time is limited to the total process cycle time, which is generally 6 to 10 weeks. With ion implantation, the ROM can be fabricated through the first metallization step as a standard device. Then, using a high-voltage implanter, the threshold voltages can be adjusted by implanting through the active regions of the device.

Using this method, vendors can provide devices in one to two days after receiving the programming codes from the buyer. This method also has the advantage of providing a very high-yielding ROM process up to metallization, thereby decreasing costs.

Buried N-grid for Soft Error Reduction

Soft errors are created in memory cells when ionizing radiation forms electron-hole pairs in the silicon substrate, after which these pairs migrate to the storage area in the cell. This effect can be circumvented by the creation of a buried grid 1 to 2 microns below the memory device. The buried grid will trap any mobile ions that have been created in the substrate and conduct them away through a biased contact.

The grid is formed in two steps using a high-voltage ion implanter. First, boron is implanted at 2 MeV through an oxide mask. A second step, after the oxide mask is removed, requires the implantation of phosphorous at the same energy level to create a compensated N-grid below the enhanced P-grid. The fabrication of the active device continues after the formation of the buried grid.

Buried Layer (CMOS Latch-up)

Much research and development is being directed toward solving the problem of latch-up in modern CMOS circuits. Latch-up occurs when the N-well and P-well regions in a CMOS device are close enough to form an n-p-n-p device structure. With this structure, a voltage pulse in the substrate can switch on the device, as in a silicon-controlled rectifier (SCR), and effectively short the power supply to ground. This destroys the device.

This effect can be minimized by biasing the substrate at some negative potential that would block the voltage excursion or by building the device on a lightly doped epitaxial layer over a highly doped buried layer. Using high-voltage implantation, latch-up can be prevented with a buried layer without the need for building an epitaxial layer.

In this case, first the N-well is created by the implantation and drive-in of phosphorus. The oxide mask is then removed, and a buried layer is created by implanting boron into the substrate 1.5- to 3-microns below the N-well. This implantation is done at 1 to 4 MeV at a dose of about 10^{13} ion/cm^2. This method obviates the out-diffusion of the buried layer into the epitaxial layer that occurs with the epitaxial method, affording much better control of the junction.

Ion Implantation Equipment

Retrograde Wells

In CMOS devices, a doped well, in which the dopant profile increases from a value on the surface to a peak value within the silicon, is called a retrograde well. This unique profile can provide a reduced susceptibility to latch-up. To achieve this profile, high-voltage implanters are used to deposit dopant at about 1.5 microns within the silicon surface. A typical implant would be boron at 1 MeV at a dose of 3×10^{12} ions/cm^2.

A marked advantage with this process is the reduced anneal time. The formation of a 2-micron deep well, with conventional pre-dep and drive-in, can require 40 hours of anneal at 1050° C. The anneal after high-voltage implantation requires only 30 minutes at the same temperature.

Annealing

Annealing accomplishes three purposes: it activates ions that have come to rest in silicon during ion implantation, it can drive-in dopant to the required depth for the formation of wells in MOS devices, and it heals defects or lattice damage caused by the ion implant process. Ions are activated when they occupy lattice sites and form bonds with the silicon atoms.

Furnace Annealing

The predominant method of activating the ions and healing the damaged regions is furnace annealing, which the industry discovered in 1972 nearly four years after the development of ion implantation. The method is not very precise, however, and can change the dopant profiles. Furnace annealing is also somewhat limited because it cannot correct the irreparable damage that is sometimes caused by high-dose ion implantation.

Pulse Annealing

To compensate for the limitations of furnace annealing, the industry is developing a new method of annealing called pulse annealing, which includes both laser and electron-beam annealing. Pulse annealing is designed to repair damage and activate ions in a more precise manner by striking the surface with some kind of energy pulse while avoiding thermal saturation.

Laser annealing consists of using a laser to produce a short-duration, high concentration of energy on the surface of the silicon wafer. Light hits the surface of the wafer for such a short period of time that it heats only a very thin layer on the surface. The advantages of laser annealing are that it may offer improved control over defect annealing and better dimensional tolerance control.

Laser annealing has its limitations, however. For example, the absorption of the laser energy depends on the index of refraction of silicon and the degree of reflection from the silicon surface. In addition, some observers believe that it is necessary to use a thermal anneal that reaches temperatures of 600 to 700°C to repair lattice damage; thus, laser annealing may cause strain defects in the crystal lattice because of its small, intense heat spot. Dataquest is not aware of any equipment suppliers that are actively pursuing laser annealing at this time.

Some equipment manufacturers have turned to the development of electron-beam annealing systems because of the disadvantages of laser annealing. Electron-beam annealing uses electrons rather than light to heat the silicon, but it too has limitations. Some observers believe that the industry does not know enough about the nature of damage created by ion implantation and its effect on devices to allow development of a new annealing technique at this time. Dataquest does not believe that the problems with pulse annealing technology are well enough understood to assess its potential as a production process.

Rapid Thermal Processing (RTP)

Annealing can be done in a rapid thermal processor where typical anneal times can range from 10 to 100 seconds. During this process, a thermally isolated wafer is bathed in a radiation field until the temperature is stabilized for uniform dopant activation. Anneal temperatures range from 800 to 1200°C. Because of the low time at temperature, the junction does not have time to migrate appreciably.

Manufacturers of RTP equipment report excellent dopant profiles and lattice repair characteristics on their equipment. It would seem that as VLSI processing approaches 1-micron geometries, RTP will be required to ensure adequate junction tolerances. However, these systems are still being evaluated in laboratories and pilot lines and have not found large-scale use in production. Dataquest believes that this technology will become the preferred method for annealing VLSI devices within the next few years.

Ion Implantation Equipment

MARKET ANALYSIS

The ion-implanter market may be segmented into three parts: medium-current implanters, high-current implanters, and a third segment, high-voltage implanters, which will not be included in the historic sales numbers in this report. We define these segments as follows: medium-current implanters have a beam current of less than two milliamps, although the current can be controlled down to 50 to 100 nanoamps; high-current machines have a beam current of greater than 2 milliamps; and high-voltage implanters have voltages greater than 200 KeV for singly charged ions. Although previous generations of high-current systems had capabilities of less than 15 milliamps, the latest generation has capability of from 20 to 30 milliamps. Table 3 presents Dataquest estimates of the world market for ion implanters since 1981.

Table 3

WORLDWIDE IMPLANTER SALES
(Millions of Dollars)

	1981	1982	1983	1984	1985	CAGR 1981-1985
North America						
Medium-Current	$36	$31	$38	$ 54	$ 36	
High-Current	14	24	34	69	45	
Total	$50	$55	$72	$123	$ 81	12.8%
Japan						
Medium-Current	$22	$27	$44	$ 67	$ 72	
High-Current	9	18	34	73	49	
Total	$31	$45	$78	$140	$121	40.6%

(Continued)

Table 3 (Continued)

WORLDWIDE IMPLANTER SALES
(Millions of Dollars)

	1981	1982	1983	1984	1985	CAGR 1981-1985
Europe						
Medium-Current	$1	$3	$12	$21	$16	
High-Current	4	4	8	15	20	
Total	$5	$7	$20	$36	$36	63.8%
ROW						
Medium-Current	N/A	N/A	$1	$ 4	$ 8	
High-Current	N/A	N/A	3	6	5	
Total	N/A	N/A	$4	$10	$13	N/A
Total Medium-Current	$59	$ 61	$ 95	$146	$132	22.3%
Total High-Current	27	46	79	163	119	44.9%
Total Implanter	$86	$107	$174	$309	$251	30.7%

N/A = Not Available

Source: Dataquest
December 1986

Ion Implanter Markets

Table 3 illustrates some important evolutions in the implanter market. First, since worldwide semiconductor shipments have grown at a 12.8 percent compound annual growth rate (CAGR) since 1981, the implanter market has grown much faster than the semiconductor market. Second, high-current systems have grown much faster than medium-current systems. And third, other world markets have grown faster than North American markets.

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Ion Implantation Equipment

Historic Implanter Market Growth

We would expect shipments of implanters to have grown much faster than the unit shipments of semiconductors, since the average number of applications per wafer has tripled in this same time period. However, several things have worked against this growth rate.

In the 1980 to 1985 period, the average yield at die probe increased from a world average of 45 percent to an average of 55 percent. This increase came about because of the concerted efforts of North American manufacturers to increase their yields in order to respond to the encroachment of Japanese chip vendors into worldwide markets. This increased yield would tend to raise the number of devices that could be processed per implanter.

In addition to probe yields, the productivity of implanters has grown phenomenally over this period. Although it is difficult to estimate the average productivity of implanters, since there are many different processes and types of systems, in 1980, typical throughputs were 150 wafers per hour for 10-second implants on medium-current systems. The same dose on a high-current system in 1985 could have yielded throughputs of over 300 wafers per hour. As we can see in Table 3, from 1981 unit shipments of high-current implanters have grown much faster than unit shipments of medium-current systems, and, since the average throughput has also increased, this would tend to raise the average number of devices processed per implanter.

Concomitant with throughput, the reliability and maintainability of implanters has increased. Both the throughput and reliability improvements are reflected in the steady increase in ASPs. In 1980, semiconductor manufacturers usually had a technician dedicated to an implanter. In many cases, this dedicated person was an engineer or had a Ph.D degree. Each system required continual tweeking, frequent restarts, and periodic maintenance. In addition, the procedure for changing species, energy, and dose was difficult. This situation has greatly improved since that time. For some systems, system start up is totally automatic. Changes in species, energy, and dose are also automatic. The operating system is now handled by a microprocessor so that a technician can handle the rudimentary tasks of routine production. Dataquest estimates that the average utilization of an implanter was about 10 percent in 1980 and increased to about 30 percent in 1985. We believe that this low utilization was responsible for the poor performance of this market with respect to other equipment markets during this recession. Dataquest's fabrication data base indicates that the average number of wafers processed on installed implant systems during 1985 was between 4,000 and 5,000 wafers per month.

Ion Implantation Equipment

Installed Base

Table 4 gives Dataquest's estimates of installed ion implanters by region. As the table shows, North America has 48 percent of the operating implanters, Japan has 40 percent, Europe has 10 percent, and the ROW countries have 3 percent. However, in the last three years the percentage of ion implanter unit shipments was 24 percent for North America, 43 percent for Japan, 12 percent for Europe, and 4 percent for ROW. These percentages suggest that the largest capacity for modern, advanced implant processes exists outside of North America. This analysis is consistent with the large investment by Japanese and ROW firms in VLSI memory device capacity, and with the recent emphasis of European manufacturers on rebuilding their descending semiconductor industry.

Table 4

WORLDWIDE ION IMPLANTER INSTALLED BASE BY REGION

	Medium Current		High Current		Total	
	Units	Share	Units	Share	Units	Share
North America	565	49%	256	46%	820	48%
Japan	473	41	209	38	682	40
Europe	101	9	64	12	165	10
ROW	23	2	25	5	48	3
World Total	1,162	100%	554	100%	1,715	100%

Note: Columns may not add to totals due to rounding.

Source: Dataquest
December 1986

Ion Implantation Equipment

Implant Process Trends

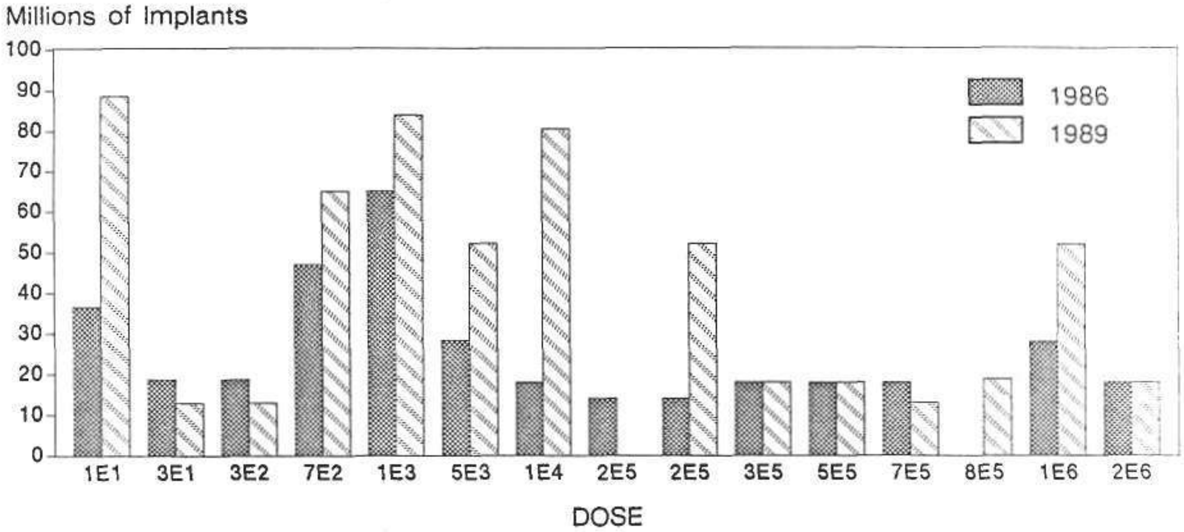
As discussed previously, high-current system sales grew much faster than medium-current systems between 1981 and 1985. It is clear from the foregoing discussion that the primary driving factor is throughput. As shown in Figure 8, recent years have seen more growth in applications for doses above 10^{14} ions/cm^2 than for below that level. Consider a throughput of 150 wafers per hour for a dose of 10^{14} ions/cm^2. A dose of 10^{16} ions/cm^2 would give a throughput of 1.5 wafers per hour on the same system. It seems ludicrous to consider the cost per wafer for 1.5 wafers per hour on a system costing \$400 thousand to \$600 thousand. Therefore, for modern semiconductor manufacturing, the development of high-current implanters was paramount.

However, as the demand for source/drain implants becomes satisfied, and as the device junction depths decrease, the growth of implants at doses greater than 10^{14} ions/cm^2 should slow relative to lower doses. Figure 9 shows our estimates of total implants by dopant concentration. The figure shows that there are many more low-dose implants than high-dose implants. (Note: We define low-dose implants as those for concentrations less than 10^{14} ions/cm^2.) This is consistent with our analysis of the installed base of implanters, where medium-current implanters outnumber high-current implanters 2.1:1. Figure 10 shows our estimates of total low- and high-dose implants for 1986 and 1989. The growth of low-dose implants is 64 percent, while the growth of high-dose implants is 45 percent.

From a cost-per-wafer standpoint, it is much more economical to process low doses on medium current implanters. This would imply that medium-current systems shipments would grow relative to high-current systems. However, we believe that this will not occur. It is prohibitive for a medium-current system to do high doses in a production environment because of throughput considerations. High-current systems can easily do low-dose applications, albeit while adding a higher than average incremental cost to the wafer processing cost. It will be more cost effective to spend incremental capital equipment dollars on high-current systems and then load those systems' excess capacity with low-dose implants. In this scenario, when the average low-dose load on the high-current system warrants a medium-current system, then the capital dollars would be allocated.

Figure 9

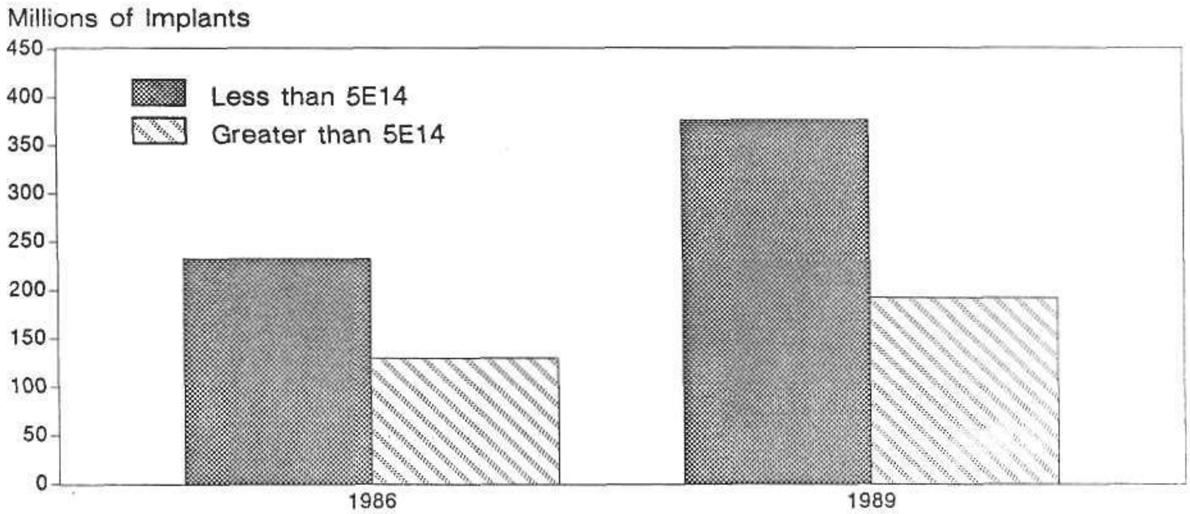
TOTAL IMPLANTS BY DOPANT CONCENTRATION



Source: Dataquest
December 1986

Figure 10

LOW- AND HIGH-DOSE IMPLANTS
1986 AND 1989



Source: Dataquest
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Market Forecast

Table 5 gives Dataquest's estimates of the markets for medium- and high-current implanters through 1989.

Dataquest expects implanter sales to continue to outpace sales of other front-end equipment as implanters replace diffusion furnaces in many of the existing process applications. Even so, the growth estimates in Table 5 are much lower than the historical sales for this equipment. This reflects the lower estimated growth of semiconductor manufacturers' capital spending for the years from 1984 through 1989. (This analysis was published in SEMS notebook, "Industry Econometrics," in the Capital Spending section.) We also expect that sales of high-current implanters will continue to grow with respect to medium-current systems.

Table 5

ESTIMATED ION IMPLANTER SALES
(Millions of Dollars)

System	1985	1986	1987	1988	1989	1990	CAGR 1985-1990
Medium-Current	$132	$85	$105	$130	$134	$150	2.6%
High-Current	119	105	145	192	182	208	11.8%
High-Voltage	5	10	15	20	34	52	59.7%
Total	$256	$200	$265	$342	$350	$410	9.9%
Growth		(22%)	32%	29%	2%	17%	

Source: Dataquest
December 1986

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New Product Markets

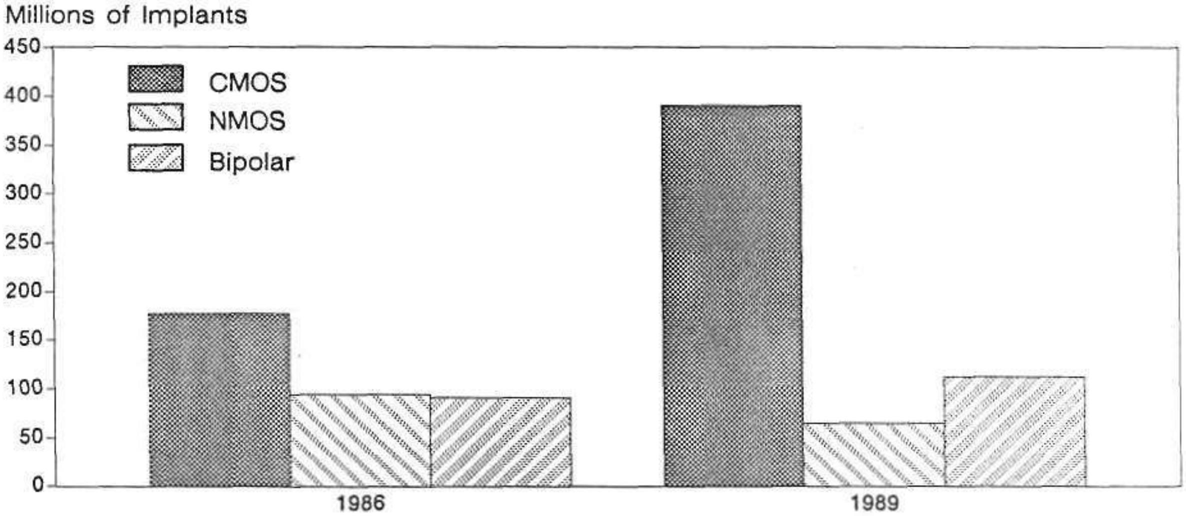
The relative growth of high-current implanters with respect to medium-current systems as shown in Table 5 is lower than historical growth. We believe that this will occur because of the growing opportunities for high-voltage and higher-current applications. Dataquest believes that there is an incipient market for systems that will target new process applications. These markets will be addressed by commercially available high-voltage implanters and by systems yet to be developed. These new product opportunities are reflected in the sales forecasted in Table 5, and they change the relative growth between the two categories.

The areas of opportunity for new products involve systems that are capable of much higher voltages and currents or are capable of higher currents with nominal voltages. These new applications are discussed in the Technology section of this report, and Dataquest believes that they represent opportunities for equipment manufacturers to penetrate or increase their shares of implanter markets.

Figure 11 shows our estimates of the number of implants as distributed by technology. It shows that the strongest growth area by far is for CMOS applications.

Figure 11

TOTAL IMPLANTS BY TECHNOLOGY
1986 AND 1989



Source: Dataquest
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One opportunity for manufacturers that this growth in CMOS processes provides is the application for high energies; energies of greater than 200KeV. For CMOS applications, these high-voltage systems can be used for the formation of CMOS wells, both conventional and retrograde. Applications also include the formation of buried layers for soft error reduction and for CMOS latch-up prevention. There is also a growing interest in late-process ROM programming. Because of the ion-current ratings on commercially available high-voltage (and hence, high-energy) systems, throughput considerations limit doses to less than 10^{13} ions/cm^2.

Table 6 lists commercial ion implantation systems that provide energies of 400 KeV or higher. In addition to these systems, Nissin and Ulvac build high-energy systems for the Japanese market. Nissin is marketed in North America by Mitsubishi International.

Table 6

COMMERCIAL HIGH-VOLTAGE IMPLANTERS

Manufacturer	Accelerator Type	Terminal Voltage(MeV)	Beam Current (particle·uA)
National Electrostatics	Tandem (MV-T30)	1.0	5 B^{+2}
	Single-End (MV-H20)	2.0	(20) (B^{+}) (40) (P^{+})
General Ionex	Tandem (1500-25)	0.75	(20) (B^{+2}) (20) (P^{+2})
Extrion	Single-End (Extrion-400)	0.4	50 B^{+} 100 P^{+} 100 As^{+}
Veeco	Single-End (400MP)	0.4	58 B^{+} 31 P^{+}
HVE Europa	Single-End	0.5	50 B^{+} 75 P^{+} 50 As^{+}
Eaton	Single-End (NV-1000)	0.8	300 B^{+} 300 P^{+}

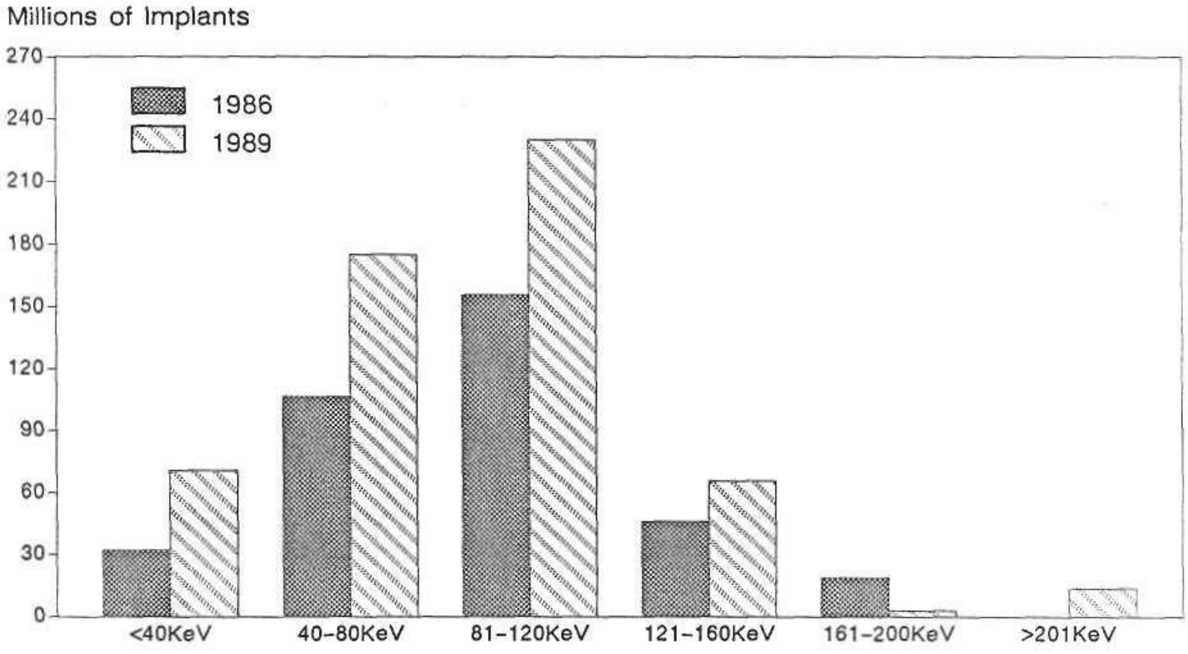
Source: Solid State Technology

There could also be an opportunity for a very high-current system for implanting buried oxides. Such buried layers represent a replacement for silicon-on-saphire (SOS). Such layers are called silicon-on-insulator (SOI), and are used for radiation hardening and isolation. SOI systems would require voltages of 200 KeV and currents of greater than 100mA. They would also need to heat the wafer in situ to over 500°C in order to anneal the implant damage to the wafer substrate.

Figure 12 shows our estimates of total implants as distributed by ion energies. This figure assumes that 10 percent of the P- and N-wells will be done in the retrograde fashion in 1989. This conservative estimate yields nearly 20 million implants per year by the end of 1989.

Figure 12

TOTAL IMPLANTS BY ION ENERGY
1986 AND 1989



Source: Dataquest
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Market Share

Table 7 lists the major ion implanter manufacturers and Dataquest's estimates of their worldwide market shares in 1984 and 1985. Table 8 restates those shares as a percentage of the total market.

It is apparent that Eaton gained considerable share in 1985 at the expense of Varian, growing from 34 percent at $104 million in 1984 to 37 percent at $92 million in 1985, while Varian fell from 44 percent at $135 million to 40 percent at $100 million. The other competitors' worldwide market share remained relatively unchanged.

Table 7

ESTIMATED WORLDWIDE MARKET SHARE
(Millions of Dollars)

	Medium Current		High Current		Total	
Manufacturer	1984	1985	1984	1985	1984	1985
Varian	$80	$76	$55	$24	$135	$100
Eaton	$17	$20	$87	$72	$104	$ 92
Nissin	$16	$15	$12	$10	$ 28	$ 25
Ulvac	$16	$14	$ 4	$ 6	$ 20	$ 20
Veeco	$ 6	$ 2	$ 5	$ 7	$ 11	$ 9
Hitachi	$ 5	$ 5	N/A	N/A	$ 5	$ 5
Balzers	$ 6	0	N/A	N/A	$ 6	0

Source: Dataquest
December 1986

Table 8

ESTIMATED WORLDWIDE MARKET SHARE
(Percentage)

Manufacturer	Medium Current 1984	Medium Current 1985	High Current 1984	High Current 1985	Total 1984	Total 1985
Varian	55%	58%	34%	20%	44%	40%
Eaton	12%	15%	53%	61%	34%	37%
Nissin	11%	11%	7%	8%	9%	10%
Ulvac	11%	11%	2%	5%	6%	8%
Veeco	4%	2%	3%	6%	4%	4%
Hitachi	3%	4%	N/A	N/A	2%	2%
Balzers	4%	0%	N/A	N/A	2%	0%

Source: Dataquest
December 1986

Table 9 shows Dataquest's estimates of installed base of ion implanters by company. This table shows that Varian has by far the most installed implanters worldwide, with 845 systems or 49 percent of the total. Eaton is second with 454 systems or 26 percent of the total. Although there are several potential threats to the leaders' position, the next seven companies contribute only 23 percent of the total implanters installed worldwide.

Table 9

ESTIMATED ION IMPLANTER INSTALLED BASE
BY COMPANY

	Medium Current		High Current		Total	
	Units	Share	Units	Share	Units	Share
Varian	674	58%	171	31%	845	49%
Eaton	161	14%	293	53%	454	26%
Ulvac	148	13%	11	2%	160	9%
Nissin	61	5%	37	7%	98	6%
Veeco	64	6%	13	2%	77	4%
Balzers	18	2%	8	2%	27	2%
Hitachi	21	2%	N/A	N/A	21	1%
App. Materials	N/A	N/A	21	4%	21	1%

Source: Dataquest
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Medium-Current Implanters

In medium-current implanters, Varian/Extrion has the leading market share and has maintained that position for many years. From 1980 to 1984, Eaton's sales of medium-current implanters had a 29.9 percent CAGR while Varian's sales grew 24.7 percent CAGR. In 1985, when the industry declined, Varian's share rose from 55 percent to 58 percent of the world, while Eaton's grew from 12 percent to 15 percent. While this relative growth is a tribute to the ingenuity of Eaton's implanter technologists, Varian quite clearly still has the dominant position. In 1985, Japanese vendors held their share.

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From 1980 to 1984, Ulvac's sales of medium-current systems in Japan grew at 27.8 percent CAGR, while Varian's sales in Japan increased at 31.6 percent CAGR. Varian's trading partner in Japan is Tokyo Electron Laboratories (TEL). Varian and TEL formed a joint venture called TEL-Varian in 1982. Most all of Varian's medium current implanters are assembled by TEL-Varian in Japan. The quality and reputation of this company helps to maintain Varian's strength in Japan.

High-Current Implanters

In high-current implanters, Eaton has the leading market share and has maintained that position for many years. Its CAGR from 1980 to 1984 was 89.8 percent, while Varian's was 78.6 percent for the same period. In 1985, Eaton grew its share from 53 percent to 61 percent of the world total, while Varian lost share from 34 to 20 percent. Most of this loss occurred in Japan. Eaton quite clearly has the dominant worldwide position in this market and is maintaining it.

However, in Japan, Eaton had a lesser share than Varian through 1984. Dataquest believes that Eaton's slower penetration of the Japanese market was due to changing trading partners before it secured a foothold in this market. Eaton had three trading partners in five years. Kokasai began marketing Eaton's systems in 1979, then Eaton switched to Marubeni in 1981. To be successful, it is paramount that an equipment company form long-term relationships with its customers in Japan. Eaton has now had a successful joint venture with Sumitomo Corporation for three years, called Sumitomo-Eaton-Nova Corporation (SEN). SEN now assembles almost all of the Eaton-designed implanters sold in Japan, with Marubeni marketing these systems and brokering the overflow from Eaton's factory in the United States when SEN capacity is oversold. Eaton's position has improved considerably since the formation of SEN and it has 31 percent of that market. However, Varian still has a very strong position in that market, although it dropped from 49 percent to 31 percent in 1985. Ulvac and Nissin have grown their collective share from 16 to 33 percent of the total in 1985.

Dry Etch Processing

SUMMARY

The semiconductor industry is rapidly approaching 1-micron and submicron lines in its quest for low-power, high-speed devices. Fine-line geometries demand changes in many wafer fabrication processes, and the etch process is no exception. In response to the demand, the industry is converting most of its etch processes from wet to dry etch. These dry etch processes can be subdivided into stripping, parallel-plate, which includes reactive ion etch (RIE), and ion-beam milling, which includes reactive ion-beam etching (RIBE).

We estimate that worldwide dry etch wafer processing equipment consumption was $406 million in 1985, down 2 percent from $414 million in 1984. Of this, $344 million was for parallel-plate applications, $45 million for barrels, and $17 million for ion-beam milling. We believe that worldwide consumption will drop 5 percent to $387 million in 1986 and then grow to $649 million in 1990, for a compound annual growth rate (CAGR) from 1985 through 1990 of 9.8 percent.

The wet process market for 1985 was $125 million, down 6.2 percent from $133 million in 1984. We estimate that it will decrease to $117 million in 1986 and then grow to $182 million in 1990, for a CAGR of 8 percent during that period. The percentage of layers that are wet etched will decrease from 58 percent in 1985 to 25 percent in 1990.

Dry etching is replacing wet etching because of the following advantages:

- Dry etching provides much better anisotropy (vertical etch profiles), which is required for small line dimensions.

- Dry etching obviates the handling and disposal of corrosive liquids, although care must be taken to protect the operator from hazardous gaseous by-products.

- Dry etch systems provide much better control of the etch process.

- Dry etch systems can do several steps in situ with one pump down, which reduces contamination that could be caused by several handling steps.

Production dry etching is being used successfully for most major semiconductor films. It has been used most widely in the past for silicon nitride and polysilicon films. Although a smaller portion of silicon dioxide layers are being dry etched, its production viability has been demonstrated and it is being more widely used. Aluminum etching has proven to be more formidable, especially where silicon and copper alloys are present, but it is still a production process for most semiconductor manufacturers.

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Dry Etch Processing

Many new processes that can only be done by dry etching are being developed. Some of these have already found their way into production semiconductor processing. One of these is the etching of multilevel photoresist for applications where severe topography reduces the resolution of photolithography. Another process is the etching of single-crystal silicon for the recessed local oxidation application, which decreases the cell area for new devices. Another is the deep trench isolation process in single-crystal silicon that provides isolation for n- and p-wells in CMOS devices. We are seeing the viability of dry etching in virtually every area of photoresist technology.

Because of the opportunities in this marketplace, the number of suppliers and new entrants has escalated. There are no less than 20 major competitors in this market today. Although most of those companies have grown rapidly, there have been considerable shifts in market share. We believe that the technology has not stabilized enough to predict long-term winners. There are emerging new technologies that could supplant current market leaders. Eventually, several niches will emerge to address different process requirements. Dominance in those niches will depend on machine excellence, product support, and process expertise.

WET CHEMICAL ETCHING

Traditionally, the most common method of etching a wafer patterned with photoresist is to submerge the wafer in a liquid chemical solution that attacks the exposed surface at a higher rate than the rate at which it attacks the photoresist. We estimate that 58 percent of mask layers are currently etched in wet chemical solutions.

Wet chemical etching has some very positive characteristics. The equipment used in the process is relatively inexpensive, and the process has very high selectivity (the difference in etch rates between the material in the layer that is being etched and the underlying layer).

Wet chemical etching also has some negative characteristics, however. It may be hazardous to personnel because of the potentially dangerous chemicals used in the solution. Furthermore, wet chemicals create a waste disposal problem. Another production problem can occur as the acids and bases in the solution are used up, causing the etch characteristics to change during the processing of a batch of wafers. This causes a lack of control in the etch process.

Dry Etch Processing

Wet chemical etching also has some serious technological limitations. It produces an isotropic etch (an etch that proceeds horizontally as well as vertically) that may lead to resist undercutting. In narrow lines, such as in VLSI, this can cause the line to etch laterally, thus erasing the line. It is also difficult to control the slope of the walls produced by the etch. Varying amounts of slope may be required in some applications in order to properly metallize in subsequent steps. These problems will become more critical as the industry approaches submicron lithography.

DRY ETCHING

Dry etch processing has production and technological advantages over wet chemical etching. Dry etching is safer because it requires fewer potentially dangerous chemicals in less volume, and because human operators are not directly exposed to the chemicals in the process. Furthermore, dry etching partially eliminates the waste disposal problem, and it reduces the problem of inconsistent etching associated with processing a batch of wafers in wet chemicals.

Among the technological advantages, dry etching allows some control over the slope of the etched sidewalls. Profiles can be varied from 60 to 90 degrees to fit the application, although such control is not a trivial matter. In wet etching, profiles are always concave because of the isotropy. Dry etching also provides the ability to etch multiple layers of several different materials in situ without undercutting the photoresist or degrading the profile. This feature can greatly reduce the contamination that would come from handling the wafer at each step.

Dry etching grew out of the vacuum industry. It uses an electrical discharge to partially ionize a gas (i.e., produce a gas plasma) in a vacuum chamber. Depending on the type of gas, reactive or inert, and the electrode configuration, the ions are used to chemically etch or sputter the material from the wafer surface. There are three generic categories of dry etching: stripping, parallel-plate etching, and ion-beam milling.

Strippers

Strippers are used for removing the photoresist from the wafer after the pattern has been etched or otherwise processed. The traditional method, which is still widely practiced, is to remove resist with wet chemicals. Strippers are becoming more popular because of the low cost and the elimination of personnel hazards caused by the dangerous chemicals. The most popular dry stripper is the barrel. However, because of some particularly tenacious resist residues, we have recently seen the emergence of single-wafer strippers.

Barrels

Barrels were first used for stripping resist. Their use was eventually extended to silicon nitride removal or patterning in cases where there were no requirements for anisotropy. These systems are simple in that they are manually loaded and use only a mechanical vacuum pump. Thus, their low cost ($20,000 to $60,000) and high throughput make them very cost effective.

The basic configuration is a cylindrical vacuum chamber with RF electrodes coupled to the outside. Wafer boats are loaded manually into the chamber (up to 100 wafers per load) and a low-pressure plasma (greater than 2 Torr or 2mm of Hg) isotropically etches the material from the substrate. The etch mechanism is that the chemically activated species in the gas form volatile gas by-products with the substrate, which are pumped out of the system. The electrical discharge imparts some anisotropy, but the profile is still mostly isotropic.

Single-Wafer Strippers

One of the most interesting new product areas in dry etch is that of single-wafer stripping. This technology is needed to minimize gate oxide damage and gate thickness loss and to increase stripping efficiency. Gate oxide damage occurs because, during stripping, the oxide is exposed to a plasma environment that contains high-energy ions and electrons, X-ray radiation, and sputtered contaminants from the processing chamber. Yield losses result from this oxide damage, since there is an attendant C-V shift and threshold voltage degradation. Although the results are not conclusive, one solution is to remove the wafer from this plasma environment by creating the plasma in an upstream chamber. In addition, by increasing the free radicals that impinge on the wafer, the etch efficiency is increased, which facilitates the removal of tenacious resist deposits such as result from high-current implantation.

Parallel-Plate

The parallel-plate application of plasma etching includes planar batch systems, single-wafer systems, and hexode systems. This technology was first developed at Texas Instruments (TI) in the late 1960s. The original TI configuration was a planar batch type and consisted of two electrodes with the upper electrode driven by an RF potential and the lower electrode grounded. The wafers were placed on the lower, circular electrode. This provided the first near-anisotropic etching in the industry.

Dry Etch Processing

Since then, the parallel-plate technology has generated the types of systems mentioned above. The single-wafer version evolved from the original version by shrinking the chamber to hold one wafer only. The planar batch approach has also generated the reactive ion etch (RIE) configuration, in which the lower electrode, with the wafers, is RF powered. In another generation, the electrodes have been arranged in a vertical hexagonal structure (hexode) where the concentric inner electrode is RF driven. Finally, there are systems being built that power both electrodes, use magnetic enhancement of the plasma, employ multiple processing chambers, or use rotating electrodes.

Etch Mechanism

The basic mechanism in all these approaches is the creation between the electrodes of a plasma in a chemically reactive gas. Such a plasma develops a voltage drop (usually termed the sheath or dark space) from the plasma to the electrodes. The voltage drop imparts energy to the ions created in plasma and they impinge on the wafers, thus radiatively assisting the gas chemistry on the substrates. Each of the above approaches has its own set of constraints on the type of chemistries that can be achieved. Because of the sheath voltage, the parallel-plate method provides much more anisotropy than the barrel method. However, there can be considerable variation in the anisotropy, depending on which approach is used.

Plasma Etching

The term plasma etcher refers to the original approach with the cathode grounded. Such systems usually operate at greater than 1 Torr. They rely mostly on gas chemistry to achieve etching. The single-wafer versions of this approach can achieve very high etch rates (and thus, high wafer throughputs) at this pressure. However, the short mean free path of the gas molecules causes collisions in the dark space that detract from perfect anisotropy.

The largest installed base of etchers is of the plasma type. The early successes of Tegal and International Plasma Corporation (now Branson/IPC) were due to their single-wafer plasma systems. This technology reflects the tendency of semiconductor manufacturers to purchase single-wafer processing systems over batch systems when the process requirements can be met by either.

These systems were used primarily for polysilicon and nitride etching at geometries where the line loss due to some isotropy could be compensated for in the design. Since these early systems, the process technology has been refined so that there is much less line loss. One method of reducing line loss is to adjust the pressure, gas mixture, and power so that a passive coating on the sidewall forms from the polymer created from resist by-products. This passive sidewall coating resists the ion flux and produces near anisotropic etching. Plasma reactors are now routinely used for oxide and aluminum etching. Lam Research Corporation and Varian's Zylin Division have had considerable success for single-wafer applications in oxide and aluminum, respectively.

Reactive Ion Etching

The term reactive ion etch (RIE) refers to the RF-driven-cathode approach. Such systems operate at lower pressures, usually 10 to 100 mTorr. They rely on the ion acceleration due to the large dark-space voltage to drive the chemistry. At these pressures, the etch rate is much lower than with the plasma method because there are only one-tenth to one-hundredth the gas densities. In addition, the electrode areas are such that the voltage drop at the cathode is much greater than in the planar method. Such systems are forced to operate in the batch mode to obtain adequate throughputs. However, the gas molecule mean free path at these pressures is much longer and results in much better anisotropy in general. The lower pressure also reduces the tendency for the chamber and chamber hardware to coat with organic polymers, which have plagued plasma reactors in the past.

Because the pressures are lower, more sophisticated pumping systems are needed, which increases the price over their planar counterparts. Although the systems are more expensive and operate in the batch mode, semiconductor manufacturers have purchased them for certain applications. They were first popularized for oxide etching. Anelva and Plasma Therm have had success in producing this type of system.

Hexode

The hexode is a special application of the RIE technology. The wafers are held vertically on a concentric, hexagonally shaped cathode within an outer bell jar. The symmetrical electrode configuration helps to achieve the uniformity within a batch of wafers that is needed for adequate yields. This approach allows maximum loading of wafers to obtain adequate throughputs with the characteristic low etch rates of the RIE approach. This is in contrast with planar electrode systems, which are constrained in wafer loading by the size of the electrode, which in turn causes reduced etch uniformity as the electrode becomes larger.

The hexode technology was invented at Bell Laboratories and subsequently licensed to Branson/IPC, LFE Corporation, Plasma Therm, and Technics. Although Applied Materials did not obtain a license, the creators of the hexode joined the company and refined the technology. Applied has been the most successful. Hexodes are used primarily for oxide and aluminum etching. They are useful for more exotic processes such as aluminum with copper alloys, refractory metals and alloys, and single-crystal silicon. While there seems to be much process flexibility for process development, the wafer expense associated with the large wafer loading requires partial wafer loading during process experiments. This can impede development time and demonstrates one of the benefits of the single-wafer systems.

The early hexodes did not have a load lock. For aluminum etching, and etching in general, the subjection of the process chamber to atmospheric conditions after each run compromised the process. In addition, the hexode has been very difficult to automate with respect to loading wafers onto the cathode. LFE Corporation added a loadlock and automatic loading mechanism but had little success. Branson/IPC and Applied Materials introduced robotic handlers that loaded wafers onto the cathode, but these approaches did not receive acceptance from semiconductor manufacturers. In 1984, Applied Materials introduced a second-generation hexode with loadlock and automatic wafer handling. This product has received much better acceptance than the previous efforts.

Magnetron Etching

To obtain the anisotropy of the RIE method in a single-wafer system, the etch rates must be drastically increased to maintain the throughput. This can be done by increasing the ratio of ions to neutral gas molecules in the plasma. One approach is to magnetically enhance the plasma. The secondary electrons are confined to circular orbits by the magnetic field near the cathode, thus causing more ionizations. Such ionization ratios are two orders of magnitude greater than for normal plasmas. This greater ion flux provides the etch rates necessary for adequate throughputs in a single-wafer system.

Two vendors have introduced magnetically enhanced etchers: Materials Research Corporation (MRC) and Tokuda Seisakusho, Ltd. Both companies had early introductions of systems and followed up within three years with a new generation. MRC's approach is to use a quadrapole magnet above the chamber and a permanent magnet below the chamber, attempting to shape the field with these magnets to obtain maximum uniformity. Tokuda's approach is to sweep long bar magnets back and forth across the wafer from below and outside the chamber. The sweeping motion averages out the magnetic field for maximum uniformity. Tokuda also has a DI water rinse and dry station at the output of the exit loadlock.

Triode

Another way to increase throughput in a single-wafer system is to increase the amount of power delivered to the electrodes. As the power is increased, the ionization ratio is also increased. However, the power density onto the wafer also increases. Such systems use sophisticated wafer cooling to protect the photoresist from becoming a hard epoxy under the increased flux. A particular application of this approach is the triode etcher, which has an upper, a lower, and an optional grounded middle electrode. Such a method provides a means of controlling the voltage on the cathode while pumping more power into the plasma.

These systems have achieved excellent process results with respect to selectivity, throughput, and anisotropy. There are three vendors with triode systems: Balzers, GCA Corporation, and Tegal. These systems are used for oxide, aluminum, refractory silicides, and silicon trench etching. They are used for polysilicon etching where the etch rate of the underlying oxide must be minimized.

All of the above approaches have their advantages and disadvantages with respect to uniformity, throughput, selectivity, anisotropy, price, and profile control. In addition, the engineering design can add or detract from the optimal use of the technologies. There is a perceived general desire in the industry to process one wafer at a time. However, it is not clear that the trade-offs will produce a better, cost-effective approach than the low-power, batch approach. The industry also desires the redundancy obtained by using several lower-priced, low-throughput systems instead of one high-priced, high-performance model. But it is not clear that a low-performance system can obtain the same quality etch that will be required on future VLSI devices.

We believe that future cost-effective approaches will be apparent in the ensuing high-growth market for dry etchers. For instance, in a typical 11-mask CMOS process, 4 mask steps require the high anisotropy of an RIE etcher, 5 steps could use plasma etchers, and 2 steps can be done by wet etching. Although the noncritical steps will decrease as devices become more complex, there will continue to be available niches for each of the technologies in the production of 256K DRAMs and beyond.

Ion Milling

Ion milling was pioneered as a production process for manufacturing bubble memories. Since then, it has become the dominant processing method for applications that contain chemically inert materials such as gold, chrome, and nickel-iron. These applications include bubble memory devices, maskmaking, and magnetic heads.

Dry Etch Processing

Unlike barrel and parallel-plate etching, ion milling uses physical ablation (sputtering) of the substrate as the etch mechanism. The gas plasma, which is usually inert, is produced remotely. The ions are extracted and accelerated toward the substrate by an electric field. This is done in a vacuum of about 0.1 mTorr. Since the gas is inert, the ions sputter each material roughly equally. Therefore, there is little selectivity over photoresist or the base material.

Since the pressure is low and the beam is collimated, ion milling can be used to etch lines well below 1 micrometer. In addition, the substrate can be oriented at an angle to the beam, which results in sloped wall profiles. Care must be taken to provide enough photoresist to survive the etch process (usually 1.5 times the etch depth). The photoresist is also subject to sideways erosion, which will transfer some slope into the wall profile.

The main disadvantages of the ion-milling process are the lack of selectivity and the low throughput. Since there is no chemical action, the etch rates are very low compared with wet or dry etching. The time to pump down the chamber to low vacuum also increased the process cycle time. For production processing of semiconductors, ion milling is not cost effective compared with other approaches.

To improve the etch rates, a reactive gas can be used instead of an inert one. This approach is called reactive ion-beam etching (RIBE). The chemical action provided by the gas (typically chlorine or fluorine with oxygen) helps to break surface bonds so that there is both a chemical and sputtering component to the etch rate. However, this action proceeds on all surface materials such that selectivity is not substantially improved. RIBE is still relegated to research and development efforts to improve these fundamental limitations.

We believe that ion milling will be used for very fine lines in inert materials. This could be a very fast growing, although small, niche. Gallium arsenide and GGG materials may fall into this market segment, and it remains to be seen whether applications can be served by the parallel-plate technology.

WET VERSUS DRY

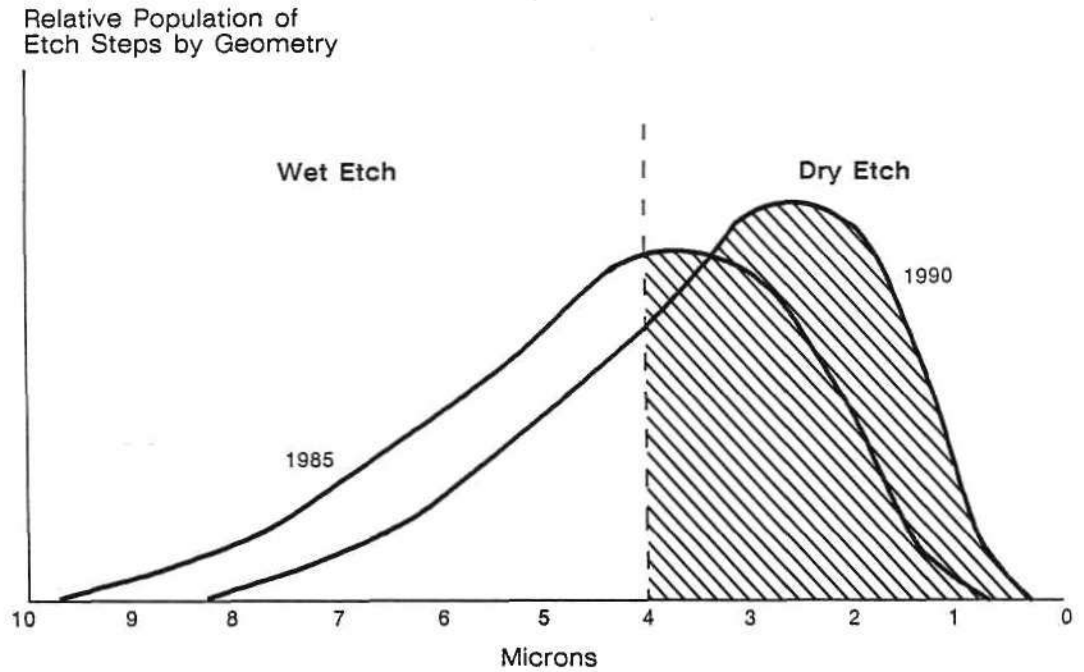
The movement away from wet etching in device fabrication has many impediments. It is still much more cost effective to perform wet chemistry on many of the devices manufactured today. The impact on yields for devices above 4 microns is not worth the considerable cost of implementing dry etching.

Dry Etch Processing

Figure 1 illustrates of the distribution of etch steps in the industry by line geometry for 1985 and 1990. Since it is more cost effective to wet etch geometries above 4 microns, the total number of layers done wet versus dry is still about 58 percent, which can be found by integrating the curve. However, in 1990, the percentage of layers that are wet etched will fall to about 25 percent.

Figure 1

ESTIMATED DISTRIBUTION OF PROCESS STEPS BY LINE GEOMETRY



Source: Dataquest
November 1986

Dry Etch Processing

For the newer devices being manufactured, the line geometries are much more critical. However, this still amounts to source and drain masks for MOS devices, emitters for bipolar devices, vias, and contact holes. Although the geometries are very small on these steps, device designers have resorted to double-layer interconnects and double-layer metallization to obviate the need for smaller geometries for those upper levels. This has retarded the application of dry etching for metals. It has even loosened the specifications on polysilicon so that less anisotropy is required, which allows the use of lower-performance dry etchers.

Since its inception, dry etch has grown significantly with respect to wet etch. As we show in Table 1, we believe that in the next five years there will continue to be growth of dry etch relative to wet etch. The viability of dry etch for interconnects and metal alloys was demonstrated in 1983. By 1985, dry etch had demonstrated its viability in virtually every etch process. The impact of yields for fine-line devices will more than justify the tenfold increase in cost per layer per device to implement dry etch.

Table 1

PERCENTAGE OF LAYERS BEING DRY ETCHED IN PRODUCTION

	1985	1990
Silicon Dioxide	25%	50%
Polysilicon	55%	80%
Silicon Nitride	65%	70%
Aluminum	20%	60%
Advanced Processes	80%	95%

Source: Dataquest
October 1986

Dry Etch Processing

PROCESS APPLICATION

The market for dry etch breaks down as shown in Table 2. Although applications for silicon nitride and polysilicon have the lion's share of the levels etched, as we show in Table 1, the cost of the equipment is generally much lower. Since higher-priced equipment is needed to etch oxide, metals, and silicides, and since there will be more growth into those process steps, the highest dollar growth is expected for those applications.

Table 2

SYSTEM MARKET SHARE BY PROCESS APPLICATION

	1985	1988
Silicon Dioxide	26%	26%
Polysilicon	14	9
Silicon Nitride	9	6
Aluminum	19	34
Advanced Processes	32	25
Total	100%	100%

Source: Dataquest
October 1986

TRENDS

Hexode

The hexode uses the RIE operation, which is positioned in the largest growth segment of the process applications--oxide, aluminum, and more advanced processes. The large wafer loading (24 four-inch wafers) provides good productivity, which is largely responsible for its success over planar batch-type systems. This success demonstrates the tendency for semiconductor manufacturers to select systems that maximize the wafers processed per dollar spent (which includes allocation of floor space).

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Dry Etch Processing

The technology was taken to Applied Materials by its inventor, Dr. Dan Mayden, who further refined it. As mentioned before, it was also licensed by Bell Labs to Branson/IPC, LFE, Plasma-Therm, and Technics. Applied's lead has proven to be quite formidable. It became the leading producer of dry etchers in its first two years and now leads the parallel-plate market with about 23 percent market share. Although Branson/IPC, LFE, and Technics tried to improve on the original design, none have shown any appreciable success, and all have since stopped building hexodes. Plasma-Therm has delivered about 20 systems to captive semiconductor manufacturers on the East Coast.

Previous designs suffered from the lack of loadlocks and cassette-to-cassette operation. LFE implemented these on its system, but the design was not accepted by semiconductor manufacturers. Applied introduced a loadlocked, cassette-to-cassette system in 1984. This system was designed to reduce the particulate that is introduced during handling and to improve the problems associated with water vapor during aluminum etching. We believe that the vertical configuration, with its attendant high productivity, will continue to be popular for large-volume production of VLSI devices.

Single-Wafer versus Batch

There has been a lot of controversy concerning which is the most advantageous method of etching--batch or one wafer at a time. The most successful manufacturer of etchers has been Applied Materials, which sells a batch system. However, there have been several successful makers of single-wafer systems, both in the United States and Japan. Lam Research, in particular, has become second in worldwide market share, having introduced its system in 1982. In the last few years, the markets for single-wafer systems and batch systems have grown at the same rate. The market was split 50/50 in 1983 and, remarkably, it was still split 50/50 in 1985. Single-wafer systems have gained their market mostly in the etching of polysilicon and, to a lesser extent, silicon dioxide. The makers of each type are listed in Table 3.

One manufacturer, Drytek, has combined the single-wafer and batch methods by using a stack of single-wafer electrodes in a single chamber. Drytek has been very successful with this approach in polysilicon and oxide applications.

Table 3

MAKERS OF SINGLE-WAFER AND BATCH SYSTEMS

Single-Wafer Systems	Batch Systems
Balzers	Anelva
Branson/IPC	Applied Materials
CIT-Alcatel	Electrotech
Electrotech	Kokusai
GCA	Plasma-Therm
Lam Research	Tokuda
MRC	Ulvac
Perkin-Elmer	
Plasma Systems	
Plasma-Therm	
Ramco	
Tegal	
Tokyo Ohka	
Zylin	

Source: Dataquest
October 1986

It is evident from Table 3 that there are suitable applications for each approach. The dollar volumes of each category are equal. From Table 2, the highest growth areas are for silicon dioxide, aluminum, and advanced processes. These applications are generally believed to benefit from the RIE technology, which can best be done in the batch mode. However, there are techniques that can enhance the anisotropy of high-pressure systems and new advances that may allow RIE in a single-wafer mode, as mentioned earlier. In these new VLSI processes, end-point detection is very important in order not to etch into the underlayer. Some new applications can tolerate no more than 30 angstroms into the base layer. Such end-point detection favors the single-wafer system. This is because, in a single-wafer system, each wafer is monitored while in a batch system, either an average end point is derived by looking at the gas effluent or one wafer per batch is monitored.

We believe that both technologies will continue to grow for the next few years, each finding its most productive applications. The batch systems will develop very high throughputs, perhaps doubling single-wafer systems' throughputs for smaller wafer sizes while maintaining process quality. Single-wafer systems will become highly automated with respect to end-point detection. Both will pay strict attention to particulate control, as contamination will become more important than shrinking line widths for device manufacturers. We believe that, as the technology matures, the single-wafer, RIE systems will begin to take market share away from batch systems.

Triode and Magnetically Enhanced Etching

The position that batch, RIE systems have held is due to being able to etch at low pressure with high throughputs. As described earlier, triode and magnetically enhanced etching allow low pressure in a single-wafer system with throughputs approaching those of hexode reactors. Once these incipient techniques are fully developed, they will compete directly with batch, RIE systems.

The triode, if it fulfills expectations, will occupy a position that competes both with plasma systems and RIE systems. However, the price of these systems is considerably higher than that of the plasma counterparts. For production, dedicated, low-cost systems will still provide higher productivity for less critical processes.

Magnetically enhanced etching has the advantage of etching at a much lower pressure than any of the techniques except ion-beam milling. As with the triode, there is no real differentiation with respect to plasma systems for less critical processes. In fact, plasma-type systems still maintain a throughput advantage over the low-pressure systems. Therefore, the importance will be where the low pressure becomes necessary--for the high-growth processes in very fine lines.

Trilevel Resist

The next few years will see device manufacturers concentrate on improving yields rather than reducing line geometries below 1 micron. One very important technique will be planarizing the severe topography with multilevel resist schemes. The ability to etch these levels will provide another market for dry etchers.

The trilevel resist process begins with the deposition of a thick film of polyimide or commercial photoresist on the base topography. Then a thin layer of Si_3N_4 or SiO_2 is deposited. In this case, the photoresist must be cured to withstand the deposition temperature of 200 degrees centigrade. An alternative to the high temperature would be to spin on glass or use cold plasma deposition of SiO_2, which obviates the need for curing. Then a layer of working resist can be spun on the thin layer. After patterning and developing the working resist, the SiO_2 is dry etched. After etching, the SiO_2 can be used as a mask for etching the thick photoresist with an oxygen plasma. The polyimide then becomes an etch mask for the base layer.

The aspect ratio of these levels (ratio of etch depth to line width) can be as much as 4 to 1. The batch, RIE systems have a real advantage here. They do not necessarily etch organic polymer any better than high-pressure systems, but they are able to etch high aspect ratios much better. In addition, the layers can be 3 microns deep, which severely affects the throughputs of single-wafer systems.

MARKET DATA

History

We estimate that worldwide dry etch wafer processing equipment consumption was $406 million in 1985, a decrease of 2 percent from $414 million in 1984 (see Table 4). North American markets grew at a 27 percent CAGR from 1980 through 1985 but fell nearly 5 percent in 1985. It is interesting to note that while the worldwide market grew at a CAGR of 35 percent from 1980 ($90 million) through 1985 ($406 million), Japanese consumption grew at a 45 percent CAGR over the same period. The European CAGR of 44 percent reflects Europeans' growing awareness that they must accelerate spending to maintain a viable electronics community. The recent growth of the ROW markets reflects the concentrated efforts of large conglomerates in Korea and Taiwan to compete as semiconductor manufacturers. While ROW companies account for approximately 1 percent of semiconductor production, they consume nearly 5 percent of dry etch equipment.

For the worldwide market, Table 5 shows that the fastest-growing dry etch equipment is the parallel-plate type. This segment grew at 40 percent CAGR from 1980 through 1985. Barrel systems grew 8 percent from $30 million in 1980 to $45 million in 1985. Ion-milling equipment grew slightly after 1980 and fell in 1985 as it was affected by the severe semiconductor recession.

Table 4

ESTIMATED WORLDWIDE CONSUMPTION OF DRY ETCH EQUIPMENT
BY GEOGRAPHIC REGION
(Millions of Dollars)

	1980	1981	1982	1983	1984	1985
North America	$60	$ 77	$ 94	$123	$201	$194
Japan	25	40	69	103	174	162
Western Europe	5	8	12	21	27	31
Rest of World	0	0	0	2	12	19
Total	$90	$125	$175	$249	$414	$406
Growth		39%	40%	42%	66%	(2%)

Source: Dataquest
October 1986

Table 5

ESTIMATED WORLDWIDE CONSUMPTION OF DRY ETCH EQUIPMENT
BY TYPE
(Millions of Dollars)

	1980	1981	1982	1983	1984	1985
Barrels	$30	$ 29	$ 26	$ 29	$ 44	$ 45
Parallel-Plate	52	88	141	206	351	344
Ion-Milling	8	8	8	14	19	17
Total	$90	$125	$175	$249	$414	$406

Source: Dataquest
October 1986

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Dry Etch Processing

The dry etch market has grown since 1980 because of the performance of parallel-plate systems. In Table 6, we show that the North American stripping and ion-milling markets actually fell in sales, while the parallel-plate market grew at a 40 percent CAGR. This reflects the high productivity of the barrels and the low growth in applications for ion-milling systems. Parallel-plate applications are those that allow the production of line geometries below 2.5 microns, a region of prodigious growth.

Table 6

ESTIMATED NORTH AMERICAN CONSUMPTION OF DRY ETCH EQUIPMENT BY TYPE
(Millions of Dollars)

	1980	1981	1982	1983	1984	1985
Barrels	$20	$18	$14	$ 17	$ 19	$ 17
Parallel-Plate	32	52	74	99	173	170
Ion-Milling	8	7	6	7	9	7
Total	$60	$77	$94	$123	$201	$194
Growth		28%	22%	31%	63%	(3%)

Source: Dataquest
October 1986

In keeping with the aggressiveness of Japanese semiconductor manufacturers, Japanese consumption of parallel-plate equipment grew at 51 percent CAGR between 1980 and 1985 (see Table 7). Barrel systems grew at a 21 percent CAGR and ion-milling systems grew from very low levels to $6 million. These growth rates reflect both the lower installed base of Japanese manufacturers in 1980 and the commitment of those companies to gaining worldwide market share.

European distribution of dry etch equipment is shown in Table 8. Although the table shows a growth rate of 44 percent from 1980 through 1985, the market was too small for the growth to be meaningful. They are given as a comparison to the worldwide figures.

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Table 7

ESTIMATED JAPANESE CONSUMPTION OF DRY ETCH EQUIPMENT
BY TYPE
(Millions of Dollars)

	1980	1981	1982	1983	1984	1985
Barrels	$ 8	$ 9	$ 9	$ 9	$ 19	$ 21
Parallel-Plate	17	30	58	89	149	135
Ion-Milling	0	1	2	5	6	6
Total	$25	$40	$69	$109	$174	$166
Growth		60%	72%	58%	69%	(7%)

Table 8

ESTIMATED EUROPEAN CONSUMPTION OF DRY ETCH EQUIPMENT
BY TYPE
(Millions of Dollars)

	1980	1981	1982	1983	1984	1985
Barrels	$2	$2	$ 3	$ 3	$ 5	$ 5
Parallel-Plate	3	6	9	16	19	23
Ion-Milling	0	0	0	2	3	3
Total	$5	$8	$12	$21	$27	$31
Growth		60%	50%	75%	29%	15%

Source: Dataquest
October 1986

The ROW market share estimates are listed in Table 9. This has been an important region in recent years. With the activity in Korea and Taiwan, some dry etch vendors have been able to survive the current recession by selling into the ROW region. With China's one billion people, there exists great potential for companies that have the distribution capabilities to market into the Pacific rim.

The market share estimates for strippers and parallel-plate systems are listed in Tables 10 and 11. As can be seen, the dominant suppliers in all three categories of dry etcher are concentrated in North America.

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Dry Etch Processing

Table 9

ESTIMATED ROW CONSUMPTION OF DRY ETCH EQUIPMENT BY TYPE
(Millions of Dollars)

	1980	1981	1982	1983	1984	1985
Barrels	N/A	N/A	N/A	$0	$ 1	$ 2
Parallel-Plate	N/A	N/A	N/A	2	10	16
Ion-Milling	N/A	N/A	N/A	0	1	1
Total	N/A	N/A	N/A	$2	$12	$19
Growth		N/A	N/A	N/A	500%	58%

N/A = Not Available

Source: Dataquest
October 1986

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Table 10

STRIPPER MARKET SHARE BY GEOGRAPHIC REGION
(Millions of Dollars)

Company	1984 Sales	1984 Share	1985 Sales	1985 Share
North America				
Branson/IPC	$ 7	37%	$ 9	53%
Tegal	6	32	4	24
Drytek	3	16	2	12
LFE	3	16	2	12
Total	$19	100%	$17	100%
Japan				
Plasma Systems	$ 8	42%	$11	52%
Tokyo Ohka	6	32	5	24
Branson/IPC	3	16	3	14
Yawata	2	10	2	10
Total	$19	100%	$21	100%
Europe				
Branson/IPC	$ 2	40%	$ 3	60%
Tegal	2	40	1	20
Electrotech	1	20	1	20
Total	$ 5	100%	$ 5	100%

Note: Columns may not add to totals due to rounding.

Source: Dataquest
October 1986

Table 11

PARALLEL-PLATE MARKET SHARE BY GEOGRAPHIC REGION
(Millions of Dollars)

	1984		1985	
Company	Sales	Share	Sales	Share
North America				
Applied Materials	$ 45	26%	$ 44	26%
Tegal	30	17	25	15
Lam Research	23	13	25	15
Drytek	22	13	20	12
Plasma-Therm	12	7	20	12
Perkin-Elmer	12	7	15	9
Zylin	14	8	8	5
Electrotech	4	2	3	2
Anelva	3	2	4	2
Tokuda	3	2	3	2
Branson/IPC	4	2	2	1
Kokasai	1	1	1	1
Total	$173	100%	$170	100%
Japan				
Applied Materials	$ 26	17%	$ 26	19%
Anelva	32	21	32	24
Tokuda	18	12	20	15
Tokyo Ohka	23	15	18	13
Lam Research	11	7	11	8
Kokasai	14	9	8	6
Ulvac	10	7	8	6
Plasma Systems	6	4	5	4
Perkin-Elmer	3	2	3	2
Ramco	3	2	3	2
Electrotech	3	2	1	1
Total	$149	100%	$135	100%

Note: Columns may not add to totals due to rounding.

(Continued)

Table 11 (Continued)

PARALLEL-PLATE MARKET SHARE BY GEOGRAPHIC REGION
(Millions of Dollars)

Company	1984 Sales	1984 Share	1985 Sales	1985 Share
Europe				
Applied Materials	$ 4	21%	$ 5	22%
Electrotech	4	21	5	22
Plasma-Therm	2	11	4	17
Tegal	4	21	3	13
Lam Research	2	11	3	13
Branson	2	11	1	4
Drytek	1	5	1	4
Total	$ 19	100%	$ 23	100%
Rest of World				
Lam Research	$ 3	30%	$ 6	38%
Perkin-Elmer	3	30	3	19
Applied Materials	1	10	3	19
Drytek	1	10	2	13
Anelva	1	10	1	6
Plasma-Therm	0	0	1	6
Zylin	1	10	0	0
Total	$ 10	100%	$ 16	100%
Worldwide				
Applied Materials	$ 76	22%	$ 78	23%
Lam Research	39	11	45	13
Anelva	36	10	37	11
Tegal	34	10	28	8
Drytek	24	7	23	7
Tokuda	21	6	23	7
Plasma-Therm	14	4	25	7
Perkin-Elmer	18	5	21	6
Tokyo Ohka	23	7	18	5

Note: Columns may not add to totals due to rounding.

(Continued)

Table 11 (Continued)

PARALLEL-PLATE MARKET SHARE BY GEOGRAPHIC REGION
(Millions of Dollars)

Company	1984 Sales	1984 Share	1985 Sales	1985 Share
Worldwide (Continued)				
Kokasai	15	4	10	3
Electrotech	11	3	9	3
Zylin	15	4	8	2
Ulvac	10	3	8	2
Plasma Systems	6	2	5	1
Branson/IPC	6	2	3	1
Ramco	3	1	3	1
Total	$351	100%	$344	100%

Note: Columns may not add to totals due to rounding.

Source: Dataquest
October 1986

Most of these companies make a significant percentage of their sales in Japan. Almost all of the Japanese vendors' sales are made in Japan and Asia. Although most of the listed Japanese suppliers have North American operations or U.S. trading partners, none have shown appreciable sales in North America or Europe.

Forecast

We believe that capital spending in general, and for dry etch in particular, will settle down to lower growth rates for the rest of the decade. Dry etch revenue should fall 5 percent to $387 million in 1986 as the semiconductor industry adjusts to the excess capacity that currently exists (see Table 12). However, this estimate includes a dollar depreciation of 30 percent against the Japanese yen. If we adjust for the depreciation, the decrease in 1986 becomes 15 percent. The market for dry etch equipment should rise 9 percent in 1987 to $422 million. However, in 1987, we expect an additional dollar depreciation against the yen of 7 percent. If we adjust for the depreciation, the 1987 rise becomes 6 percent. Worldwide consumption should reach $649 million in 1990, representing a 10 percent CAGR from 1985 through 1990.

Dry Etch Processing

Table 12

FORECAST WORLDWIDE SALES OF DRY ETCH EQUIPMENT
BY TYPE
(Millions of Dollars)

	1986	1987	1990	CAGR 1986-1990
Stripping	$ 42	$ 45	$ 91	15%
Parallel-Plate	330	361	535	9%
Ion-Milling	15	16	23	7%
Total	$387	$422	$649	10%

Source: Dataquest
October 1986

Stripping should grow at a 15 percent CAGR to $91 million in 1990. This growth reflects the emerging market for single-wafer strippers. Ion-milling systems will grow at a 7 percent CAGR to $23 million in 1990.

Appendix A

DRY ETCH PRODUCTS

Company	Model/Series	Price Range	Comments
Barrels			
Branson/IPC	L2100	$30,000 to $40,000	
	L3100	$40,000	
Electrotech	PE508	N/A	
Psi Star	8200	$90,000	With pump; remote plasma
Tokyo Ohka	OPM-A Series	$100,000	Cassette to cassette
Plasma Systems	AEN, AH, AV	N/A	Several configurations
Single-Wafer Strippers, Remote Plasma			
Machine Technology	AfterGlo DPR	$110,000	
Matrix	N/A	$87,500	
Gasonics	Aura	$78,000	
Alcan Tech	MAS 800	$100,000	
Emergent Technologies	Phoenix NORD	$110,000	Pump included
Branson/IPC	L3200	$130,000	Without pump

(Continued)

Appendix A (Continued)

DRY ETCH PRODUCTS

Company	Model/Series	Price Range	Comments
Single-Wafer Strippers, Contact Plasma			
Plasma-Therm	Wafer/Strip	$95,000	Without pump
Tegal	Model 900e	$110,000	With pump
Plasma Systems (Semix)	PE 615	$125,000	With pump
Single-Wafer Plasma Systems			
Lam Research	600 Series	$250,000 to $365,000	
Varian/Zylin	Zylin 10	$400,000	Aluminum
	Zylin 100	$500,000	Aluminum, oxide, and poly
Drytek	Quad System	$395,000	4 chambers
Tegal	900 Series	$110,000 to $220,000	
Tokyo Ohka	OAPM-300	$100,000	
	OAPM-400	$200,000	Loadlocked
	OAPM-500	N/A	Loadlocked, 2 chambers
Plasma Systems	DES-A303	$180,000	Loadlocked
	PE-615	$116,000	
Ramco	RAM-400SE	$290,000	All processes except Al

(Continued)

Appendix A (Continued)

DRY ETCH PRODUCTS

Company	Model/Series	Price Range	Comments
Single-Wafer Plasma Systems (Continued)			
Plasma-Therm	X-160	N/A	Oxide
	P-360	N/A	Poly
	In-line	N/A	Aluminum
Perkin-Elmer	20000	$395,000	2 chambers
Electrotech	M4	N/A	RIE, triode options, multi chambers
Single-Wafer RIE Systems			
Tokuda	Hirrie 100	$500,000	Magnetron
Materials Research	Aries	$395,000	Magnetron
Balzers	SWE 654	$250,000	
GCA	WaferEtch 606	$400,000	Triode
Tegal	Model 1500e	$310,000 to $390,000	Triode
Anelva	4013	$450,000	4 chambers
Batch Systems			
Applied Materials	8100	$300,000 to $400,000	Hexode, no load-lock
	8300	$675,000	Hexode, cassette to cassette, loadlock

(Continued)

Appendix A (Continued)

DRY ETCH PRODUCTS

Company	Model/Series	Price Range	Comments
Batch Systems (Continued)			
Anelva	4000	N/A	
Plasma-Therm	Batch	N/A	24 wafers
Tokuda	555	$400,000	12 wafers
Electrotech	5200 Series	N/A	
Kokasai (Veeco)	DV-40	N/A	

N/A = Not Available

Source: Dataquest
October 1986

Equipment Communications

SUMMARY

To maintain a competitive edge in manufacturing technology, major semiconductor manufacturers worldwide are adopting a strategy for automation of fabrication facilities in the 1980s. Processing and test equipment, workstation terminals, robots, and material transfer systems are being linked together through a communications network to support integrated manufacturing on the shop floor. Sophisticated software packages to control and coordinate the manufacturing environment are being developed in order to provide semiconductor manufacturers with timely access to the flow of information that characterizes the fabrication sequence of today's advanced devices.

The financial and strategic incentives for implementing computer integrated manufacturing (CIM) in the semiconductor industry have been the subject of numerous symposia and publications. The central goals of automation include efficient WIP (work in progress) monitoring of wafers through the processing sequence, increased equipment utilization through efficient line balancing, process recipe management, as well as access to and analysis of data to optimize process control in real time. In addition, the removal of the operator from the processing environment results in yield enhancement through reduced particulates. Semiconductor manufacturers must choose from a variety of criteria to evaluate the payback analysis most appropriate for automation of their facilities.

Protocol Specifications

Regardless of the CIM software package being employed, whether it is the result of an in-house development effort or a commercially available product, a successful automation effort requires a communications protocol for the network in order to establish the electronic guidelines for communication between the various computing devices on the shop floor. A communications protocol helps to ensure operational consistency and compatibility among the equipment-level, cell-level, and factory host computers operating in the network environment. In the semiconductor industry, SEMI (Semiconductor Equipment and Materials Institute) has proposed and developed SECS (SEMI Equipment Communications Standard) as a communications protocol for semiconductor manufacturing. Semiconductor equipment manufacturers are responsible for implementing the SECS protocol on their equipment to enable equipment/host communications within the fab.

Several semiconductor manufacturers such as Intel, Texas Instruments, and Thomson Components-Mostek Corporation, have already established minimum protocol specifications. DATAQUEST believes that equipment manufacturers that can satisfy the needs of IC manufacturers will gain a

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strategic market advantage in providing equipment to the semiconductor industry. Equipment manufacturers have the opportunity to participate in the formative stages of automation in the semiconductor industry, and in the process, to establish firm relationships with the automation leaders.

Equipment/Host Communications

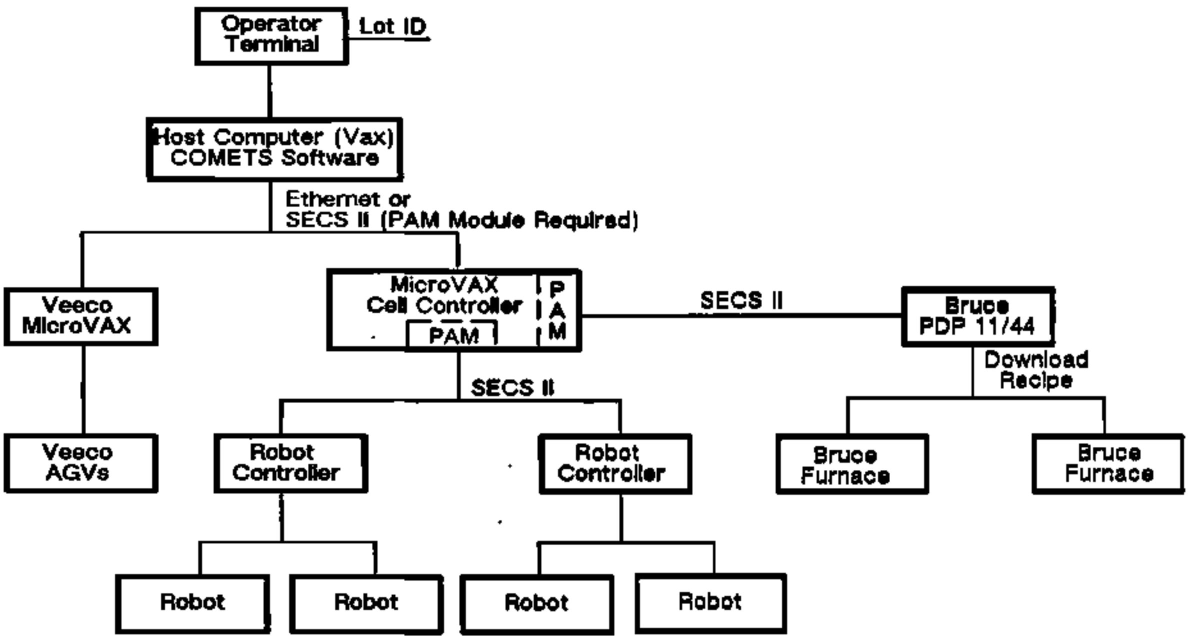
The SECS protocol supports a hierarchical topology of computing devices in the semiconductor manufacturing environment. A host computer (for example, a VAX computer from Digital Equipment Corporation) is located at the top of this network topology and communicates with node or cell-level computers at an intermediate level. The node computers (for example, MicroVAX computers), in turn, communicate directly with a given set of processing equipment or robots that has been grouped together in a manufacturing cell. The equipment within a cell typically has similar processing functions and responsibilities, and as such exists as a distinct area of manufacturing activity. Semiconductor manufacturers have chosen a cell-by-cell approach to equipment automation in their facilities by automating one processing area at a time, such as a diffusion cell or photobay, and adding automation capabilities to new cells as time and resources allow.

As an example of an actual installation, Figure 1 illustrates the configuration of processing equipment, robotics, and computers in a fully automated diffusion furnace cell. Thomson Components-Mostek Corporation has chosen the Consilium COMETS package, including the PAM (Process Automation Management) module, for computer integrated manufacturing at its Carrollton, Texas, facility. An operator is responsible for inputting the appropriate lot identification (ID) at a workstation terminal in the fab. The host receives the ID number of the lot awaiting diffusion, and communicates the information to the cell-level controller and Veeco-dedicated MicroVAX, which in turn communicate with the robots and AGVs (automatic guided vehicles) that are responsible for material movement within the cell. The appropriate process recipe is downloaded from the node (cell-level) computer to the diffusion furnace, and the process is initiated automatically. All of the relevant processing status information and results are communicated to the node computer and the host system via the SECS II protocol, a subset of the SECS protocol that specifies a detailed message set for semiconductor manufacturing.

The purpose of this study is to evaluate and quantify the current status of SECS implementation by equipment manufacturers. The other equipment issues related to automation that will be discussed include the development of equipment-specific interfaces to link equipment to a given CIM software system, and the level of operator interactions with the processing equipment in a fabrication environment. The study also presents an overview of the SECS protocol, the communications standard MAP (General Motors' Manufacturing Automation Protocol), and MAP's potential impact on the semiconductor industry. Appendix A provides general background information on the concepts and terminology used to describe communications networks; particular emphasis is placed on those network components supported by the SECS and MAP protocols.

Figure 1

FULLY AUTOMATED DIFFUSION FURNACE CELL



Source: Thomson Components-Mostek Corp.
DATAQUEST
February 1986

Equipment Communications

THE SECS PROTOCOL

In response to a growing concern to establish a communications protocol specifically focused on manufacturing in the semiconductor environment, the Semiconductor Equipment and Materials Institute (SEMI), through its Communications Subcommittee, proposed and developed an equipment communications protocol known in the industry as SECS. SECS is designed to provide communication capabilities between computers in semiconductor processing equipment and upstream node or host computers. In its simplest implementation, process recipe information can be downloaded from a host system to the equipment, and the equipment in turn can communicate process and equipment status information as well as collected data to the host system. Equipment-level communication (also referred to as Level 1 or cell-level communication) is the first step in a bottoms-up approach to integrated factory automation.

The SECS protocol is divided into two parts, known as SECS I and SECS II. The SECS I protocol, which addresses the electrical specifications and data link protocol between computers, was not designed to be specific to the semiconductor industry. The SECS II document, however, defines the general message set for transactions in a semiconductor processing environment, and as such, deal with units and concepts familiar to the industry, such as wafers, boats, and process recipes.

SECS I

The SECS I document was first published in SEMI Standards in 1980 and deals with the specifics of the electrical interface for connections between computers and the data link protocol (also known as the access method), which is responsible for establishing and governing the direction of communications between computers. (The electrical interface, RS-232, and the access method specified in the SECS protocol are discussed in Appendix A.) The SECS I document also defines the basic format for the message header, a 10-byte section of the message block that contains information used to ease the task of decoding transaction details.

SECS II

The SECS II document (first published in 1982) defines the message and data structures for the actual transactions between computers and processing equipment. The message set that has been chosen for the SECS protocol is meant to represent the typical activities required for IC manufacturing. Some number of custom messages may be required for equipment-specific applications. For a more thorough understanding of the protocol, the reader is encouraged to consult the SEMI document itself, or to participate in a tutorial short course on SECS such as that available from GW Associates, Mountain View, California.

Message Structure

A standard SECS message consists of a specified number of blocks of information. Multiblock messages are allowed by the SECS protocol and may contain up to 32,767 blocks for a total of 7.99 Mbytes of information in a single message. Each block includes a length byte, the message header (10 bytes), the text itself (0 to 244 bytes), and a checksum (2 bytes). The header (defined in SECS I) has a fixed format with bytes specified for the device ID (message source or destination can be designated), stream and function codes (identifies type of message to be sent), block number (specifies which block is being sent in a multiblock sequence), and system bytes (used for internal bookkeeping by the message source computer). The length and checksum bytes are used to validate successful message transmission between the source and destination.

Data Structure

The general topic of the message text is identified by the stream and function codes designated in the header. The message text within any given block of a multiblock message is structured as a series of data items. Each data item contains information that specifies the format of the data (ASCII, integer, floating point, etc.), the length of the data (in bytes), and the actual data itself. The protocol currently identifies 14 types of data format, and the choice of format is left to the user's discretion. A "list" data item may also be used to designate a series of data items in the message text. In a list data item, the length field specifies the number of data items contained in the list rather than the length in bytes of the list. In addition, list items can be embedded within other list items. Where appropriate, the protocol specifies the data and list structure of the different stream/function codes.

Message Set

The SECS II protocol classifies the different types of messages into eleven streams or general message types. Streams 1 through 11 are specifically defined in the protocol, while stream 0 is not used, and streams 12 through 63 are reserved for future use. Stream 64 through 127 are available for user-defined message topics.

Within each stream, there are a number of function codes that identify the associated subtopics of each stream. The same function code can have different meanings in the different streams, but function 0 is always defined as the abort message within that stream. For each stream, functions 1 through 63 are reserved for the specified messages of the SECS II protocol and its future updates. Functions 64 through 255 are available for user-defined functions, which are also known as custom messages. The number of functions currently defined in the protocol varies from stream to stream, and new function codes will continue to be specified as the protocol matures. However, within every stream, when a conversation is undertaken between equipment and host, the query message always has an odd function value, and the response always has an even function message; together they constitute a transaction. In some streams, only the odd function codes are used because, due to the type of message, no response is required. The associated even function code for those types of messages are not used.

Stream Definitions of the SECS II Message Set - The eleven streams that have been defined in the SECS II protocol are found in Table 1, along with a brief description of the general message category. The number of specified functions within each stream is also identified. Aborts (function 0, or F0) are present in every stream and are included in the number of functions in Table 1.

Problems with the SECS Protocol

Several issues have been raised with regard to problems in the SECS protocol. Some of the concerns focus on SECS I issues and include speed of data transmission, as well as problems with "message flooding." Ambiguity in the SECS II message set and choice of data format have also been mentioned by equipment manufacturers. These points will be discussed in the following paragraphs.

SECS I Problems

The SECS I protocol specifies an RS-232 connection between equipment and host systems with a typical data transmission rate of 9,600 baud (characters per second). This is considered by many as too slow for effective shop floor communications between a large number of processing stations and a host system. Since some types of metrology and process/test equipment acquire large amounts of data, the SECS I protocol is not well suited for massive data transfers because of its limited speed. For those applications, some level of preliminary data reduction and analysis would be required before data are sent to an upstream host system. The SECS protocol also specifies a point-to-point topology, which many manufacturers consider cumbersome because of the requirement for discrete wiring and channels of communication for every communications device on the shop floor.

Table 1

SECS II STREAM DEFINITIONS

Number	Stream Name and Definition	Specified Functions (#)
1	**Equipment Status** Allows host to monitor equipment status including current operating mode, depletion of consumables, and transfer status of material ports	11 (5 transactions, 1 abort)
2	**Equipment Control and Diagnostics** Messages deal with control operations of equipment from the host, includes remote operations and equipment self-diagnostics and calibration	29 (14 transactions, 1 abort)
3	**Material Status** Used to communicate material-in-process and time-to-completion information to the host	11 (5 transactions, 1 abort)
4	**Material Control** Used for automatic transfer of material between equipment	9 (8 odd functions, no responses specified, 1 abort)
5	**Exception Reporting** Communicates alarms generated by equipment in response to changing conditions detected by the equipment	7 (3 transactions, 1 abort)
6	**Data Collection** Covers the needs of in-process measurements and equipment monitoring	11 (5 transactions, 1 abort)
7	**Process Program Management** Used to manage and transfer equipment-specific process programs	35 (17 transactions, 1 abort)

(Continued)

Table 1 (Continued)

SECS II STREAM DEFINITIONS

Number	Stream Name and Definition	Specified Functions (#)
8	**Control Program Transfer** Provides method for loading equipment-specific boot and executive programs	5 (2 transactions, 1 abort)
9	**System Errors** Allows for equipment to inform host that received message block cannot be handled, or that time-out on transaction has occurred	8 (7 odd functions, no responses specified, 1 abort)
10	**Terminal Services** Used to pass text messages between equipment operator terminals and the host	6 (5 odd functions, no responses specified, 1 abort)
11	**Host File Services** Provides limited access to host file system	13 (5 transactions, 2 odd functions with no responses, 1 abort)

Source: 1985 SEMI Standards Volume II, E5-85

In the SECS Communication Handbook, published by GW Associates (1985), two situations are identified in which the SECS protocol does not adequately deal with message flooding of the communications link. In the first example, a piece of equipment, designated as the master, may flood the host with alarm messages and, since the host system as the slave always yields to the master, the host system may be unable to send a message to the equipment to shut itself off. Some SECS implementations have added the capability for the host to send a reverse interrupt, which would temporarily shift the master designation from the equipment to the host system.

In the second example of message flooding, the host may inadvertently flood a piece of equipment that lacks sufficient buffer with a heavy flow of messages. If the equipment is too busy to receive additional messages, there is nothing in the protocol that would allow the equipment to send a wait-acknowledge response to the host system. The only alternatives available to the equipment result in what appears to be a transmission failure on the part of the equipment. These two examples of message flooding illustrate some insufficiencies of the SECS I protocol that could cause problems in some applications.

SECS II Problems

Semiconductor equipment manufacturers have expressed concerns that the SECS II message set of the protocol is too ambiguous. Several equipment vendors have indicated that it is not clear which stream/ function code should be chosen for certain transactions. In addition, many manufacturers feel that the data format (binary, ASCII, floating point, etc.) for given messages should be specified, and not left as an arbitrary decision. The protocol currently provides 14 options for the data format. This level of discretion for the choice of data format can be a problem when an equipment manufacturer is trying to meet the particular specifications of different semiconductor manufacturers. These matters should be taken up with the SEMI Communications Subcommittee, which is responsible for the development and modifications of the SECS protocol as it matures.

THE MAP PROTOCOL

In the early 1980s, General Motors adopted a strategy of automation for its facilities to allow them to compete more effectively against the Japanese automotive industry. General Motors realized that a multivendor approach to automation would require a widely accepted, nonproprietary communication protocol for shop floor communications. The Manufacturing Automation Protocol (MAP) was developed by General Motors in 1982 in response to the need for such a standardized protocol for its manufacturing environment, and MAP has since gained acceptance as an evolving communications standard for general factory automation.

Specifically, MAP is a seven-layer, broadband, token-bus based communication protocol. The seven layers of MAP are based on the International Standards Organization's (ISO) Open Systems Interconnection (OSI) model for network communications. Broadband transmission, specified by the protocol, provides high-speed communications along multiple channels in the single transmission line of the bus network. The bus topology (the physical arrangement of computers within the network) specifies that the communications devices are linked to a single cable throughout the factory floor. Token passing is a type of access method that determines which computer within the network gets to transmit at any given time. The nature of token passing eliminates any possibility for more than one computer to talk along the same channel at the same time. (Broadband transmission, token passing and the bus topology are described in more detail in Appendix A.)

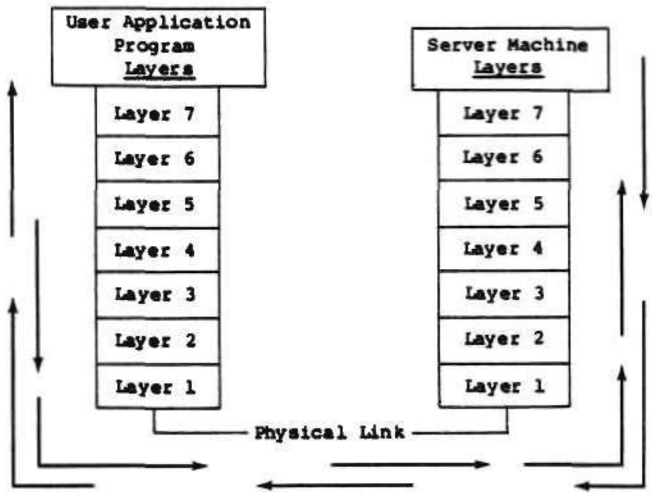
MAP incorporates nationally and internationally accepted standards developed by the National Bureau of Standards (NBS), the Institute of Electrical and Electronic Engineers (IEEE), the International Standards Organization (ISO), and the American National Standards Institute (ANSI). Much interest has been focused on the MAP protocol because it has managed to gain a sizable backing from many large companies in the United States and the international community within a relatively short period of time. Many credit the influence of General Motors for accelerating what is typically a glacial rate for protocol and standards development.

In network communications, there are two separate issues: applications, which are concerned with the preprogrammed functioning of computers, and communications, which provide a method by which computers can talk to one another. The OSI model separates out the applications from communications, and it is the structural details of the latter that are divided into the seven layers of the model. Table 2 illustrates the structure and defines the functions of the seven-layer model.

A block of information transmitted through the MAP network increases in size as it is transferred from the application program down through the communications levels from layer 7 to layer 1. At each level, the appropriate message header information is added to the message block in order to facilitate the subsequent transfer of information to the next level. After the data have been encoded at layer 1 and physically transferred to the next communications device, the information is transferred back up through the layers of the protocol to layer 7 and the application program. The message header information specific to each given layer is stripped off as the block of information passes through that level. In this sense, the system is hierarchical, with each layer providing communication-related services to the layer immediately adjacent to itself. This "nesting of protocols" allows the application to be separate from the communications functions. The effect is that the microcomputer, controller, processing equipment, or robot on the factory floor is responsible only for performing its task, not for communicating its results through the layers of the communication network.

Table 2

THE SEVEN LAYERS OF MAP



Layer 1: **The Physical Layer**
This layer deals with most of the hardware questions involved in networking, such as the actual medium that will be used and the rates at which data will be sent.

Layer 2: **The Data Link Layer**
This layer concerns the composition of the actual "frames" of data that are sent out on the network, as well as the protocols for getting those transmissions onto the network.

Layer 3: **The Network Layer**
This layer sets up the procedure for communications between different networks.

Layer 4: **The Transport Layer**
This layer makes sure a message reaches its destination. It is responsible for assembling a message into frames, then reassembling the frames upon arrival and sending back an acknowledgement.

Layer 5: **The Session Layer**
At this layer, connections are established between stations and logical names are mapped onto physical addresses.

Layer 6: **The Presentation Layer**
This layer converts the message into a form that can be used by the receiving device.

Layer 7: **The Application Layer**
This layer brings network services, such as electronic mail, to the end user.

Source: Intel Corporation
DATAQUEST
April 1986

A useful communications analogy to the OSI reference model is that of sending a letter through the postal system. When a letter (essentially a message or a block of data) is written and mailed, it must go through a series of intermediate steps before it is received at its final destination. The letter is placed in a mailbox, it is collected by a postal carrier, taken to the local post office, collated, sent on to a central post office, and collated once more for final destination. It is then transported (in some sense, analogous to the physical link) by truck, rail, air, or by ship to the receiving central post office. The letter goes through the appropriate sort mechanism, is sent off to the receiving local post office, sorted again, and delivered to the final destination. The communication sequence is independent of the contents of the letter that was written. In an analogous fashion, the seven layers of the OSI reference model facilitate communications in a factory network, but their operations are independent of the contents of the message that is being transmitted.

MAP Users Group

The MAP protocol has been aggressively promoted by General Motors as a viable standard for factory communications between equipment and computers supplied by multiple vendors. Many manufacturers have endorsed the protocol, including Boeing, Ford, General Electric, and Westinghouse. In addition, more than 350 companies have joined a MAP Users Group to promote industry-wide understanding of the protocol and provide a forum for discussion of MAP issues as the protocol matures. The MAP Users Group was established in February 1984 by General Motors with the assistance of such firms as DuPont, Eastman Kodak, and McDonnell Douglas. The Society of Manufacturing Engineers (SME) is responsible for coordinating the administrative activities of the MAP Users Group.

Boeing, in addition to supporting MAP, has developed TOP (Technical Office Protocol), which applies the same seven-layer architecture to office automation that MAP applies to manufacturing on the factory floor. A MAP/TOP Steering Committee is looking at integration of these two protocols that would allow transfer of data between management and manufacturing applications.

The MAP standard has been endorsed by many computer-based system suppliers as well. The list includes Allen-Bradley, Concord Data Systems, Digital Equipment Corporation, Hewlett-Packard, IBM, and Texas Instruments. In the semiconductor industry, Motorola, Intel, Industrial Networking Inc. (a joint venture between General Electric and Ungermann-Bass Inc.), and Concord Data Systems (in conjunction with Gould/AMI Semiconductor) have been very active in the production of chip and board-level products for the MAP standard.

International Activity

The MAP protocol has also generated interest from European and Japanese manufacturers. In Europe, MAP's counterpart is known as the European Communications Network for Manufacturing Automation (CNMA), a project of the ESPRIT research and development program sponsored by the European community. CNMA also plans to establish protocol capabilities for automated manufacturing and to evaluate and test them in practical applications. Siemens recently joined the CNMA, and will also continue to support MAP activities worldwide. The U.S. MAP Users Group has held discussions with Siemens concerning the compatibility of the MAP standards with the direction of communications development by the CNMA. MAP is also being evaluated in Japan. General Motors delivered a major presentation on the MAP protocol to Japanese manufacturers in the summer of 1985, and one GM official recently commented that he expects Japanese manufacturers to develop MAP products within the next year.

Testing of the MAP Protocol

One of the major obstacles to overcome in the acceptance of the MAP protocol as a de facto standard for manufacturing communications lies in the area of testing. Not only do individual products need to be tested for compliance to the multilayered MAP standard, but the successful interoperability between products from multiple vendors must be established. As with any emerging standard, vendor interpretation of the MAP specifications may still differ, which means that systems can be built that conform to the standard, but may not work with other "standard" products.

A demonstration at last November's Autofact '85 (a factory automation trade show held annually in Detroit) included an exhibit of products from 23 vendors tied together by a MAP system. The demonstration was sponsored by General Motors and Boeing, and vendors participating in the demonstration included Allen-Bradley, AT&T, Concord Data Systems, Digital Equipment Corporation, Gould, Hewlett-Packard, Honeywell, IBM, Industrial Networking Inc. (INI), Intel, Motorola, NCR, Northern Telecom, and Siemens. While the demonstration was hailed as an important step toward successful MAP implementation, it was considered by many as still a far cry from an actual installation of the communications protocol in a manufacturing and assembly line plant.

Work to develop MAP test equipment is under way at several locations, including General Motors, NBS, and the International Technology Institute (ITI), a nonprofit organization in Ann Arbor, Michigan. In September of 1985, the ITI became the first organization to introduce an independent conformance testing service for MAP products. General Motors is developing test facilities for MAP products in Canada, England, France, Germany, and Japan. Proposals have also been made for consortiums funded by multiple vendors and users of the MAP protocol to support the development of MAP testing tools. Many, however, concede that current test systems cannot check out MAP adequately for all operating situations that may be encountered in a real network, and that significant tasks lie ahead to determine how to test equipment for MAP compatibility and interoperability in a black-box test environment.

Problems with the MAP Protocol

In addition to a lack of test equipment and procedures for the MAP protocol, several other areas must be addressed before widespread implementation of the standard can be achieved. These include the specification of standards at the upper levels of MAP, development of low-cost interfaces to the network, and development of gateways to allow communication between MAP and non-MAP networks.

The MAP protocol is still in the development stage. Standards have been specified at the lower levels of the seven-layer model; however, standard specification at the upper levels has not been completed. The IEEE 802.4 standard, which is familiar to most people following MAP development, is employed only at layers 1 and 2, the physical and data link levels. General Motors officials claim that all of the standards should be in place by the end of 1988.

A network interface connects a node or network station to the broadband backbone of the MAP network. Between an equipment controller and the network itself, there will always be a "box," the network interface. It provides conversion of the node's protocol to the protocol used by the network and controls when the node can transmit. The interface could be, for example, a modem or an intelligent card. Currently, the costs for node/network interfaces are still high, and the lack of low-cost interfaces impedes the development of MAP-based communications networks. The continuing development of chip and board-level products to interpret the different levels of MAP will replace existing software programs and reduce costs for network interfaces.

A gateway provides interconnect capability from a MAP-based network to another digital communications system. It not only serves as the interface between two networks, but also provides protocol conversion between the two communications systems. Many facilities have local area networks such as DECNet or Ethernet in place. These systems would still be able to communicate with a MAP-based system through the gateway. For example, a group of CAD stations might communicate through an Ethernet system. When it comes time to send data to a host system, one computer in the cluster would be responsible for sending the information through a transfer device, or gateway, into the larger MAP network. Implementation of the MAP protocol in a semiconductor manufacturing environment might well employ a gateway to provide protocol conversion between SECS used at the lower levels of the communications network and a MAP-based system operating at the upper levels.

Finally, perhaps MAP's biggest problem is that the protocol is not simple, and thus there is a large degree of confusion as to how to design MAP-compatible products and how to implement a MAP-based communications network. Education will need to continue at all levels to ensure that MAP will continue to gain acceptance as a general communications protocol for factory automation.

SECS AND MAP IN THE SEMICONDUCTOR INDUSTRY

There has been some discussion that SECS might eventually be replaced by MAP as the communications protocol for semiconductor automated facilities. Some manufacturers have expressed doubt whether SECS has sufficient capability to provide the requirements of interactive communications in a large communications network. These manufacturers' complaints include that SECS is too slow, that it is based on only one standard (RS-232), and that it requires a point-to-point configuration that has logistic and economic disadvantages when the automation environment grows beyond a certain size. The question has been raised whether MAP may be a suitable substitute for SECS or if complementary components of the two protocols might be brought together for implementation in the semiconductor industry. Table 3 summarizes the advantages of these two protocols that would provide complementary functions in possible future applications in the semiconductor manufacturing environment.

Table 3

MAP AND SECS COMPARISON

MAP	SECS
Based on ISO/OSI model, which allows different types of network interconnections; uses ISO, NBS, and IEEE standards, all large standards organizations	Has an existing organization (SEMI) that focuses on specific semiconductor industry needs
Designed for general manufacturing environment; has the backing of large organizations	Has a good message set, specifically designed for semiconductor manufacturing environments
Thousands of man-hours have been invested; many MAP-related products have been developed	Many working implementations of the protocol exist
A real network (broadband, token-passing bus), not just a point-to-point configuration	

Source: DATAQUEST
May 1986

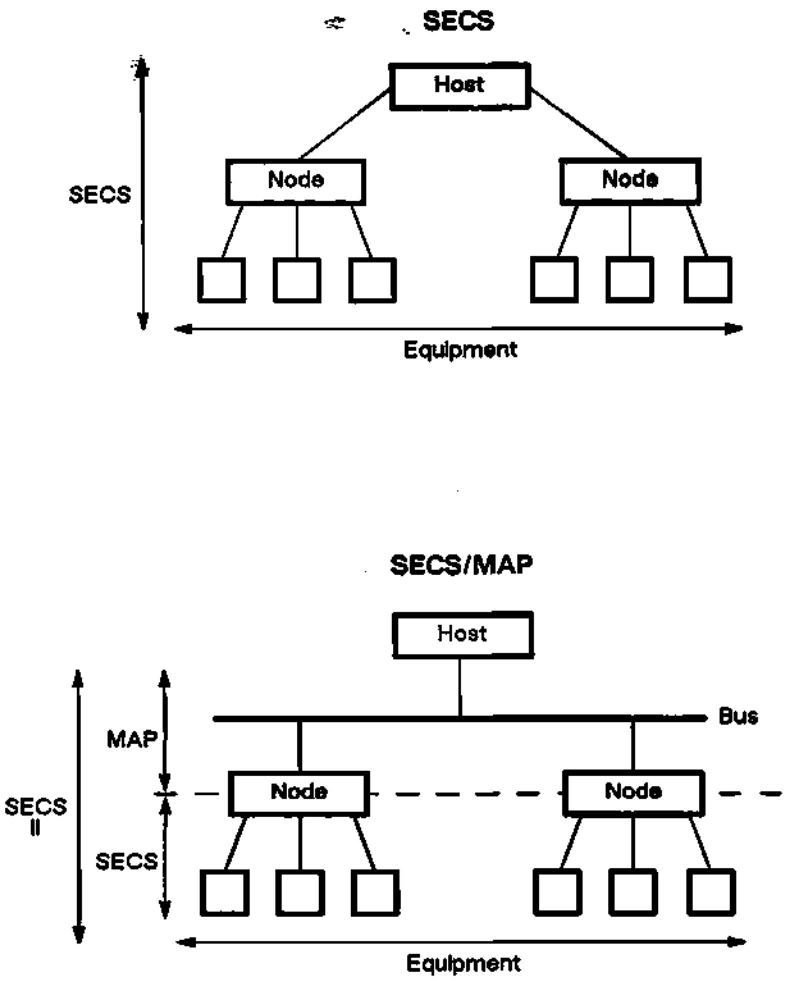
SEMI's Communications Subcommittee established the Network Implementation Task Force (NITF) in 1985 to develop network standards for the semiconductor industry. In particular, the NITF has decided to evaluate the potential for implementing the MAP protocol in a semiconductor manufacturing environment. Figure 2 illustrates the point-to-point arrangement of computers and equipment specified by the SECS protocol, and presents for comparison the topology that DATAQUEST expects will be employed in a SECS/MAP environment. This scenario retains the SECS protocol for communications between equipment and cell-level and node-level computers. Upper-level communications between host and node computers would follow the MAP specifications for a broadband, token-bus network that would provide high-speed communications along the multichannel transmission line of the bus. The SECS II message set would be maintained throughout the network environment because of its specificity to semiconductor manufacturing. MAP's message set is currently free-form in design and does not focus on the specific message needs of any given industry.

Equipment Communications

CIM manufacturers, such as Consilium and PROMIS Systems (a wholly owned subsidiary of I.P. Sharp), would be responsible for providing gateways between the MAP and SECS protocols. The gateway would likely reside at the level of the node computer to act as a translator between communications on the bus network of MAP and the point-to-point topology of semiconductor processing equipment that communicates with SECS. Equipment manufacturers most likely will not be responsible for linking their equipment directly to the MAP token-bus network, but will continue protocol implementation as specified in the SEMI SECS document.

Figure 2

SECS AND SECS/MAP TOPOLOGIES



Source: DATAQUEST
May 1986

However, equipment vendors cannot afford to entirely ignore the design and development of the MAP protocol and its associated chip and board-level products. The lack of understanding and education in automation issues, including protocol development, can result in substantial confusion, misdirected activities, and misspent resources for all concerned in the automation effort. MAP is a particularly complex and involved protocol, and DATAQUEST strongly encourages equipment manufacturers to either start now or continue current efforts in monitoring MAP development.

VENDOR IMPLEMENTATION OF THE SECS PROTOCOL

Equipment Survey Overview

DATAQUEST recently conducted a survey of semiconductor equipment manufacturers in order to evaluate the level of vendor commitment to the SECS protocol. Twenty-six equipment manufacturers representing eight general types of front-end processing equipment participated in the study in which a total of 42 models of equipment were discussed. The eight categories of front-end processing equipment include chemical vapor deposition (CVD) reactors, diffusion furnaces (including annealers) epitaxial reactors, dry etch equipment, ion implanters, lithography, sputtering, and automatic photoresist processing (track) equipment. The 26 survey participants combined represented 50 percent overall market share of the 1984 worldwide semiconductor front-end processing equipment market. The combined market share of survey participants in each equipment category is presented in Table 4. For example, the five lithography companies surveyed represented 75 percent of the 1984 lithography market.

Table 4

SURVEY PARTICIPANTS' 1984 WORLDWIDE MARKET SHARE BY EQUIPMENT CATEGORY

Equipment Category	Participants' Sum Market Share
CVD	14%
Diffusion/Anneal	55%
Dry Etch	62%
Epitaxy	58%
Ion Implantation	79%
Lithography	75%
Sputtering	54%
Track	61%

Source: DATAQUEST
May 1986

Equipment Communications

Discussions with equipment vendors were undertaken with the condition that information provided would not be reported by company; instead the information would be used to establish an industry perspective on equipment-level implementation of the SECS protocol and related automation issues. Participants in the study are identified in Table 5. The number beneath each equipment category indicates the number of equipment models that were discussed in the survey. In some instances, several models of equipment from the same vendor have been included. Vendor responses were for existing equipment models that are considered to be the most advanced, as well as for next-generation equipment currently under development.

Table 5

EQUIPMENT SURVEY PARTICIPANTS

	CVD	Diffusion/ Anneal	Dry Etch	Epitaxy	Ion Implant	Lithography	Sputtering	Track
Models of Equipment	4	6	9	3	3	6	4	7
Companies								
Advanced Crystal Sciences, Inc.		X						
ASM America		X						
Anicon Incorporated	X							
Applied Materials, Inc.			X	X	X			
BTU Engineering Corporation		X						
Drytek Inc.			X					
Eaton Corporation					X	X		X
GCA Corporation			X			X		X
Gemini Research				X				
Genus Incorporated	X							
Lam Research Corporation			X					
Machine Technology, Inc.								X
Materials Research Corporation			X				X	
Nikon Precision, Inc.						X		
Perkin-Elmer			X			X	X	
Semiconductor Systems, Incorporated								X
Silicon Valley Group, Inc.	X							X
Solitec, Inc.								X
Tegal Corporation			X					
Temescal							X	
Thermco Systems, Inc.		X						
Tylan Corporation		X						
Ultratech Stepper						X		
Varian Associates	X	X			X		X	
Veeco Instruments Inc.								X
Zylin Corporation			X					

Note: In some cases, more than one model of equipment from the same vendor has been included in a given equipment category.

Source: DATAQUEST
April 1986

SECS II Implementation by Equipment Vendors

Of the 42 equipment models that were surveyed, 39 models have SECS capability. Of those 39 equipment models, 28 models already have an existing SECS protocol implementation, while 11 models have their SECS implementation currently under development such that a software release will be available in 1986. Table 6 summarizes the vendor response on SECS implementation by equipment category.

Table 6

IMPLEMENTATION OF THE SECS PROTOCOL

Equipment Category	Yes	UD	No
CVD	2	2	0
Diffusion/Anneal	5	1	0
Dry Etch	6	3	0
Epitaxy	1	1	1
Ion Implantation	2	1	0
Lithography	3	2	1
Sputtering	3	1	0
Track	6	0	1
Total	28	11	3
Percent Response	67%	26%	7%

Source: DATAQUEST
April 1986

In order to quantify the level of vendor implementation of the SECS protocol, equipment manufacturers were requested to provide specific information on their SECS II message set, in particular the total number of SECS II messages and the number of messages per stream, whether specified or custom. Message detail was provided by equipment manufacturers for 27 of the 39 models of equipment. Transactions between equipment and host typically consist of a query and a response, each of which has a different function code designation in a given stream. Survey respondents were requested to include the total number of stream/function codes (messages) that the equipment is responsible for sending to or receiving from a host system. Custom messages are included in the message count. Vendors were also requested to indicate whether they had chosen to include any of the abort transactions (function 0) provided in each stream.

Total Message Count

The SECS II protocol provides a general message set for transactions between processing equipment and a host computer system in an automated semiconductor fabrication environment. However, as one equipment vendor was quick to point out, "No two people do SECS the same way." Therefore, while the SECS protocol does provide a standardized structure for communications, a great deal of variety exists in the interpretation and number of messages a vendor has chosen to specify for his equipment.

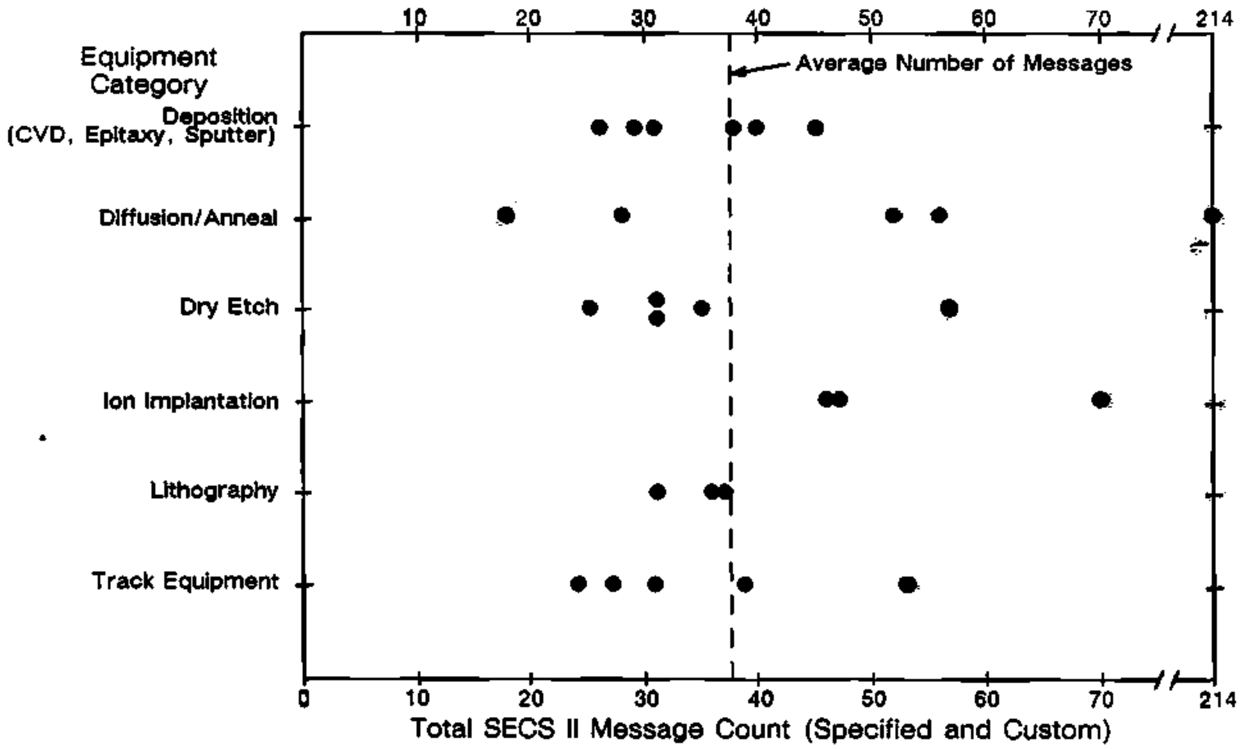
Each point in Figure 3 represents the total number of SECS II messages from a particular model of equipment (total 27 models of equipment). For example, the three models of lithography equipment have message sets consisting of 31, 36, and 37 function codes, respectively. The number of messages in Figure 3 represents those function codes (both specified and custom) that equipment vendors have implemented in the eleven standard streams of the protocol. (Two vendors have developed messages for custom streams; these messages are not included in Figure 3.) Not only is there a wide range in the number of messages between the various categories (18 to 214), but also within a given equipment category. (Sputtering equipment, epitaxial, and CVD reactors have been classified in a general deposition equipment category in this figure to maintain equipment vendor anonymity.)

The average number of total messages implemented by equipment vendors in Figure 3 is 38 (excluding the one diffusion entry of 214 messages). The absolute number of messages implemented by a given equipment manufacturer does not necessarily reflect the level of protocol software sophistication for the equipment. It is possible that some equipment manufacturers have chosen to implement a very efficient, compact message set while others have included a large number of special-function custom messages to enhance the protocol's capabilities.

What is most important is not the absolute number of messages that have been chosen but rather that the implemented message set includes all of the necessary functional components of the protocol such as recipe management (uploading and downloading), process and equipment status, and alarm information. Two factors--specific message code implementation and functionality of the message set--could well be represented by a unique set of stream/function codes, which, if detailed in the exact same manner by all equipment manufacturers, would ensure a standardized implementation across the board for all types of equipment. However, in reality vendor interpretation and implementation of the SECS II messages can vary considerably, and yet still meet the necessary requirements for functionality of the message set.

Figure 3

TOTAL SECS II MESSAGE COUNT--SPECIFIED AND CUSTOM BY EQUIPMENT CATEGORY



Source: DATAQUEST
MAY 1986

Upon the completion of their SECS protocol, equipment manufacturers must be able to provide semiconductor manufacturers with a document that contains details of their SECS II message set. Semiconductor manufacturers such as Intel, Texas Instruments (TI), and Thomson Components-Mostek Corporation (TCMC), have taken the first step in equipment-level automation and have provided equipment manufacturers with minimum SECS II message set requirements. These manufacturers feel that their minimum message sets include the essential functionality of the SECS II protocol. In addition, they are attempting to ensure standardization throughout their own facilities by providing clear guidelines to the equipment industry. Other semiconductor manufacturers have chosen to specify the broad functional components of the protocol, which they feel are necessary for equipment/host communication in an automated facility. The details of the protocol implementation are left to their equipment vendors and the CIM manufacturer responsible for coordinating their automation efforts.

Specified Message Count

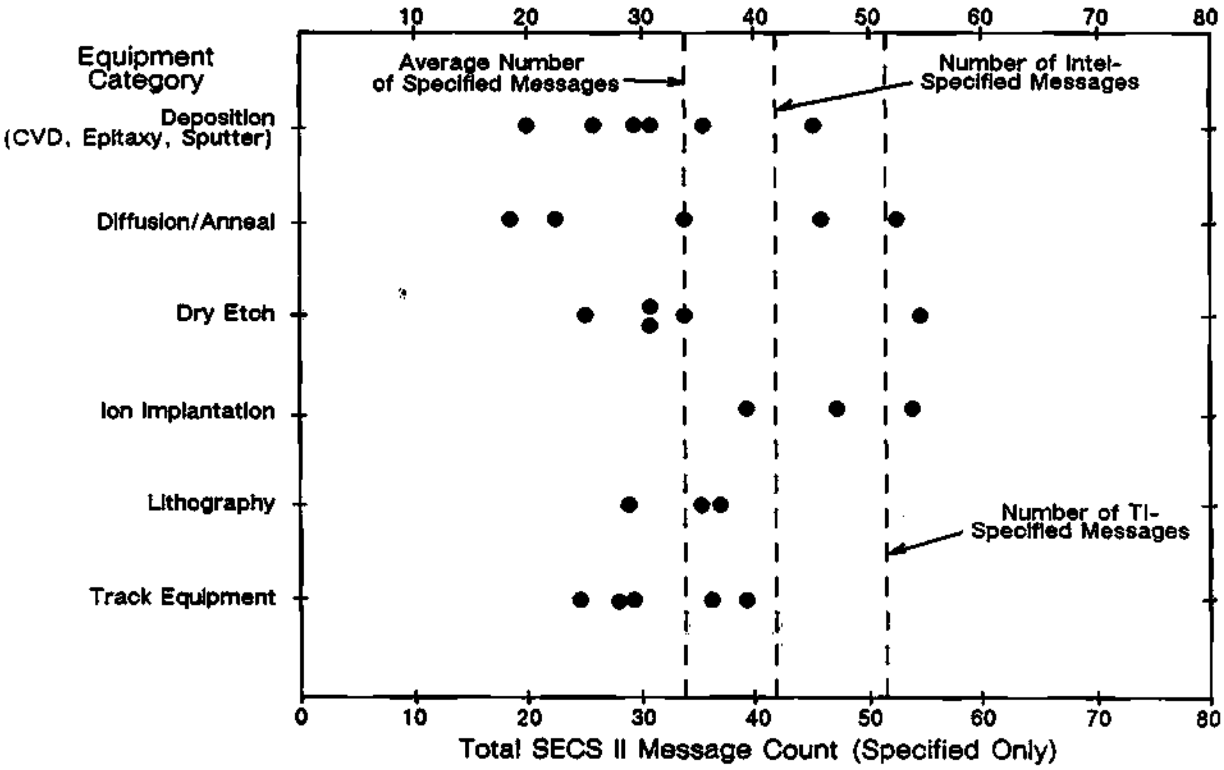
Figure 4 compares the number of protocol-specified messages implemented by equipment manufacturers with the number of messages specified by Intel and Texas Instruments in their minimum SECS message sets. The information in Figure 4 is essentially the same as that contained in Figure 3, except that custom messages have been removed from the total message count for 14 of the 27 equipment models that include these equipment manufacturer-defined functions. On the basis of specified message count, the average number of messages implemented for the 27 equipment models is 34.

Intel's SECS II specification identifies 42 messages from 7 different streams as the minimum set necessary for implementation on process and analytical equipment. Only 6 equipment models of the 27 represented in Figure 4 can meet Intel specifications based on specified message count alone. Similar to Intel, TI also has a set of specifications that defines a minimum set of messages for equipment vendor implementation. In TI's case, 51 messages in 9 streams have been identified. Only 3 of the 27 equipment models in Figure 4 have more than 51 specified messages in their SECS II message set. In addition, only 14 of the 27 survey respondents that provided detailed information on their SECS II message sets included any abort messages in their protocol implementation. Both Intel and Texas Instruments require the abort message for every stream in which messages have been specified. On the basis of the information presented in Figure 4, the majority of equipment manufacturers will have to make substantial additions to their present message sets in order to satisfy Intel and Texas Instruments requirements.

Intel and Texas Instruments recognize that minimum SECS II requirements from semiconductor manufacturers should be focused on specific categories of equipment rather than on a general message set for all wafer processing equipment. Both manufacturers are willing to negotiate their minimum message set requirements with equipment vendors since in some cases, the messages may not be appropriate for a given type of equipment. However, these semiconductor manufacturers will not negotiate when an equipment vendor has chosen to implement his own custom messages when existing messages in the protocol would have sufficed. The generic minimum message subsets from Intel and TI are meant as a guideline for equipment protocol development to ensure that equipment purchased for Intel and TI facilities has sufficient communications capability to operate in an automated environment. Clearly, if Intel's and Texas Instruments' message sets are indicative of the minimum requirements for general SECS II implementation in the industry, the majority of equipment vendors face major customization of their SECS protocol at some stage when a semiconductor manufacturer decides to automate its facilities. DATAQUEST believes that this is an extremely important finding to come out of this survey.

Figure 4

TOTAL SECS II MESSAGE COUNT--SPECIFIED ONLY BY EQUIPMENT CATEGORY



Source: DATAQUEST MAY 1986

Message Count per Stream

Table 7 contains information on the average number and range of function codes implemented per stream for the 27 equipment models represented in Figure 3. Equipment manufacturers choose the set of messages that they feel are most appropriate for implementation on their equipment. The first column in Table 7 indicates the number of equipment models for which any messages (whether specified or custom) have been implemented from the 11 streams. The second column identifies the total number of function codes per stream that have been specified to date in the *SECS II protocol document (from Table 1)*. The average and range in the number of function codes that equipment manufacturers have chosen to implement is presented in columns three and four of Table 7.

Table 7

FUNCTION CODE COUNTS PER STREAM

	Equipment Models with Function Codes in the Stream	Total Number of Function Codes Specified in Protocol	Average Number of Function Codes Implemented	Range in Number of Function Codes
Stream 1				
Specified	27	11	4	2-9
Custom	6	0	3	1-7
Stream 2				
Specified	27	29	7	2-20
Custom	8	0	7	1-34
Stream 3				
Specified	7	11	2	1-5
Custom	4	0	5	1-8
Stream 4				
Specified	7	9	6	1-9
Custom	6	0	12	2-36
Stream 5				
Specified	25	7	3	1-6
Custom	3	0	3	1-6
Stream 6				
Specified	16	11	4	1-10
Custom	4	0	3	1-10

(Continued)

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Table 7 (Continued)

FUNCTION CODE COUNTS PER STREAM

	Equipment Models with Function Codes in the Stream	Total Number of Function Codes Specified in Protocol	Average Number of Function Codes Implemented	Range in Number of Function Codes
Stream 7				
Specified	25	35	8	4-15
Custom	5	0	16	1-54
Stream 8				
Specified	0	5	0	0
Custom	1	0	30	30
Stream 9				
Specified	27	8	6	1-8
Custom	2	0	2	1-3
Stream 10				
Specified	10	6	3	1-5*
Custom	0	0	0	0
Stream 11				
Specified	1	13	5	5
Custom	0	0	0	0

*Note: One manufacturer has chosen to include an additional 7 specified function codes in Stream 10 that have yet to be accepted by the SEMI Communications Subcommittee for incorporation into the SECS II message set. With the inclusion of those additional 7 responses, the average number of messages specified in Stream 10 is 4, with a range of 1 to 11.

Source: DATAQUEST
May 1986

Specific stream/function message detail is regarded by many equipment manufacturers as proprietary information, so only the number of function codes implemented are included in Table 7. The SECS protocol provides equipment vendors with the option of implementing custom streams (S64-S127) as well as custom function codes (F64-F255). Two of the 27 message sets that were received by DATAQUEST in the survey include custom streams and 14 of the 27 message sets contain custom function codes. Table 7 does not contain custom stream information, only those function code counts for the 11 specified streams of the SECS II protocol.

In Table 7, the streams that show the largest degree of protocol activity are Streams 1 (Equipment Status), 2 (Equipment Control and Diagnostics), 5 (Exception Reporting), 7 (Process Program Management), and 9 (System Errors). At this time, only 7 equipment models in the survey have specified functions implemented in Stream 4, which defines messages associated with material control and provides for equipment/robotic interactions. No equipment models include specified functions from Stream 8, which is responsible for loading equipment-specific boot and executive programs. (For some models and types of equipment, this type of application is not possible.)

Again, it is instructive to compare equipment vendor activity in a given stream with the specifications that Intel and Texas Instruments have defined as a minimum message set for SECS II protocol implementation. Table 8 compares the average number of specified function codes per stream implemented by equipment vendors (from Table 7) with the number of messages in the 10 streams that Intel and TI recommend for a minimum message set. Both Intel and TI require that the abort transaction (F0) be included in every stream in which messages have been specified, therefore, these messages are accounted for in Table 8. As mentioned previously, of the equipment vendors that provided protocol information to DATAQUEST, only 14 of 27 responses have chosen to include any abort transactions in their protocol implementation.

Table 8

FUNCTION CODE COUNTS PER STREAM FOR VENDOR IMPLEMENTATION, INTEL, AND TI REQUIREMENTS

	Equipment Models with Function Codes in the Stream	Total Number of Function Codes Specified in Protocol	Average Number of Function Codes Implemented	Intel Number of Function Codes Specified	TI Number of Function Codes Specified
Stream 1					
Specified	27	11	4	3	7
Stream 2					
Specified	27	29	7	11	7
Stream 3					
Specified	7	11	2	*	7

(Continued)

Table 8 (Continued)

FUNCTION CODE COUNTS PER STREAM FOR
VENDOR IMPLEMENTATION, INTEL, AND TI REQUIREMENTS

	Equipment Models with Function Codes in the Stream	Total Number of Function Codes Specified in Protocol	Average Number of Function Codes Implemented	Intel Number of Function Codes Specified	TI Number of Function Codes Specified
Stream 4 Specified	7	9	6	*	9
Stream 5 Specified	25	7	3	7	3
Stream 6 Specified	16	11	4	3	5
Stream 7 Specified	25	35	8	*	5
Stream 8 Specified	0	5	0	5	*
Stream 9 Specified	27	8	6	8	5
Stream 10 Specified	10	6	3	5	3
Stream 11 Specified	1	13	5	*	*

*No specifications at this time.

Source: Intel Corporation
Texas Instruments
DATAQUEST
May 1986

While the specific function codes that Intel and Texas Instruments have identified in their minimum subsets are not compared directly with the vendors' choice of messages, it is only in Streams 1 and 6 that equipment vendors have exceeded the number of minimum messages specified by Intel, and in Streams 2, 5, 6, 9, and 10 that equipment vendors have equaled or exceeded the message count specified by Texas Instruments.

Table 8 also illustrates the degree of variability between the message sets of the two semiconductor manufacturers. In the case of Stream 8, Intel specifies that all five function codes be implemented, when applicable, while Texas Instruments has chosen not to include any messages from Stream 8. On the other hand, Texas Instruments has identified messages from Streams 3, 4, and 7, where Intel has no specifications at this time. If an equipment manufacturer chose to comply with the number of messages that would satisfy both Intel and TI specifications (based on the overlap of the stream/function message set between TI and Intel), a total of 73 specified messages from the SECS II protocol would be required. Not a single equipment model of the 27 that provided detailed protocol information in the DATAQUEST survey can meet both Intel and TI's minimum message set specifications on the basis of message count alone.

As mentioned previously, both TI and Intel recognize that protocol message requirements really should be directed toward specific equipment categories, and both are willing to negotiate with equipment manufacturers over messages that are not necessarily appropriate for a given type of processing equipment. However, for a fully automated manufacturing facility, semiconductor manufacturers probably will require equipment communications capability to exceed those specifications already identified by Intel and Texas Instruments.

Additional Specifications

Up to this point, discussion in this analysis has centered only on the number of function codes that have been specified in each stream. For a more accurate comparison of protocol specifications between equipment and semiconductor manufacturers, the actual function code numbers used to identify the messages and the data structure also must be identified. The data structure includes the data element name, the format, and the length (in bytes) of the data. The SECS II protocol does provide data element names but data format, of which there are 14 options in the protocol, and data length are variable. Therefore, even if semiconductor and equipment manufacturers specify the identical stream/function codes, it is still possible that the message sets are not entirely compatible due to differences in the data format and length. Equipment and semiconductor manufacturers must come to a common consensus for data structure as well as protocol specifications in order to achieve some level of standardization in equipment communication throughout the industry.

Custom Messages

The SECS protocol provides equipment vendors with the option of implementing custom streams (S64-S127) and custom function codes (F64-F255). The SEMI Communications Subcommittee recognizes that there will be user needs beyond the specific definitions given in the protocol because of equipment-specific applications. In addition, the protocol reserves stream and function codes for future messages that will be adopted by the Communications Subcommittee as the protocol matures. One vendor that supplied protocol information to DATAQUEST included an additional 7 messages in Stream 10 that as yet have not been adopted by the committee. Two of the 27 message sets in the survey include custom streams and 14 of the 27 message sets contain custom function codes. Table 9 summarizes custom message implementation by equipment category for the 27 message sets.

Table 9

CUSTOM MESSAGE IMPLEMENTATION BY EQUIPMENT CATEGORY

Category	Yes	No
CVD	1	2
Diffusion/Anneal	3	2
Dry Etch	3	2
Epitaxy	1	0
Ion Implantation	2	1
Lithography	2	1
Sputtering	0	2
Track	2	3
Total	14	13

Source: DATAQUEST
April 1986

From Table 9, it is clear that equipment manufacturers are implementing custom messages in all categories of front-end processing equipment (except sputtering, for which only a limited sampling size was available). While custom messages provide extended communication capability for equipment-specific applications, their presence also demands that semiconductor manufacturers and equipment vendors have a clear, consistent understanding of the interpretation of these messages. Some semiconductor manufacturers will not accept processing equipment utilizing a custom message set without conducting substantial negotiations. In particular, TI and Intel will not accept custom messages when specified messages within the SECS II message set would have sufficed. In addition, the development of an equipment-specific interface by a CIM manufacturer requires additional time, resources, and cost for those equipment models that implement a large custom message set. Thus, equipment manufacturers that choose to include custom messages in their protocol should carefully evaluate semiconductor and CIM manufacturer response to their message set in order to avoid unnecessary costs or delays in protocol acceptance and interface development required before the equipment can be integrated into an automated environment.

Testing of the SECS Protocol

It is very important that an equipment vendor's implementation of the SECS protocol is tested, not only to ensure compliance with protocol specifications, but also to provide semiconductor manufacturers with the appropriate support documentation for the equipment. Several products are available that allow a semiconductor equipment manufacturer to test the implementation of his protocol. These systems include a SECS Protocol Emulator available from Texas Instruments, and SECSIM, a SECS Simulator from GW Associates. Both systems provide host and equipment emulation, and can send valid or invalid messages to monitor host/equipment responses. Both systems are PC-based for flexibility and low cost, and allow field engineers to provide trouble-shooting capability at the time of equipment installation within the communications network. Equipment protocol testing with CIM manufacturers is also possible with a CIM-based SECS emulator package or through a telephone hookup. CIM manufacturers encourage equipment manufacturers to have the proper dial-out and dial-in modems available at their facilities for the initial testing phase of their SECS protocol.

In addition, some equipment manufacturers have chosen to develop host emulator software packages. For example, Silicon Valley Group (SVG) provides an IBM XT-compatible software package for communication and protocol testing of its Host Computer Interface Unit, which is a local controller that coordinates operations and process control for SVG's track equipment. The software package allows semiconductor manufacturers to install and test the communication capabilities of the track equipment without requiring a fully operational host system in the fab.

The surveyed equipment vendors that have implemented or are currently developing the SECS protocol for their equipment were asked to identify the companies with whom they have tested their protocol. These companies include the major CIM manufacturers such as Consilium, Hewlett-Packard, PROMIS Systems, and Sentry/Schlumberger. (Note: Hewlett-Packard and Sentry/Schlumberger have recently chosen to exit the computer-integrated manufacturing market. HP is still active in the custom software market in Japan and the Far East, but chose not to fund major software rewrites for its CIM systems operational in Europe and the United States. Sentry/Schlumberger was not able to successfully commercially market their system.) Responses from equipment vendors also included testing of the protocol at beta sites with semiconductor manufacturers, as well as with a SECS emulator and with an in-house testing program.

Typically, a test of a SECS protocol implementation would include a direct or remote hookup to a host (or host-emulator) system that is capable of generating and responding to the basic message transmission and reception. Table 10 summarizes the vendor responses for testing of SECS protocol implementation. For the 39 equipment models in the survey for which a SECS protocol has been implemented or is being developed, some type of protocol testing program has been undertaken for 27 models of equipment. In several cases, multiple responses were given for a single equipment model and are included in Table 10.

Table 10

SECS PROTOCOL TEST PARTNERS

Test Source	Responses	Percent Responses
Consilium	14	30%
I.P. Sharp	9	19
Hewlett-Packard	6	13
Sentry/Schlumberger	2	4
Beta Site Test	11	23
In-House Test	3	6
SECS Emulator	2	4
Total	47	99%

Source: DATAQUEST
April 1986

Equipment Communications

EQUIPMENT-SPECIFIC INTERFACES

CIM manufacturers are responsible for the development of software equipment interfaces that allow a vendor's equipment to communicate with other computers linked by the factory automation network. The equipment-specific interface is dependent on the equipment vendor's interpretation of the SECS protocol. If the protocol changes, then the equipment interface must also change to reflect the software update. When an equipment manufacturer has to customize his SECS protocol for different semiconductor manufacturers, any equipment interfaces that have been developed by CIM manufacturers for that equipment model will also have to be modified. While the SECS II message sets can vary considerably from vendor to vendor, there is no fundamental problem in developing an equipment interface as long as the functional components of the protocol are present, such as recipe management, process and equipment status, and alarm information. However, the time and cost for equipment interface development could be reduced if vendor implementation of the protocol were not so diverse. The choice for interface development by a CIM manufacturer is driven by semiconductor customer needs.

Table 11 summarizes the total number of different types of equipment interfaces, by equipment category, that have been developed by Consilium, Hewlett-Packard, and PROMIS Systems. These three companies are the major CIM manufacturers that currently supply or have supplied software systems to the semiconductor industry. For every model of equipment, even within the same general category such as diffusion equipment, a unique interface must be developed by each of the different CIM manufacturers. The interface acts as an interpreter between the equipment and a given CIM software system to ensure that the host understands the set of equipment messages (both specified and custom) that are generated.

In several cases, equipment interfaces for the same model of equipment have been developed by the different CIM manufacturers. Table 11 includes multiple counting when several CIM manufacturers have developed an interface for the same model of equipment. Table 11 does not contain the total number of equipment interfaces that are operating on equipment in the installed base; rather, the numbers reflect only the number of different equipment models for which an interface has been developed. The number of interfaces currently under development for other models of equipment are indicated in parentheses. Metrology tools, parametric testers, and AGVs (automatic guided vehicles for material transport) have been included in Table 11.

The number of equipment interfaces presented in Table 11 focuses on equipment supplied by U.S. manufacturers. Hewlett-Packard has also developed equipment interfaces for more than 20 models of equipment for Japanese customers across the full spectrum of front-end processing equipment.

Table 11

EQUIPMENT-SPECIFIC INTERFACES
BY EQUIPMENT CATEGORY

Equipment Category	Number of Interfaces	
Diffusion	9	(1)
Dry Etch	1	(2)
Epitaxy	1	(1)
Ion Implantation	3	(2)
Lithography	0	(2)
Sputtering	1	
Wafer Clean Station	1	
Metrology	17	
Parametric	2	
AGV	2	(1)
Total	37	(9)

Note: Numbers in parentheses indicate the number of interfaces currently under development in a given equipment category.

Source: DATAQUEST
April 1986

Cameo Systems and CTX International offer equipment interfaces that focus on metrology and test equipment. Isitec Corporation offers equipment interfaces for wafer fabrication equipment, metrology tools, test, and assembly equipment for which no SECS protocol has been developed. Many semiconductor manufacturers have chosen to implement automation in their facilities in the front-end test and measurement areas first because of the data-intensive nature of the equipment. Short-term payback is achieved through efficient data collection, reduction, analysis, and archiving, which can be greatly simplified with the installation and implementation of a CIM automation package.

OPERATOR INTERFACE

While the previous discussion has focused on the protocol issues of equipment automation, it is also important to evaluate what level of operator interface and interaction is still required for equipment operation in today's version of an automated manufacturing environment. As part of the survey, equipment manufacturers were asked to identify the current level of operator interactions with processing equipment in three areas: operator input capability at the equipment, process parameter setup once the recipe has been received, and process initiation.

Operator Input Capability at the Equipment

Lot tracking is an important component of an integrated manufacturing system. DATAQUEST asked equipment vendors to indicate whether their equipment currently can accept the input of a lot identification number from an operator at the equipment. In an automated facility, there are several scenarios for entering the lot ID number into the host system and for subsequent verification of lot arrival and departure from the various processing stages. These include bar code readers as well as direct operator input at a keyboard that is part of processing equipment or at a workstation within the manufacturing cell. In addition, there is still the alternative of the traditional lot traveler that accompanies each lot through the processing sequence.

Several semiconductor manufacturers have indicated that they would like to see processing equipment capable of transferring lot ID information to the host system for verification rather than have the full burden fall on the host system to inform the equipment which lot should be arriving next for processing. This verification of lot ID at the equipment before and after processing would minimize potentially costly mistakes that might arise during the early stages of implementing a CIM system on the shop floor.

Table 12 summarizes the vendor responses categorized into four areas: equipment can accept lot ID from operator input and host download (via a SECS link); equipment can accept ID from host download only; equipment can accept ID from operator only; and equipment has no lot ID input capability. In the survey, for 18 of 42 equipment models, the equipment can receive lot ID input from the operator as well as from the host system, while an additional 21 models of equipment surveyed can receive lot ID information only from a host system. In one survey response, the equipment can accept a lot ID only from operator input at the equipment, and for two models of equipment, there is no access to the lot identification.

Table 12

LOT ID INPUT AT THE EQUIPMENT

Equipment Category	Operator Input/ Host Download	Host Download	Operator Input	No Input
CVD	1	3	0	0
Diffusion/Anneal	3	3	0	0
Dry Etch	2	7	0	0
Epitaxy	1	1	0	1
Ion Implantation	3	0	0	0
Lithography	4	1	1	0
Sputtering	2	2	0	0
Track	2	4	0	1
Total	18	21	1	2
Percent Responses	43%	50%	2%	5%

Source: DATAQUEST
April 1986

The methods of current operator input include keyboard and terminal that are part of the equipment (16 equipment models), alphanumeric touch screen (2 equipment models), and a light pen at an alphanumeric screen on the equipment (1 equipment model). In three cases, survey respondents indicated that bar code readers were being considered for next-generation equipment.

Less than half of the equipment models that were surveyed have the capability for operator input of a lot ID. This means that for some equipment that might be installed in an island of automation on the factory floor, some method of alternative lot ID verification would need to be established. In the absence of operators, advanced automated manufacturing fabs will include material logging systems such as automatic bar code readers directly at the equipment or at adjacent workstations under robotic control. As an interim measure in the transition to a "peopleless" fab, operator workstations and terminals throughout the fab may be logical points for material logging. DATAQUEST believes that processing equipment that provides operator input capability directly at the equipment offers semiconductor manufacturers a flexible alternative for lot ID verification. Processing equipment that provides such features and thus eases the transition to automation will receive special attention from semiconductor manufacturers.

Parameter Setup

An important and necessary step in an automated processing environment is the ability of equipment to accept a recipe download from the host system, to institute an automatic parameter setup, and to initiate the processing sequence. Table 13 addresses the issue of parameter setup that occurs after a recipe download or operator input has been received by the equipment, and includes setting and verifying parameters such as temperature, pressure set points, and alignment settings. Of the 42 models of equipment surveyed, 39 have the capability of accepting a recipe download via the SECS protocol. For the other 3 equipment models for which no SECS protocol has yet been developed, the only methods for current recipe input are either through direct operator input at the equipment, or by operator selection from a menu of recipes stored at the equipment.

Equipment manufacturers were asked to indicate whether their equipment initiates automatic parameter setup prior to process initiation or whether operator interaction with the equipment is necessary once the recipe has been received by the equipment. Some vendors responded that parameter setup responsibility is divided between operator and equipment, as noted in Table 13. In the survey, 35 of 42 equipment models can implement parameter setup with no operator interactions. DATAQUEST believes that fully automatic parameter setup is an essential component of equipment operation in an automated fab.

Table 13

PARAMETER SETUP

Equipment Category	Equipment	Operator	Equipment/ Operator
CVD	4	0	0
Diffusion/Anneal	6	0	0
Dry Etch	9	0	0
Epitaxy	2	1	0
Ion Implantation	1	1	1
Lithography	4	1	1
Sputter	3	0	1
Track	6	1	0
Total	35	4	3
Percent Responses	83%	10%	7%

Source: DATAQUEST
April 1986

Process Initiation

One final area of operator interaction with the equipment is in the area of process initiation. Vendors were asked to indicate whether the equipment or an upstream host system can initiate the process or whether an operator is required to "push the start button." As shown in Table 14, vendor responses indicate that there is essentially a 50-50 mix with regard to process initiation responsibility.

DATAQUEST believes that the current level of operator interaction with equipment must be reduced further in order to provide processing capability in a fully automated environment. Equipment that can operate solely on the basis of equipment/host transactions will be judged as that most suitable for operation in an automated facility. While manufacturers are making the transition to a "peopleless" processing environment, equipment that can accept a lot ID input from an operator provides a useful alternative for lot ID verification with host expectations. Semiconductor manufacturers are evaluating processing equipment today on the basis of such criteria as present and future automation strategies are being developed in the industry. DATAQUEST encourages equipment manufacturers to continue to focus on these issues as well as on increased equipment reliability, for which the level of operator interactions and assists also must be minimized in order to achieve manufacturing goals in an automated semiconductor fabrication facility.

Table 14

PROCESS INITIATION

Equipment Category	Equipment	Operator	Not Available
CVD	3	0	1
Diffusion/Anneal	4	2	0
Dry Etch	6	3	0
Epitaxy	1	2	0
Ion Implantation	1	2	0
Lithography	0	6	0
Sputtering	2	2	0
Track	5	2	0
Total	22	19	1
Percent Responses	52%	45%	3%

Source: DATAQUEST
April 1986

Equipment Communications

DATAQUEST ANALYSIS

DATAQUEST believes that equipment-host communications is a critical component in the automated manufacturing environment. Our current evaluation of this topic concludes that:

- The SECS protocol has been accepted as the industry standard for communications.

- While MAP may have a future in the semiconductor industry, it will not replace SECS at the equipment level.

- The opportunity exists for equipment manufacturers to gain a strategic market advantage with active participation in SECS protocol development.

- Equipment protocol implementation should not be a proprietary issue.

- DATAQUEST strongly encourages IC manufacturers to establish a clear consensus on SECS protocol specifications.

The SECS protocol clearly has been established as the standard for communications in the U.S. semiconductor industry. European and Japanese semiconductor manufacturers are also adopting the protocol in their facilities. To assist in the distribution of information on the protocol, the SEMI Communications Subcommittee has made presentations in Japan and the SECS protocol document has recently been translated into Japanese. Japanese equipment and computer manufacturers are contributing to protocol modifications and development through JEIDA (the Japan Electronic Industry Development Association) in order to achieve standardization of the SECS protocol.

The majority of semiconductor manufacturers involved in advanced device fabrication now require SECS compatibility for new equipment purchases. However, many offer little else for guidance. Equipment vendors have commented that most semiconductor manufacturers do not seem to know what they want with regard to automation or in the specifications of a SECS II message set. Many equipment vendors are thus faced with the prospect of developing a SECS protocol that will require special customization when the equipment is finally installed in an automated environment at a given semiconductor manufacturer's facility.

Clearly, there is a need for semiconductor and equipment manufacturers to establish a common framework for protocol implementation in order to remove the confusion surrounding the protocol and lower the software development costs of manufacturers. DATAQUEST believes that semiconductor manufacturers involved in the automation effort need to take the first step and establish a clear consensus on what they feel is necessary for SECS protocol implementation by equipment manufacturers.

It has been suggested that a SECS Users Group for IC manufacturers be organized as a forum for identifying protocol and automation needs from a manufacturing perspective. In particular, the SECS Users Group would identify protocol specifications for specific equipment categories. Equipment manufacturers would participate in the SECS Users Group and provide their current protocol documentation as an aid in evaluating the status of protocol implementation. Some equipment manufacturers, however, regard their protocol implementation as confidential information. Semiconductor processing equipment should not be competing on the basis of protocol implementation but rather on equipment design and special features.

CIM manufacturer involvement with a SECS Users Group is also very important because the development and implementation of a CIM software package is the critical link between the equipment and the manufacturing elements of the fab. The time and cost for linking equipment to a CIM system in a semiconductor fab would be reduced considerably if the implementation of a SECS protocol offered a standardized procedure for interactive communications.

DATAQUEST believes that equipment manufacturers that actively participate in the development of the SECS protocol and the formulation of protocol specifications for their specific equipment categories will gain a strategic market advantage in providing equipment to the semiconductor industry. Equipment manufacturers have the opportunity to participate in the formative stages of automation in the semiconductor industry, and in the process can establish firm relationships with the automation leaders. Semiconductor manufacturers that are not yet active in the automation arena will evaluate future equipment purchases not only on equipment performance, but also on equipment manufacturers' proven automation experience and protocol acceptance.

The potential for incorporating the MAP protocol into the automation networks of semiconductor manufacturing facilities is still under evaluation. SECS, however, is the protocol that manufacturers are specifying today. DATAQUEST believes that the SECS protocol, in one form or another, will survive the transition to any MAP-based system in the future. Regardless of which protocol is employed, the need for better communication between equipment, semiconductor, and CIM manufacturers mirrors the automation goal itself: to develop reliable, interactive communications between the various components in an integrated, automated, manufacturing environment.

APPENDIX A

THE NETWORK ENVIRONMENT: AN OVERVIEW

Introduction

The focus of the development of a computer integrated manufacturing (CIM) environment is to tie together all sources of information and production on the shop floor. The infrastructure that describes such a system is a communication network, typically a local area network that provides reliable, medium-to-high speed, interactive communications between various computing devices and processing equipment. A local area network, by definition, is located within a limited geographical area, typically within a single building or adjacent facilities.

Network Components

A communications network can be characterized by several different components, including the physical medium used for data transmission, the type of data transmission employed, the configuration or topology of the network, and, finally, the data link (or access method) by which communication devices gain use of the network's physical medium. The communications protocol is an important component in ensuring operational consistency and compatibility among the variety of computers and equipment operating in a network environment. The following sections review the network components that are supported by the SECS and MAP protocols.

Physical Medium/Data Transmission

In the SECS protocol, electrical connections between equipment and computers utilize the international standard known in the United States as EIA RS-232-C (or, more simply, RS-232) for connector and voltage levels. RS-232 is a mature standard and the familiar 25-pin, "D"-shaped connector can be found on almost every type of computer today. While RS-232 uses the 25-pin connector, the SECS protocol specifies bit serial data transmission along only a single wire (plus a ground); one wire is used for transmission in one direction and a second wire for the reverse direction. The SECS protocol, therefore, uses only a total of three signal wires (plus frame ground) for transmitting data and only one flow of information is allowed at any one time (half-duplex transmission).

SECS I also specifies that equipment will provide power on two additional pins for external line-drivers for the purpose of extending the cable length. The RS-232 connector also has several additional pins that are useful for testing purposes but are not specified by the SECS protocol. Since some computer systems may require that these pins be active, appropriate signals will have to be locally generated by the equipment for those systems.

In the SECS protocol, the data transmission rate is limited to 9,600, 4,800, 2,400, 1,200, 300 or 150 baud (characters per second), with a high-speed option of 19,200 baud also available with modification. The preferred data transfer rate of 9,600 baud is considered sufficient for most equipment-to-host communications; however, speed can be a problem when data-intensive measuring equipment communicates with a host system. For that reason, some level of data reduction is usually required before uploading information to the host, so as not to "tie up" the lines for too long a period of time.

The MAP protocol specifies broadband coaxial cable as the physical medium for the network. Broadband coaxial cable is a shared medium that consists of multiple independent channels. Broadband transmission uses CATV technology (Community Antenna TeleVision, more commonly known as CAble TeleVision), which is characterized by a wide bandwidth that uses frequency division multiplexing to establish multiple channels. It has a high data bandwidth, typically 400 MHz, with 5 to 10 MHz per channel. Broadband coaxial cable can also support a closed circuit television system and voice telephone in addition to providing the physical communications medium for digital transmission in a local area network. One additional advantage of broadband coaxial cable is that it can be installed over distances of up to 10 kilometers; longer distances can be achieved with the installation of repeaters. Its primary disadvantages are the cost and complexity of installation. Broadband coaxial cable is very cumbersome to work with and, in addition, each tap to the network requires a modem.

Since baseband transmission is often mentioned in context with broadband, it is useful to understand the difference between these two types of transmission that are used in an automated factory environment. Baseband transmission (not supported by MAP or SECS) specifically employs bit serial digital transmission in which a variety of coding techniques are used that rely on time division multiplexing. When each communications device transmits on a baseband system, it makes use of the entire bandwidth of the channel, typically 5 MHz. Baseband coaxial cable technology is well understood. It is a low-cost, easy-to-install cable. However, its disadvantages are that it is a single channel system and can only be applied over a limited distance on the order of 3 kilometers.

Topology

A network topology or configuration is the geometric arrangement of computing devices, or nodes, and the physical media links that make up the network. A node may be defined as a communication system connection point, and is typically represented by either a controller or a computer. The network configurations that will be discussed here include the point-to-point hierarchical structure, as well as the ring and bus network topologies. Figure A-1 shows schematic representations of the three general types of geometrical configurations that have been implemented in automated network environments.

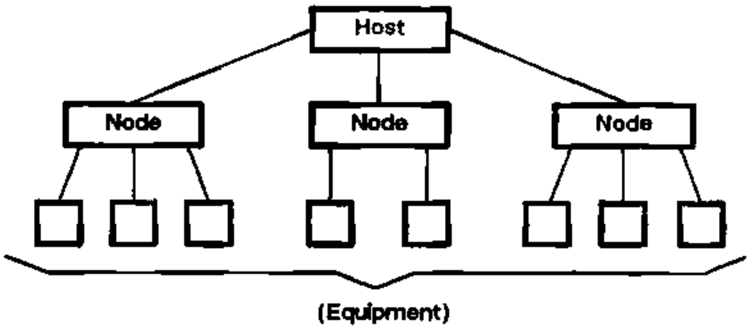
The SECS standard supports a point-to-point configuration or topology in which a single communication line links two stations that each have the capability to initiate a conversation. The point-to-point configuration may be extended into a more complex topology known as the tree or hierarchical configuration. In the hierarchical configuration, a host system is resident at the uppermost level, with an intermediate level of communication devices (node computers) installed between the host and the equipment-level computer systems. The tree configuration is a particularly useful topology for SECS as the SECS message header contains information that indicates the direction of information flow (i.e., "up" or "down" the tree).

The ring topology, while not used in the semiconductor industry, can be found in other communication networks. In the simple ring configuration illustrated in Figure A-1, each communication node is connected to exactly two other nodes. Data that travels through the ring must go through each station in its path between the original source and final destination of the message. The simplicity of the design provides that no routing decisions must be made; however, the system has predictable timing delays because of the geometrical arrangement. One major disadvantage of the ring configuration is that a failure in any one device on the ring can have a global effect on the system unless relay shunts are provided around each device. The SECS and MAP protocols do not support the ring topology.

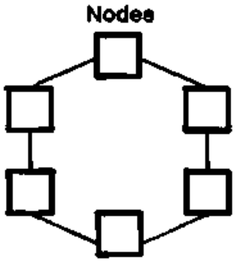
In the bus configuration, each node in the system is connected to a central transmission line. The transmission line or bus is passive so that in the event that a node communications device fails, the bus still remains operative. However, because of the arrangement of a bus configuration, specific protocols must be established to deal with which communications device has the control of the network at any given time. The MAP protocol employs a bus topology.

Figure A-1

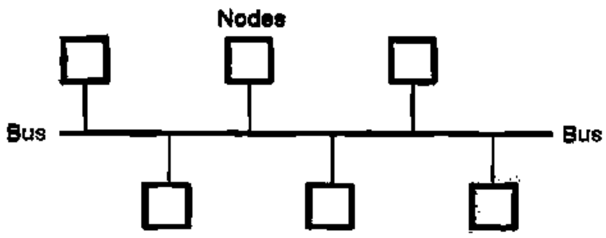
SCHEMATIC REPRESENTATIONS OF NETWORK TOPOLOGIES



Point-to-Point Topology
(Hierarchical)



Ring Topology



Bus Topology

Source: DATAQUEST
MAY 1986

Access Method

The access method by which a communication device obtains use of a network's physical medium is part of the the overall data link control of a given communications protocol. The data link establishes the direction of transmission, verifies proper data link status, and resolves contention when more than one device attempts to transmit at the same time.

The data link protocol in SECS I is the procedure used by the serial line to establish the direction of communication between the equipment and a host computer. As mentioned previously, transmission between host and equipment under the SECS protocol is half-duplex, so that essentially only one party is allowed to talk at any one time. When both ends of the line attempt to communicate at the same time, it results in a line contention or a "collision." Collisions are resolved in the SECS protocol by the specification of one station as the master and the other end of the link as the slave. In the event of a collision, the slave postpones transmission and yields to the master. The SECS I protocol also provides a series of timeouts and retries that are used to correct communication errors.

In a semiconductor processing environment, the equipment typically is designated as the master and the node or host computer as the slave. This initially may seem contrary to the hierarchical topology that is supported by the SECS protocol, but since the equipment computer usually has limited storage capability for messages, it must be allowed to send any messages it has before receiving new requests for information from the host system.

Polling can be described as a controlled media access method. It requires a master/slave relationship among the communication nodes in the system. The master computer typically controls the link and initiates all communications within the system. All other devices on the network, designated as slaves, respond only when polled by the master for information.

Token passing is a shared media access method. In this type of configuration, the "token" or special message is passed around the network in a prescribed manner. The station that holds the token is given exclusive but temporary control of the network to transmit information. All other stations in the network can only listen when the token is not in their possession. Ring and bus topologies typically employ a token passing access method. The MAP protocol, in particular, utilizes token passing as the access method in its bus network.

The carrier sense multiple access/collision detection (CSMA/CD) access method can be simply described as a system in which a station listens before talking and listens while talking. It is important that before transmitting information, each communications device first listens to the network to see if the media is occupied or idle. When access has been gained to the physical media and transmission has begun, each device also listens for a collision--someone else in the network trying to gain access to the system. If a collision occurs, each station backs off the network for a prescribed and unique period of time in order to prevent another collision. Ethernet, a local area network developed by Xerox, utilizes the CSMA/CD access method.

Both the polling and token passing access methods avoid the issue of contention by their very design. The CSMA/CD access method is similar to that specified in the SECS protocol since both have mechanisms to deal with line contention. However, the difference between these two methods is that in the SECS protocol, contention is resolved by the slave yielding to the master, while in CSMA/CD, both stations back off the network for a prescribed and unique period of time in order to prevent another collision.

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Photoresist

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SUMMARY

In 1985, optical photoresist sales to the semiconductor industry were $133.0 million. Positive optical resist represented $106.0 million, (79.7 percent) of this figure, and negative optical resist represented $27.0 million (20.3 percent). The average selling price of positive optical resist ranged from $305 to $320 per gallon, compared with a range of $58 to $90 per gallon for negative optical resist. Table 1 summarizes the worldwide optical photoresist market (sales and volume) by region of semiconductor manufacturing activity in 1985.

Table 1

WORLDWIDE OPTICAL PHOTORESIST MARKET, 1985
(Millions of Dollars, Thousands of Gallons)

	Total Market		Positive Resist		Negative Resist	
Region	Sales	Volume	Sales	Volume	Sales	Volume
United States	$ 63.3	296.0	$ 51.0	160.0	$12.3	136.0
Japan	45.9	284.0	36.3	119.0	9.6	165.0
Europe	17.3	84.0	13.9	44.0	3.4	40.0
ROW	6.5	38.0	4.8	15.0	1.7	23.0
Total	$133.0	702.0	$106.0	338.0	$27.0	364.0

Source: Dataquest
August 1987

INTRODUCTION

This study is Dataquest's analysis of the worldwide photoresist market. It presents an overview of photoresist companies and their products including positive and negative optical resists, deep-UV resists, e-beam, and X-ray resists. Due to the large number of review articles and texts available on the subject of photoresist chemistry and processing, only summary background information will be presented on these topics. The primary focus of this study will be the optical resist market. Market size and company share for positive and negative optical resists is reported for 1985. Dataquest's forecast of positive and negative optical resist consumption by region through 1991 is presented, also. Please note that the regional designation "United States" includes Canadian semiconductor manufacturing activities.

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Photoresist

PHOTORESIST OVERVIEW

Photoresist, in its simplest description, is a light-sensitive, polymer-based material applied to wafers during semiconductor fabrication to transfer the circuit pattern from a mask to the underlying substrate. (Photoresist is also applied to photoblanks in maskmaking and, to a lesser extent, in direct-write e-beam applications in which circuit patterns are directly written on a resist-coated wafer.) Photoresist is applied to the wafer at every mask level during the fabrication process; the number of mask levels correlates with device complexity. Typically, the photoresist process application involves multiple steps including wafer prime, photoresist coat, softbake, exposure, development and rinse, post-bake, etch, and strip.

Photoresist is a very complex, finely balanced chemical system based on the interplay between polymeric resin and photosensitizer chemicals in the presence of UV, e-beam, or X-ray radiation. The sensitizer and resin usually are complex chemical mixtures whose behavior in photoresist formulations depends on the specific chemical synthesis and purification procedures used in their manufacture. Chemicals such as solvents and other additives are mixed with resins and sensitizers to make the final photoresist products.

The class of starting materials in photoresist synthesis alone does not determine reproducible resist behavior during the lithography process. The properties and behavior of a resist formulation depend on many factors including the raw material isomer ratios, the degree of conversion during synthesis, composition, purification, molecular weight distribution, blending, and, finally, the resist manufacturing process. The subtle relationship between chemical structure and chemical properties of resist materials is an ongoing subject of research for both photoresist companies and semiconductor manufacturers. Because of these subtle relationships, the behavior of any given resist in a lithographic process depends strongly upon the precise composition and specific raw materials used in the manufacture of the resist product.

Lot-to-lot consistency is one of the most critical requirements for a consistent semiconductor fabrication process. Resist consistency requires raw material consistency, well-controlled resist manufacturing, purification, and quality control. Many different parameters must be characterized and controlled in order to ensure consistent resist performance. Parameters include resist adhesion to the wafer, linewidth resolution, processing latitude, resist sensitivity (a measure of chemical bonds broken under radiation), viscosity, step coverage, photospeed, coating uniformity, thermal stability, dry etch resistance, and purity of material. Other factors also influence the use of resist in the semiconductor industry such as shipping and storage, packaging, toxicity, and disposal considerations.

Photoresist

Photoresist Classification

Positive- and Negative-Working Photoresists

Photoresist materials are classified as positive- or negative-working resists. The basic difference between a positive and a negative resist depends upon the material's response to light or radiation. A positive resist leaves behind an image on the wafer that matches the pattern on the mask, while a negative resist leaves behind an image that is the reverse of the mask. This occurs because positive resist materials become soluble when exposed to light; those portions of the resist beneath the clear areas of the mask will be removed when the resist-coated wafer is developed and rinsed with the appropriate solutions. Conversely, negative resist materials are initially soluble but become insoluble when exposed to light; those portions of negative resist beneath the opaque mask pattern will be rinsed away while a reverse image of the mask pattern in resist will remain on the wafer. This difference between positive and negative resists is illustrated in Figure 1.

One- and Two-Component Systems

Two different designs of resist formulations exist: one-component and two-component systems. Examples of a one-component system are polymethylmethacrylate (PMMA) and poly(butene-1-sulfone) (PBS). In these materials, the polymer itself carries all the characteristics for the resist system such as the etch resistance, coating characteristics, and sensitivity. The PMMA and PBS resists are used in deep-UV, e-beam, and X-ray applications.

The second design is described as a two-component system because it contains both a matrix resin and a sensitizer. The matrix resin may not necessarily have any radiation sensitivity itself; however, it typically has the coating and etch characteristics that are required. The second component, the sensitizer, may not coat very well but it exhibits the required radiation sensitivity. Positive and negative optical resists are generally two-component systems. Most positive optical resist formulations comprise a nonphotoactive novolac resin matrix, with a photosensitive diazoquinone compound. Most of the currently available negative resist systems are based on cyclized polyisoprene (a rubber-based product), which is sensitized by bis-arylazides.

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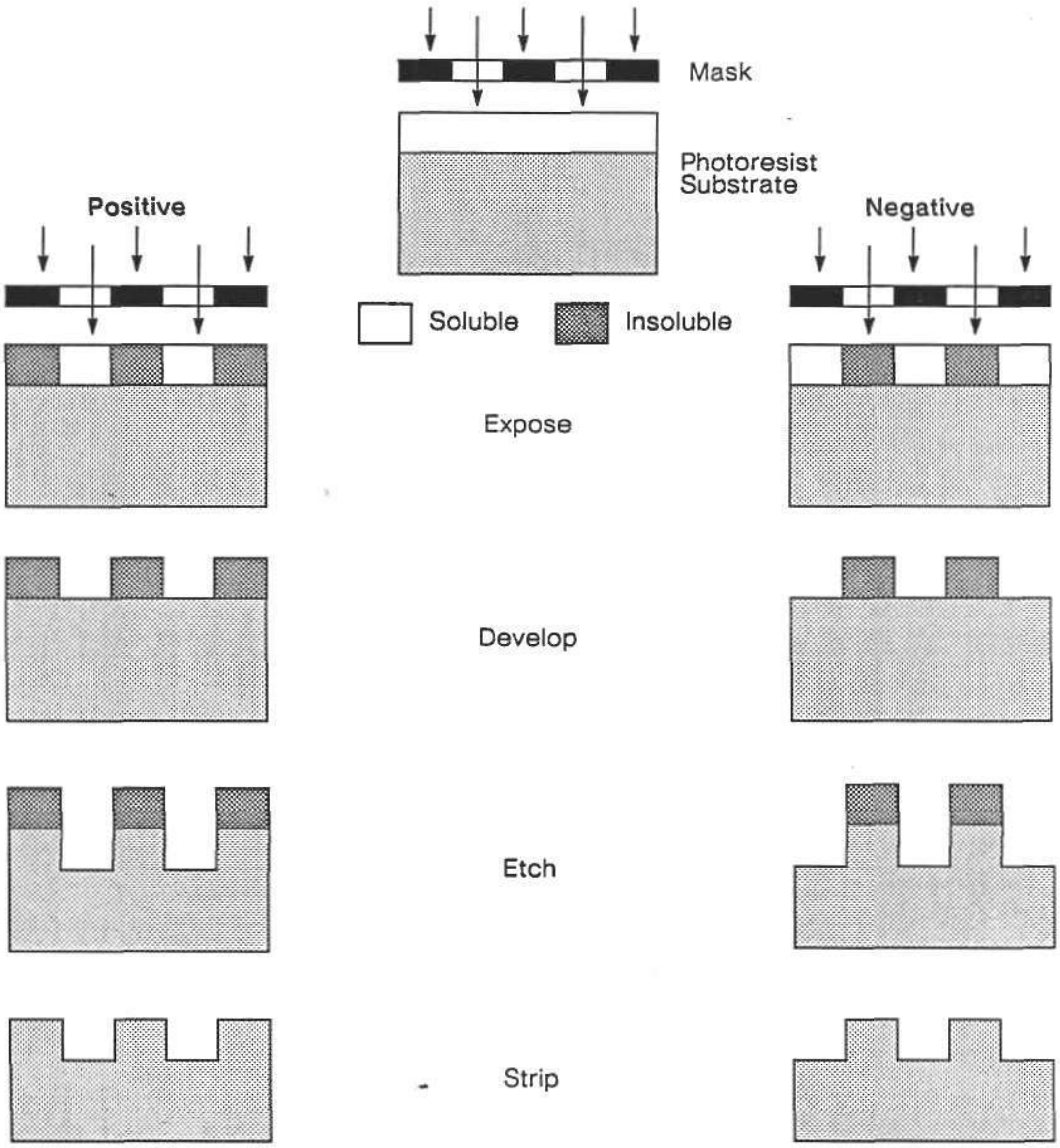
Figure 1

**MECHANISMS OF
POSITIVE- AND NEGATIVE-WORKING PHOTORESIST**



Source: Dataquest
August 1987

Photoresist

Photoresist Categories

Resists used in semiconductor device fabrication typically are classified into four different categories that reflect the sensitivity of the resist to a given type of radiation. The four categories are optical, deep-UV, e-beam, and X-ray resists. There are currently two major directions of research in resist chemistry: the development of new resist materials for advanced device processing, and the continuing characterization and study of existing materials in order to extend their processing capabilities.

Optical Photoresist - Optical photoresists are the primary imaging materials used in semiconductor device manufacturing. As manufacturers continue to shrink line geometries, the relative use of optical photoresist continues to shift from negative to positive. In general, negative optical resists are limited to processing above 2.5 microns because of problems with image swelling. However, other factors in addition to line width resolution affect the choice of positive or negative photoresist in a manufacturing process. Table 2 provides a summary of the advantages and limitations of positive and negative optical photoresist systems.

Table 2

ADVANTAGES AND LIMITATIONS OF POSITIVE AND NEGATIVE OPTICAL PHOTORESISTS

Resist	Advantages	Limitations
Positive Optical	Excellent resolution Good step coverage Aqueous developed (image unaffected by developer; disposal is relatively simple) Good thick film resolution No oxygen sensitivity	Relatively slow photospeed Fair adhesion on substrates High cost Difficulty in resist removal due to formation of insoluble, high molecular weight products formed during exposure
Negative Optical	Excellent adhesion High photospeed Low cost Good resistance to liquid etchants	Limited resolution Oxygen sensitivity Solvent developed (results in image swelling; disposal is difficult)

Source: Dataquest
August 1987

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<u>Deep-UV Resists</u> - The main thrust behind deep-UV lithography is to obtain greater resolution by exposing with shorter wavelengths of light. The classical wavelength definitions for visible and UV light are as follows:

400-700nm	=	Visible light
250-400nm	=	Near UV
100-250nm	=	UV
4-100nm	=	Deep UV (Far UV)

In the semiconductor industry, the term "deep UV" is used to refer loosely to light below 310nm; however, there are many interpretations of the range of wavelengths that describes deep-UV light. Deep-UV resists are regarded as specialty resists as their use in photolithography applications is still quite limited.

<u>E-Beam Resists</u> - In e-beam lithography, a finely focused beam of electrons is deflected accurately and precisely over a surface coated with a radiation-sensitive polymeric material in order to produce a high-resolution pattern on chromium blanks or wafers. Electrons, like photons, possess both particle and wave properties, and typical electron wavelengths are on the order of a few tenths of an angstrom (hundreths of a nanometer). The minimum line width produced in e-beam lithography is much less than that achieved with photolithography; however, the resolution is still limited by forward scattering of the electrons in the resist layer and back-scattering from the underlying substrate. Typical line widths in e-beam direct-write applications are on the order of 0.5 micron.

Electron beam resists are used primarily in maskmaking and, to a much lesser extent, in direct-write e-beam applications. Many resists have been formulated for use with e-beam exposure systems. Some common e-beam resists are PMMA, PBS, COP (a copolymer of glycidyl methacrylate and ethyl acrylate), and substituted polystyrene compounds.

<u>X-Ray Resists</u> - X rays with wavelengths in the 0.04 to 0.5nm range represent another alternative radiation source with potential for high-resolution pattern imaging in polymeric resist materials. The advantages of X-ray lithography--including line width resolution down to 0.1 micron, large depth of focus, high throughput, and wide process latitude--will become more and more important as the semiconductor industry continues its push to smaller and smaller geometries. Resists suitable for X-ray lithography are currently being developed, and existing e-beam resists are also finding their way into X-ray applications. The demand for X-ray resists is still quite small, however, and substantial improvements in processing characteristics will be required along with better X-ray sources and masks before X-ray lithography moves out of the lab and onto the production line.

Photoresist

Ancillary Products

Ancillary products in resist processing include developers, rinses, dyes, strippers, thinners, adhesion promoters, and etchants. The developers, in particular, are closely designed to complement a given resist formulation in order to optimize resist performance. All of the photoresist companies offer a range of ancillary products to complement their individual resist formulations. In response to concerns for operator safety and the environment, many photoresist manufacturers have developed resist formulations with "safe" solvents that do not contain ethyl cellosolve acetate. Recent studies based on tests with laboratory animals have revealed that overexposure to this solvent may cause male and female reproductive disorders and birth defects.

PHOTORESIST COMPANY ACTIVITIES

Table 3 contains a list of photoresist companies that were active in the world market in the 1985/1986 time frame. This list, organized by region in which the company headquarters are based, summarizes the resist products offered by each company. Several companies, such as Olin Hunt Specialty Products, have regional subsidiaries and affiliates, which are listed below the parent company in Table 3. The regional location of these subsidiaries and affiliates has been identified in parentheses. The subsidiaries and affiliates offer the same resist product line as their parent corporations. All except two of the companies listed in Table 3 perform primary manufacturing, reformulation, or packaging of resist products. The two exceptions are Hoechst Japan and Merck Japan. Dataquest believes that these two companies are the Far East marketing and sales operations for their parent corporations.

Part of Table 3 also identifies new entrants and departures in the photoresist market since 1985.

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Table 3

PHOTORESIST COMPANIES AND PRODUCTS

Photoresist Companies	Optical Pos.	Optical Neg.	Deep-UV	E-Beam Pos.	E-Beam Neg.	X-Ray Pos.	X-Ray Neg.
U.S. Companies							
J.T. Baker	X	X			X		X
Dynachem Corporation	X	X		X			
Eastman Kodak	X	X			X		X
Esschem					X		X
GAF Corporation					X		
B.F. Goodrich		X					
KTI Chemicals, Inc.	X	X			X		X
MacDermid	X						
Olin Hunt Specialty Products	X	X		X	X		
Fuji-Hunt Electronics Technology (Japan)							
Mead Technologies (U.S.)							
N.V. Olin Hunt Specialty Products (Europe)							
ROK Division, Chemtech Ind.	X	X		X			
Shipley Company	X		X			X	
Shipley Europe, Ltd. (Europe)							
Shipley Far East, Ltd. (Japan)							
Transene			X				
Japanese Companies							
Chisso					X	X	
Daikin Industries				X		X	
Dainippon Ink and Chemicals	X						
Hitachi Chemical	X	X	X	X	X	X	
Japan Synthetic Rubber	X	X	X		X		X
Mitsubishi Chemical Industries	X						
Nagase Chemicals	X	X			X		X
Somar					X		
Sumitomo Chemical	X						
Tokyo Ohka Kogyo	X	X	X	X	X	X	X
Toray Industries				X			
Toyo Soda			X		X		X

(Continued)

Table 3 (Continued)

PHOTORESIST COMPANIES AND PRODUCTS

Photoresist Companies	Optical Pos.	Optical Neg.	Deep-UV	E-Beam Pos.	E-Beam Neg.	X-Ray Pos.	X-Ray Neg.
European Companies							
Hoechst AG	X			X			
American Hoechst, AZ Photoresist (U.S.)							
Hoechst Japan (Japan)							
E. Merck	X	X	X	X		X	
EM Chemicals (U.S.)							
Hopkin & Williams (U.K.)							
Merck Japan (Japan)							
Micro-Image Technology	X	X		X	X		X
M.I.T.-Halbleiterchemie GmbH (West Germany)							
Soprelec SA (France)							
New Entrants (Since 1985)							
Aspect Systems (U.S.)	X						
Dynamit Nobel Chemicals (U.S.)	X						
Molecular Electronics Corporation (U.S.)					X		
Spectrum Resist Products (U.K.)	X	X					
Syn Labs (U.S.)			X		X		X
UCB Electronics (Belgium)	X	X	X		X		X
Departures (Since 1985)							
Allied Chemical (U.S.)*	X						
Monsanto Company (U.S.)**	X						

*Allied Chemicals sold its resist operations to Dynamit Nobel Chemicals in May 1986.
**Monsanto Company sold its photoresist operations to Aspect Systems in September 1986.

Source: Dataquest
August 1987

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Photoresist

Photoresist reformulators purchase bulk resist materials from other resist companies, formulate and custom blend the photoresist products according to individual customer specifications, and specialize in providing technical support and service to their customers. This type of service-oriented approach to material distribution in the photoresist market was pioneered by KTI Chemicals in the mid-1970s. Table 4 contains a summary list of photoresist reformulators and identifies the major resist suppliers for each company.

Table 4

PHOTORESIST REFORMULATORS

Reformulator	Region	Photoresist Supplier
J.T. Baker	United States	Eastman Kodak
KTI Chemicals	United States	AZ Photoresist, Eastman Kodak, Japan Synthetic Rubber, Shipley
Micro-Image Technology	United Kingdom	Eastman Kodak
Nagase Chemicals	Japan	Eastman Kodak
ROK Division, Chemtech Industries	United States	Eastman Kodak, Micro-Image Technology

Source: Dataquest
August 1987

U.S. Photoresist Companies

J.T. Baker

J.T. Baker Chemical Company supplies photoresist to the U.S. semiconductor industry. The company has no primary manufacturing of bulk resist materials, but rather reformulates Eastman Kodak resists to customer specifications. J.T. Baker's resist products include positive and negative optical resists, negative e-beam resist, and negative X-ray resist. Photoresists are processed through J.T. Baker's proprietary VLSI low-particulate filtration treatment, and resist viscosity is customized. Rather than pursue the commodity resist business, J.T. Baker has opted to focus its services and products on new applications, new fab start-ups, and custom specifications. J.T. Baker's applications support center and company headquarters are both in Phillipsburg, New Jersey.

Optical		Deep-UV	E-Beam		X-Ray	
Pos.	Neg.		Pos.	Neg.	Pos.	Neg.
x	x			x		x

Dynachem Corporation

Dynachem Corporation manufactures and supplies positive and negative optical resist and positive e-beam resist to the semiconductor industry. Dynachem initially purchased its OFPR 800 positive optical resist from Tokyo Ohka Kogyo, Japan's leading photoresist manufacturer. Dynachem has since obtained a license for the process technology of the OFPR and OMR (negative optical) resists of Tokyo Ohka, and manufactures these resists at its facility in Moss Point, near Pascagoula, Mississippi. Dynachem's new positive e-beam resist, EPR 5000, was conceived and developed by Dynachem researchers; it is not a Tokyo Ohka product.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x		x			

In addition to photoresist, Dynachem is a major manufacturer of dry resist materials that are used in printed circuit board applications. Dynachem's position in this market segment was part of the impetus for the original agreement between Dynachem and Tokyo Ohka. In the agreement, Tokyo Ohka obtained the right to act as the representative and distributor for all Dynachem dry film products in Japan. In return, Dynachem entered the semiconductor photoresist market by becoming a Tokyo Ohka licensee for the OFPR and OMR resists in the United States. Dynachem has since terminated the agreement to act as Tokyo Ohka's representative and distributor, and has established its own Japanese dry resist manufacturing operations at its Kodama Plant in Kamikawa City, Saitama prefecture. The licensing agreement for OFPR and OMR photoresist process technology was not affected by this termination.

Dynachem's administration, applications group, and warehousing facilities are located in Tustin, California. Limited manufacturing also occurs at this location. Dynachem is a subsidiary of Morton Thiokol, Inc.

Eastman Kodak

Eastman Kodak manufactures positive and negative optical, negative e-beam, and negative X-ray resists for use in semiconductor device fabrication. While Kodak's resists have high visibility within the semiconductor industry, the company does not sell its resist products directly to semiconductor companies. Its resists are sold through reformulators such as J.T. Baker, KTI Chemicals, Micro-Image Technology, Nagase Chemicals (Kodak's exclusive distributor in Japan), and the ROK Division of Chemtech Industries. In the past, Eastman Kodak made some small sales of resist materials to Harris Semiconductor, but as of 1985, the company has had no direct sales of resist to semiconductor manufacturers. Eastman Kodak provides both sales and technical product support direct to resist distributors and semiconductor manufacturers.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x			x		x

In May 1987, Eastman Kodak announced the sale of its photoresist operations to Union Carbide Corporation. With the acquisition of Kodak's resist operations, Union Carbide obtained the manufacturing and sales operations of Kodak's resist products, including both macro- and microresists and the ancillary products. Application markets for Kodak's macroresists include printed circuit boards, gravure cylinders, and chemical milling. Kodak's microresists are used in the semiconductor industry to transfer circuit patterns to wafers and photomasks. In addition to existing resist technology, Union Carbide has acquired Kodak's current research projects in advanced resist materials. This research includes product development in new deep-UV, e-beam, and X-ray resist materials. The Kodak resist products will be customized, packaged, and distributed by KTI Chemicals, Inc., a wholly owned subsidiary of Union Carbide. The sales price of Eastman Kodak's photoresist operations was not made public.

Esschem

Esschem is a custom polymer company that manufactures bead polymer material prepared from methyl methacrylate and various co-monomers. The company specializes in offering narrow molecular weight distribution polymer material for e-beam and X-ray resist applications. Esschem has supplied PMMA in bead polymer form since 1973. PMMA is used as a positive-working resist in both e-beam and X-ray applications. Esschem also offers a series of methyl methacrylate/methacrylic acid copolymers; one system in particular is used in bilayer resist applications. All of the resist polymers offered by Esschem come in dry bead form; the price of the bead polymer material ranges from $40 to $100 per 100 grams.

Esschem has been providing bead polymer material to the semiconductor industry for more than 10 years. The company sells its polymeric resist starting material to resist companies, a few merchant mask houses, and some semiconductor manufacturers with well-established captive maskmaking operations. However, most semiconductor manufacturers that purchase the bead polymer material use it in an R&D environment. Esschem's primary sales are in the United States and Europe. Its manufacturing facility is located in Essington, Pennsylvania.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
			x		x	

Photoresist

GAF Corporation

GAF Corporation manufactures and supplies a negative-working e-beam resist to the semiconductor industry. The proprietary resist, known as Gaftronic EB-46, is suitable for both maskmaking and direct-write applications. The resist specifications include 0.5-micron line width resolution. A proprietary developer and rinse have also been designed by GAF for use with the EB-46 resist. In addition to negative e-beam resist, GAF Corporation manufactures specialty chemicals, mineral products, engineering plastics, and building materials. The company's headquarters are in Wayne, New Jersey.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
				x		

B.F. Goodrich

B.F. Goodrich manufactures and supplies a line of negative resists suitable for sub-2-micron processing. Negative resists traditionally are not used for processing at this resolution because of the problems associated with line width swelling. B.F. Goodrich, however, has developed the GoodRite NR 3000 series of negative resists based on proprietary polymer structures, rather than the traditional cyclized polyisoprene materials used today. The 3000 series resists have been designed for dry etch compatibility. The GoodRite NR 1000 series of negative photoresists complements the 3000 series, but is designed for wet-etch rather than dry-etch compatibility. B.F. Goodrich claims that its GoodRite resists maintain image definition with virtually no swelling at fine line resolutions of 1.0 to 1.5 microns. Dataquest believes that in addition to its negative optical resists, B.F. Goodrich is developing a line of deep-UV resists. The B.F. Goodrich Electronic Materials Group is located in Brecksville, Ohio.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
	x					

KTI Chemicals

KTI Chemicals, located in Sunnyvale, California, supplies positive and negative optical, negative e-beam, and negative X-ray resists to the U.S. semiconductor industry. KTI Chemicals is a major reformulator of photoresist products. Photoresist reformulators purchase bulk resist materials from other resist companies, formulate and custom blend the photoresist products according to individual customer specifications, and provide focused technical support and service to its customers. This type of service-oriented approach to materials distribution in the photoresist market was pioneered by KTI Chemicals in the mid-1970s.

KTI currently provides reformulated resists based on products from AZ Photoresist, Eastman Kodak, and Shipley Company, as well as a small amount of material from Japan Synthetic Rubber. In January 1987, KTI Chemicals was named the U.S. distributor for Toray Industries' semiconductor chemical products, including the company's positive e-beam resist and photosensitive polyimide materials. In addition to its Sunnyvale plant, KTI Chemicals has three other facilities to service semiconductor manufacturers located in Tempe, Arizona; Carrollton, Texas; and Wallingford, Connecticut.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x			x	x	

In May 1987, Eastman Kodak announced the sale of its photoresist operations to Union Carbide Corporation (see the section on Eastman Kodak). The Kodak resist products will be customized, packaged, and distributed by KTI Chemicals, Inc., a wholly owned subsidiary of Union Carbide. As a photoresist reformulator, KTI Chemicals has been a major supplier of Kodak resist products for many years. KTI, however, does not have primary resist manufacturing capability within its organization. Although Union Carbide has been involved in some R&D aspects of photoresist development, Dataquest believes that the acquisition of Kodak's technology will substantially augment Union Carbide's existing programs. In addition to existing resist technology, Union Carbide has acquired Kodak's current research projects in advanced resist materials. This research includes product development in new deep-UV, e-beam, and X-ray resist materials. Photoresist manufacturing will occur at Union Carbide's plant in South Charleston, West Virginia, where its Chemicals and Plastics Group has its primary manufacturing facility.

In addition to KTI Chemicals, Eastman Kodak also supplies resist products to other reformulator companies including J.T. Baker, Micro-Image Technology, and the ROK Division of Chemtech Industries, as well as its Japanese distributor, Nagase Chemicals. Union Carbide and KTI Chemicals have planned to continue to honor existing supplier/distributor relationships with the other photoresist reformulator companies for now. Long-term continuation of such relationships will be under evaluation during the latter half of 1987. Dataquest, however, expects that the Kodak microresist supplier relationship with other reformulator companies eventually will be severed since KTI Chemicals is a direct competitor with these companies in the photoresist market place.

MacDermid, Inc.

MacDermid manufactures and supplies positive optical photoresist to the semiconductor industry, primarily in the U.S. region. MacDermid's resists are marketed under the Ultramac brand name, and include the PR-60 and PR-900 series of positive resist systems. Ultramac PR-914 is one of MacDermid's most advanced products; it is designed to control reflective notching when the resist is processed on highly reflective substrates. This resist achieves 0.6-micron line geometries and is compatible with existing g-line lithography equipment. The available options include safe-solvent and antireflective photoresist formulations. MacDermid has been manufacturing production quantities of photoresist since 1982; sampling occurred in the 1980/1981 time frame.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x						

In April 1987, MacDermid announced an agreement to license its positive photoresist technology to Toray Industries of Japan. Toray will construct a new manufacturing facility that will be integrated with its existing electronic materials plant in Shiga, where the company currently produces e-beam resists, high-purity polyimide coatings, and other associated materials. Photoresist production at the new facility will begin in September 1987. Terms of the licensing agreement allow Toray to begin immediately to market MacDermid's PR-900 series resists and associated products for 1- and 4-Mbit VLSI devices.

MacDermid is a worldwide specialty chemicals company. In addition to its photoresist products, MacDermid manufactures and supplies chemicals used by the printed circuit board industry. The company's headquarters and microelectronics technical center are in Waterbury, Connecticut. European markets are supplied through the company's business center and storage facilities in Telford, England; Asian customers are supplied through MacDermid's wholly owned subsidiary, MacDermid Japan, located in Tokyo, Japan.

Olin Hunt Specialty Products

Olin Hunt Specialty Products manufactures and supplies positive and negative optical and positive and negative e-beam resists to semiconductor manufacturers worldwide. The company's positive and negative optical resists are marketed under the Waycoat brand name. Olin Hunt's newest positive photoresist, Xanthachrome, was designed to reduce the problems of step coverage over variable topography as well as substrate reflectivity, particularly on polysilicon and metal layers. Olin Hunt supplies both positive and negative e-beam resists to the semiconductor industry through a marketing agreement with Mead Technologies.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x		x	x		

Photoresist

Over the last ten years, Olin Hunt Specialty Products has undergone two acquisitions and a name change; for clarification, a brief company chronology is presented at this time. In 1977, Turner & Newall plc (Manchester, England), a supplier of chemical and asbestos products, purchased a 51 percent stake in Philip A. Hunt Chemical Corporation (Palisades Park, New Jersey) for $59 million. In March 1983, Olin Corporation (Stamford, Connecticut) acquired the controlling interest in Philip A. Hunt Chemical Corporation by purchasing 63.4 percent of outstanding stock held by Turner & Newall Industries, a U.S. subsidiary of Turner & Newall plc. The transaction was valued at $90 million. Philip A. Hunt Chemical Company became a wholly owned subsidiary of Olin Corporation in July 1984. The company name was changed from Philip A. Hunt Chemical Corporation to Olin Hunt Specialty Products in the second quarter of 1986 to reflect the diversity of Olin Hunt's product line as well as to identify the company with its corporate parent. Throughout the remainder of this study, the company will be referred to as Olin Hunt Specialty Products (or Olin Hunt) rather than Philip A. Hunt Chemical Corporation.

Through its business units and subsidiaries, Olin Hunt Specialty Products manufactures a variety of products for the electronics industry. In addition to photoresist, Olin Hunt's semiconductor-related products include high-purity acids and solvents, liquid dopants, and dry strip equipment for semiconductor device fabrication. Olin Hunt also manufactures etchants and equipment for the printed circuit board industry, chemicals and toners for the copier and duplicating industry, and black-and-white and color processing chemicals used in graphics publishing. Olin Hunt's subsidiary, Advanced Chemicals and Coatings, is a major manufacturer of conductive polymers.

Olin Hunt's photoresist manufacturing and R&D facilities are in Rhode Island; its U.S. technical service support center is in Tempe, Arizona; and its corporate headquarters are in West Paterson, New Jersey. Olin Hunt's joint venture in Japan, its relationship with Mead Technologies, and its European operations are discussed in the following sections.

<u>Fuji-Hunt Electronics Technology</u> - In July 1983, Fuji-Hunt Electronics Technology Co., Ltd., was formed as a joint venture by Olin Hunt Specialty Products and Fuji Photo Film Co. of Japan. The joint venture was formed to promote the manufacture and marketing of Olin Hunt's Waycoat photoresist and ancillary products to semiconductor manufacturers in Japan and the Pacific Rim. The venture is owned 51 percent by Fuji Photo and 49 percent by Olin Hunt Specialty Products. Fuji-Hunt's manufacturing facility and technical center is in Yoshida City, Shizuoka prefecture, in central Japan.

<u>Mead Technologies</u> - In October 1983, Olin Hunt acquired 30 percent of Mead Technologies, Inc. (Rolla, Missouri), a privately held supplier of e-beam resists for maskmaking and direct-write e-beam applications. The agreement calls for Olin Hunt to assume worldwide marketing rights to the Mead line of resists, including PBS (positive e-beam) and COP (negative e-beam) resist.

Photoresist

Mead Technologies recently completed the development of a new negative e-beam resist that is designed for submicron applications and dry etch processing. The product should be in commercial production in the third quarter of 1987. A fourth resist in the Mead line of resists is currently under development. Like Mead's new negative e-beam resist, this new positive e-beam resist has been designed for submicron applications and dry etch processing. Mead Technologies is an AT&T Bell Labs' licensee for e-beam resist technology.

N.V. Olin Hunt Specialty Products - Olin Hunt's European manufacturing, marketing, and sales organization has its headquarters in St. Niklaas, Belgium. Olin Hunt built a technical service center in St. Niklaas to provide photoresist characterization analysis and customer support for the European semiconductor community. Construction of the technical service center began in December 1978.

ROK Division, Chemtech Industries

The ROK Division of Chemtech Industries supplies positive and negative resists to the U.S. semiconductor industry. ROK reformulates and prepares custom blends of resist products from Eastman Kodak including Kodak's KTFR, KPR, 732, 747, 752, and 757 negative resists, and Kodak's 809 and 820 positive resists. In addition to optical resists, the company also supplies positive e-beam resist (PMMA) to semiconductor manufacturers. The ROK Division of Chemtech Industries is located in Gardena, California.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x		x			

Shipley Company

The Shipley Company is a major manufacturer and supplier of positive optical and positive deep-UV photoresists to the worldwide semiconductor industry. Shipley introduced its first microelectronics photoresist in 1964, and was the first photoresist manufacturer to offer metal ion-free developers in 1972. In January 1987, Shipley began selling its new X-ray resists designed for 16-Mbit device fabrication. The X-ray resists were developed in conjunction with Rohm & Haas, a major U.S. chemical corporation. In 1982, Rohm and Haas acquired 30 percent ownership of Shipley Company, which until then was privately held.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x		x			x	

In addition to manufacturing its own photoresist products, Shipley currently purchases a small amount of resist materials from AZ Photoresist for reformulation. Prior to December 1982, many of the AZ brand positive resist products manufactured by AZ Photoresist were distributed in the United States through Shipley, via an exclusive distribution agreement. Under the distribution agreement with Shipley, AZ manufactured the basic product line while Shipley provided marketing and service support. The exclusive distributorship agreement between AZ and Shipley was terminated in December 1982, at which time AZ Photoresist began direct sales and marketing of its products in the United States.

During an interim period, AZ Photoresist continued to supply Shipley with photoresist products, while Shipley substantially expanded its primary manufacturing capability. For legal reasons, however, Shipley could no longer use the AZ brand name so the company began marketing its photoresist products under the Microposit name. This change caused considerable confusion among Shipley and AZ customers. Dataquest believes that Shipley obtains only a few percent of its photoresist materials from AZ Photoresist at this time and that the remainder is provided through internal primary manufacturing operations.

Other Shipley products include electroless plating chemicals and equipment for the printed circuit board industry, and electromagnetic interference (EMI) shielding for the plastics industry. Shipley Company's headquarters are in Newton, Massachusetts. Shipley's U.S. manufacturing facilities for chemical products are located in Irvine, California, and Marlborough, Massachusetts.

Shipley Europe, Ltd. - Shipley Europe, Ltd., a subsidiary of the Shipley Company, was formed in 1970. Photoresist manufacturing and company headquarters are in Coventry, England.

Shipley Far East, Ltd. - Shipley Far East, Ltd., was formed as a subsidiary of Shipley Company in 1975. Shipley Far East has responsibility for sales and marketing of Shipley photoresist products in Japan and the Far East. The company manufactures photoresist at its facilities in Sagasami City, Niigata prefecture. Plans for a second photoresist manufacturing facility in Hiroshima were recently placed on hold in light of sluggish market conditions for the semiconductor industry in Japan.

Transene

Transene supplies negative optical photoresist to the semiconductor industry. The company purifies and reformulates resist materials from Eastman Kodak at Transene's Rowley, Massachusetts, facility. Transene is a minor participant in the photoresist market. In addition to photoresist, the company provides an extensive line of formulated materials for thin film applications and the microelectronics industry, including silicone products, epoxies, etchant mixtures, and plating solutions.

Optical		Deep-UV	E-Beam		X-Ray	
Pos.	Neg.		Pos.	Neg.	Pos.	Neg.
	x					

Japanese Photoresist Companies

Chisso

Chisso is a major manufacturer and supplier of positive and negative e-beam resists to the Japanese semiconductor industry. Its products include PMMA and PBS (positive e-beam), and COP (negative e-beam) resists. Chisso's resists are used primarily in maskmaking applications. In addition to its semiconductor-related products, Chisso is a major manufacturer of industrial chemicals including polyvinyl chloride, polypropylene, and polyethylene.

Optical		Deep-UV	E-Beam		X-Ray	
Pos.	Neg.		Pos.	Neg.	Pos.	Neg.
			x	x		

Daikin Industries

Daikin Industries manufactures and supplies positive e-beam resist products based on fluoroalkylmethacrylate polymers to the Japanese semiconductor industry. The company's e-beam resist applications include both maskmaking and X-ray lithography. Daikin Industries is strong in fluorine-based chemical products. In addition to resist, the company also supplies plastics, solvents, etchants, and gases based on fluorine derivatives. Daikin Industries is a major supplier of air conditioning and refrigeration equipment in Japan. Its new business segments include computer graphics, robotics, and cryogenics.

Optical		Deep-UV	E-Beam		X-Ray	
Pos.	Neg.		Pos.	Neg.	Pos.	Neg.
			x		x	

Dainippon Ink and Chemicals

Dainippon Ink and Chemicals manufactures and supplies general-purpose positive optical photoresist to the Japanese semiconductor industry. The company has developed a new high-resolution positive resist, DPR-2600, that is expected to be used in 4-Mbit DRAM processing applications. Dainippon Ink and Chemicals' photoresist manufacturing takes place at its Saitama plant in Kitaadachi District, Saitama prefecture. Other company products include printing ink, pigments, varnishes, synthetic resins, and plastic molded compounds.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x						

Hitachi Chemical Company

Hitachi Chemical Company manufactures and supplies a variety of specialty resists to the semiconductor industry including optical, deep-UV, e-beam, and X-ray resists. Hitachi Chemical is part of the Hitachi group of companies, which is led by Hitachi, Ltd. Photoresist development work is performed at the Hitachi plant (Hitachi City, Ibaragi prefecture), while manufacturing occurs at the Yamazai plant (also in Hitachi City). Photoresist development work is performed in conjunction with the central R&D group at Hitachi, Ltd., the semiconductor manufacturer. Hitachi Chemical then brings the products to the manufacturing environment and is responsible for worldwide sales and marketing. The company headquarters for Hitachi Chemical is in Tokyo.

Hitachi Chemical's resist products include its negative e-beam (RE-4000N) and positive e-beam (RE-5000P) resists, both of which are suited for mask-making applications. The RE-5000P is also sensitive to X-ray radiation. In addition to its conventional negative and positive optical resists, Hitachi Chemical also manufactures a negative deep-UV resist (RD-2000N) and has recently developed a new positive UV resist that is oxygen-RIE (reactive ion etch) resistant. Hitachi Chemical's photoresist products go by the brand name of RAYCAST.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x	x	x	x	x	

Hitachi Chemical manufactures and supplies materials used by semiconductor manufacturers including photosensitive polyimides, isotropic graphite materials, silicon carbide products, printed wiring boards, ceramic substrates, die bonding pastes, and epoxy molding compounds for encapsulation. In addition to its semiconductor-related products, Hitachi Chemical also manufactures synthetic resins, pharmaceuticals, and biochemicals.

Photoresist

Japan Synthetic Rubber

Japan Synthetic Rubber (JSR) manufactures and supplies a full line of resists including positive and negative optical, deep-UV, negative e-beam, and negative X-ray resists. JSR has been actively involved in photoresist research since the early 1970s. Its first resist products were negative optical resists based on cyclized polyisoprene and cyclized polybutadiene. In 1982, JSR introduced its first positive-working resist, PFR3003, and in late 1985, the company introduced its PFR3600 positive resist for 1- and 4-Mbit device fabrication. JSR began quantity production of negative X-ray resists in the second quarter of 1986.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
*	*	*		*		*

In addition to direct sales of resists in Japan, JSR supplies its photoresist products to semiconductor manufacturers in the United States through KTI Chemicals and in Europe through UCB Electronics. JSR's photoresist manufacturing facility is in Yokkaichi City, Mie prefecture, while research and new product development takes place at the Tokyo Research Laboratory in Kawasaki City, Kanagawa prefecture. JSR, established in 1957, is the largest manufacturer of synthetic rubber products in Japan. Bridgestone Corporation of the United States is a major stockholder in the company.

Mitsubishi Chemical Industries

Mitsubishi Chemical Industries manufactures and supplies positive optical resists to the Japanese semiconductor industry. The company introduced a new positive resist, MCPR2000H, at SEMICON/Tokyo in December 1986. This resist for submicron applications was developed in conjunction with researchers at Mitsubishi Electric. Applications include 1-Mbit and higher-density DRAM device fabrication. Fujitsu and Oki were beta sites for the new resist formulation. Production quantities of MCPR2000H began in the second quarter of 1987. The company's photoresist manufacturing takes place at its Kurosaki Plant in Kitakyushu City, Fukuoka prefecture.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
*						

Mitsubishi Chemical Industries was established in 1934 as Japan Tar Industries Ltd. The company's activities have expanded from an initial involvement in coke, dyes, and fertilizers to a highly diversified product range including petrochemicals, plastics, electronic materials, and pharmaceuticals. In addition to its photoresist operations, Mitsubishi Chemical Industries also manufactures sputtering targets for the semiconductor industry.

Photoresist

Nagase Chemicals

Nagase Chemicals is a top Japanese chemical trading company with exclusive sales rights for Eastman Kodak products in Japan. Nagase supplies several different Kodak resists to Japanese semiconductor manufacturers including Kodak's 732, 747, and 752 negative resists as well as the 809 and 820 positive resists. Nagase's reformulation facility is its Harima Plant in Tatsuno City, Hyogo prefecture. In addition to supplying photoresist to the Japanese semiconductor industry, Nagase also has joint ventures with major non-Japanese interests to produce epoxy resins and engineering plastics.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
*	*			*		*

Somar

Somar supplies negative e-beam resists to the Japanese semiconductor industry. The company has developed negative e-beam resists for maskmaking applications based on both polyglycidylmethacrylate (PGMA) and polystyrene (PST) polymer chemistries.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
				*		

Sumitomo Chemical

Sumitomo Chemical manufactures and supplies positive optical photoresist to the Japanese semiconductor industry. Its positive resist, Sumiresist, is manufactured at the Oita Works Plant in Oita City, Oita prefecture. In April 1987, Sumitomo Chemical announced a new single-layer photoresist for 16-Mbit DRAM applications. The company claims that the new resist, Sumiresist PF9200, can achieve 0.6-micron line geometries using standard g-line (436nm) lithography systems.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
*						

Sumitomo Chemical is one of Japan's major chemical companies and supplies a comprehensive line of products. In addition to its photoresist products, it manufactures sputtering targets, optical disks, ceramic capacitors, and high-purity alumina for the semiconductor and electronics industries. Agrichemicals constitute a major portion of Sumitomo Chemical's business operations. Sumitomo Chemical is part of the Sumitomo group.

Photoresist

Tokyo Ohka Kogyo

Tokyo Ohka Kogyo (TOK) is the leading manufacturer and supplier of photoresist to the Japanese semiconductor industry. Its products include its OFPR and ONPR series (positive optical), OMR and ONNR series (negative optical), ODUR series (deep-UV), and OEBR series (e-beam) resists. In 1986, Tokyo Ohka announced product development activities in X-ray resists for 16-Mbit device applications. Tokyo Ohka Kogyo currently has four resist manufacturing facilities: Kawasaki Plant, Kawasaki City, Kanagawa prefecture; Sagami Plant, Samukawa City, Kanagawa prefecture; Utsunomiya Plant, Utsunomiya City, Tochigi prefecture; and Aso Plant, Ichinomiya City, Kumamoto prefecture. In the fourth quarter of 1986, construction began at a fifth facility in Gotemba, Shizuoka prefecture. A sixth facility to be built in Ikuno, Hyogo prefecture, is planned for 1988.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x	x	x	x	x	x

Dataquest estimates that greater than 95 percent of Tokyo Ohka's resist sales are in Japan. In its efforts to expand its presence in overseas markets, Tokyo Ohka opened a new sales office and warehouse center in 1986 in Livingston, Scotland, for packaging and storage of TOK resist materials for distribution to the European market. Tokyo Ohka is currently supplying NEC's semiconductor facility in Livingston.

In the second quarter of 1987, Tokyo Ohka Kogyo established a wholly owned subsidiary in the United States to handle photoresist inquiries from U.S. semiconductor manufacturers. The new company, Ohka America, is capitalized at $1 million and has its headquarters in Santa Clara, California. Dataquest believes that Tokyo Ohka Kogyo is already supplying NEC's Roseville, California, facility with photoresist products.

Dynachem, a U.S.-based photoresist manufacturer, is the only photoresist manufacturer that has licensed photoresist process technology from Tokyo Ohka Kogyo. The terms of the agreement allow Dynachem to manufacture and sell the OFPR (positive optical) and OMR (negative optical) resists in the United States.

In addition to photoresist, Tokyo Ohka Kogyo manufactures and supplies plasma etch and ashing systems to the semiconductor industry. Other TOK products include electronic-related materials for chemical milling and the printed circuit board industry, printing materials and equipment, and inorganic and organic chemicals.

Photoresist

Toray Industries

Toray Industries manufactures and supplies positive e-beam resist for use in VLSI device fabrication and maskmaking. Toray's resist, EBR-9, has high-resolution capability that permits submicron pattern accuracy.

Optical		Deep-UV	E-Beam		X-Ray	
Pos.	Neg.		Pos.	Neg.	Pos.	Neg.
			x			

In April 1987, MacDermid announced an agreement to license its positive resist technology to Toray Industries of Japan. Toray will construct a new manufacturing facility that will be integrated with its existing electronic materials plant in Shiga, where the company currently produces e-beam resists, high-purity polyimide coatings, and other associated materials. Photoresist production at the new facility will begin in September 1987. The licensing agreement allows Toray to begin immediate marketing of MacDermid's PR-900 series resists and associated products for 1- and 4-Mbit VLSI devices. The PR-900 series resists can yield dimensions of 0.6 micron and are compatible with existing g-line lithography equipment.

Toray also supplies the semiconductor industry with photosensitive polyimides, which are used as protective layers and multilayer insulation films for semiconductors. In the fourth quarter of 1986, KTI Chemicals was named the U.S. distributor for Toray's semiconductor chemical products.

In addition to semiconductor-related materials, Toray is a major manufacturer of synthetic fibers and has a diversified product mix in engineering plastics, reverse osmosis membranes, and pharmaceuticals.

Toyo Soda Manufacturing Co.

Toyo Soda Manufacturing Co. manufactures and supplies deep-UV and negative e-beam resists to the semiconductor industry. Its CMS series of resists have applications in both direct-write e-beam lithography and maskmaking. (CMS is the abbreviation used to denote partially chloromethylated polystyrene; the chloromethyl group of this polymer system is highly sensitive to e-beam, soft X-ray, and deep-UV radiation.) Toyo Soda developed its Toyobeam CMS series of high-performance resists for VLSI processing in cooperation with NTT's Ibaragi Electrical Communication Laboratory. Toyo Soda's SNR series resists are e-beam and deep-UV resists for bilayer applications. Marketing for the Toyobeam resists began in the spring of 1981.

The company currently is working on the development of X-ray resists for 16-Mbit DRAM process applications. Toyo Soda's manufacturing facility is located in Shin-Nanyo City, Yamaguchi prefecture.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
		x		x		x

Toyo Soda is a major Japanese chemicals manufacturer and is one of the largest producers of caustic soda and chlorine in Japan. Toyo Soda's industrial products include polymers such as polyethylene, polyvinyl chloride, and synthetic rubbers; chromium and manganese metals; and ceramics materials. In addition to its photoresist operations, the company manufactures sputtering targets and quartz glassware for the semiconductor industry. In mid-1985, Toyo Soda announced plans to form a joint venture with Siltec Corporation, a U.S.-based silicon wafer manufacturer. However, plans were canceled at the end of 1985 in response to the deepening recession in the semiconductor industry and weak demand for wafers in Japan.

European Photoresist Companies

Hoechst AG

Hoechst AG (Frankfurt, West Germany) is a major manufacturer and supplier of positive resists to semiconductor manufacturers throughout the World. Hoechst's photoresist products are marketed under the AZ brand name and manufactured in Wiesbaden, West Germany, by Kalle Niederlassung der Hoechst AG. Hoechst's resist products are positive optical resists (1300 series, 1400 series, 4000 series, and 5200 series). The AZ 5200 series of positive resist can be used for image reversal; an additional post-exposure bake between exposure and development will allow a negative image to be formed. The 5200 series resists have wavelength sensitivity in the 310 to 405 nanometer range and so can act as positive UV and g-line resists. The AZ 5214 resist has potential application as a positive e-beam resist material. Both the 5200 series and the 1300 series were developed by AZ Photoresist Products (an operating group of American Hoechst Corporation) in the United States, rather than by Kalle, Hoechst's photoresist research and manufacturing operation.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x			x			

Photoresist

Hoechst AG manufactures and supplies a diversity of materials and products for the èlectronics industry. In addition to photoresist, Hoechst's other semiconductor-related products include polysilicon and wafer substrate materials (through its 50 percent ownership of Wacker Chemie); high-purity acids, solvents, dopants, etchants, and related processing chemicals; semiconductor specialty gases and gas-handling equipment (through its subsidiary, Messer Griesheim); graphite susceptors; and ceramic and plastic packaging materials for assembly operations. In addition, Hoechst supplies dry resists, laminates, chemicals, and substrates to the printed circuit board industry, as well as substrate materials and thick and thin film pastes for hybrid applications. Its component products include capacitors, resistors, transformers, and piezo ceramics.

American Hoechst, AZ Photoresist Products - AZ Photoresist is a major manufacturer and supplier of positive resist in the United States. The company is an operating group of American Hoechst Corporation, which is a wholly owned subsidiary of Hoechst AG of West Germany. AZ Photoresist Products was formerly part of Azoplate Corporation, which was acquired by American Hoechst in 1971. The company's headquarters are in Somerville, New Jersey. (American Hoechst acquired Celanese Corporation in the first quarter of 1987. American Hoechst has recently undergone a name change to Hoechst Celanese.)

Prior to December 1982, many of the AZ brand positive resist products manufactured by AZ Photoresist were distributed in the United States through Shipley, via an exclusive distribution agreement. Under this distribution agreement, AZ manufactured the basic product line while Shipley provided marketing and service support. The exclusive distribution agreement between AZ and Shipley was terminated in December 1982, at which time AZ Photoresist began direct sales and marketing of its products in the United States.

During an interim period, AZ Photoresist continued to supply Shipley with photoresist products, while Shipley proceeded to expand its primary manufacturing capability substantially. For legal reasons, however, Shipley could no longer use the AZ brand name so Shipley began marketing its photoresist products under the Microposit name. This change caused considerable confusion among both Shipley and AZ customers.

Over the last several years, AZ Photoresist has made the transition from supplying bulk resist materials and its AZ-brand positive resists only through distributors to becoming a major direct supplier of photoresists to the U.S. semiconductor industry. Dataquest estimates that AZ Photoresist's direct sales of positive resists to U.S. semiconductor manufacturers represented approximately 60 to 65 percent by volume of its total photoresist sales in 1984, while by 1985, direct sales to semiconductor manufacturers increased to 75 percent of AZ's photoresist sales. In 1985, AZ Photoresist ranked third behind Shipley and Olin Hunt Specialty Products in direct sales of positive optical resists to U.S. semiconductor manufacturers. In addition to its direct sales, AZ Photoresist continues to sell small amounts of photoresist materials to Shipley, as well as supplying reformulator companies, KTI Chemicals, and the ROK Division of Chemtech Industries.

Hoechst Japan - Hoechst Japan is the sales and marketing arm for Hoechst AG in the Far East. Hoechst Japan's technical center is located in Daito Town, Shizuoka prefecture.

E. Merck

E. Merck is a major manufacturer and supplier of positive and negative optical, deep-UV, positive e-beam, and positive X-ray resists. Merck's optical photoresists are marketed under the Selectilux name. Merck's first resist products were negative optical photoresists (Selectilux N). Positive optical resists (Selectilux P) were introduced in 1984. Merck's positive e-beam resist, EB250A, is a PMMA-type resist, with applications in deep-UV, e-beam, and X-ray lithography.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x	x	x		x	

E. Merck is a major European chemical company with operations worldwide; its general product categories include industrial chemicals, reagent chemicals, specialty pigments, and pharmaceuticals. The company's headquarters are in Darmstadt, West Germany. In addition to photoresist, Merck's semiconductor-related products include solvents, acids, liquid dopants, and spin-on-dopants. Merck recently announced the development of a negative-working photosensitive polyimide, Selectilux HTR 3. Polyimide applications in semiconductor device fabrication include passivation and protection layers; interlayer dielectrics; as well as masks for metal lift off, ion implantation, and ion etch process steps.

EM Chemicals - EM Chemicals, a division of EM Industries, is an associate of E. Merck of West Germany. While the primary photoresist R&D activities are located in Darmstadt, West Germany, EM Chemicals has full manufacturing capability at its Hawthorne, New York, facility. (EM Industries is unable to use Merck within its name because another U.S. corporation has legal rights to the Merck name within the United States.)

Hopkin & Williams - Hopkin & Williams is a wholly owned subsidiary of E. Merck of West Germany. The company provides photoresist marketing, sales, and technical support for Merck photoresists in the United Kingdom.

Merck Japan - Merck Japan is the sales and marketing arm for E. Merck in the Far East. Merck Japan has its headquarters in Tokyo.

Micro-Image Technology

Micro-Image Technology was established in 1972 to provide ultraclean chemicals and photoresists to the European semiconductor industry. Micro-Image Technology has been reformulating Eastman Kodak bulk resist materials since 1974. Micro-Image Technology's resists are marketed under the names Isofine (positive resist systems) and Isopoly (negative resist systems). In addition to reformulating Kodak resist products, Micro-Image Technology offers e-beam resists based on Philips research with COP and other resist formulations.

Optical		Deep-UV	E-Beam		X-Ray	
Pos.	Neg.		Pos.	Neg.	Pos.	Neg.
*	*		*	*		*

Micro-Image Technology was acquired by Laporte Industries of the U.K. in 1983, and is now part of the Laporte Electronic Products and Services (EPS) Division. Laporte Industries, founded in 1888, is a British-based international chemicals group; it is one of the largest independent chemical companies in the United Kingdom. The Laporte EPS Division supplies a wide range of products to semiconductor manufacturers worldwide including high-purity chemicals, etchants, photoresists, pellicles, and clean room garments. In addition to these products, Laporte EPS Division offers a wafer reclamation service and air filtration systems for clean rooms. Other photoresist companies in the Laporte EPS Division are M.I.T.-Halbleiterchemie GmbH of West Germany, Soprelec S.A. of France, and Spectrum Resist Products of the United Kingdom (see the "New Entrants" section). Spectrum Resist Products is the only company within the Laporte EPS Division that has primary manufacturing capability for photoresist materials.

M.I.T.-Halbleiterchemie GmbH - M.I.T.-Halbleiterchemie GmbH of Solingen, West Germany, was formed in 1981 as a subsidiary of Herbert Schmidt GmbH & Co., a major supplier of chemicals to European printed circuit board and metal finishing companies. M.I.T.-Halbleiterchemie has been a wholly owned subsidiary of Laporte Industries since early 1986. M.I.T.-Halbleiterchemie supplies reformulated Kodak resists from Micro-Image Technology to West German semiconductor manufacturers.

Soprelec S.A. - Soprelec S.A. was established in 1977 in Bondoufle, France, to provide products and services to the semiconductor industry; the company was acquired by Laporte Industries in 1984. Soprelec provides sales and service support of Micro-Image Technology's photoresist products to French semiconductor companies. In addition to photoresist, Soprelec specializes in manufacturing and supplying ultrahigh-quality chemical products. Its products and services include a full range of custom etchants and cleaners, high-purity acids and solvents, optical fiber products, and chemicals used in manufacturing and cleaning printed circuit boards.

Photoresist

New Entrants

Aspect Systems

In September 1986, Monsanto Company sold its photoresist operations to Aspect Systems, a start-up company formed to purchase the operations. Monsanto had been involved in photoresist research and development for a number of years; its first photoresist products were introduced in 1984. The former Photoresist Products division was part of Monsanto Electronic Materials Company, a Monsanto Company subsidiary whose major products are silicon and epitaxial wafers for the semiconductor industry.

Aspect Systems' photoresist products, originally developed by Monsanto, include System 7 and System 8. Both are high-resolution, positive optical photoresists. Aspect Systems, formed in June 1986, received venture funding from Advent International. The company's marketing, sales, and field applications operations are located in Cupertino, California. Photoresist manufacturing is performed on a contractual basis at Monsanto's facility in St. Louis, Missouri.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x						

Dynamit Nobel Chemicals

In May 1986, Dynamit Nobel AG acquired Allied Chemical's photoresist operations. (Allied Chemical had closed its four-year-old photoresist operations in August 1985. The decision to shut down the resist program was attributed to the difficulty in penetrating the photoresist market for the semiconductor industry.) Dynamit Nobel's new resist operation is located at Dynamit Nobel Microelectronics Center in Bristol, Pennsylvania. During the second quarter of 1987, the company was field testing its MicroSi MS6000 series positive optical resist. This is a novolac-based resist that has been designed as a safe solvent formulation.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x						

In May 1987, Dynamit Nobel AG announced its decision to sell its European and U.S. silicon operations and Dynamit Nobel Chemicals to Veba AG, a major West German chemical manufacturer. Dataquest believes that as part of the transaction, Dynamit Nobel's parent company, Feldmuhle Nobel AG, will retain the explosives division, the injection molding technology, and the rights to the name Dynamit Nobel. As a consequence of this acquisition, the chemicals, photoresist, and silicon operations of Dynamit Nobel will be required to undergo a change of name some time in the near future.

Molecular Electronics Corporation

Molecular Electronics Corporation (Torrance, California) was formed in 1984 to investigate and develop products using molecular film technology in electronic applications. Molecular film technology involves the deposition of single molecular layers of organic materials on solid substrates. The technology is based on the principle that those portions of organic and polymeric molecules that have similar solubility properties will align themselves in an orderly structure. By careful application, very thin uniform films with no defects can be achieved. The deposition of such monolayers of organic molecules was developed more than 50 years ago by Langmuir and Blodgett, who won a Nobel prize in 1930 for their research.

Molecular Electronics Corporation's first product is an advanced negative e-beam resist system. The company's resist system includes equipment, the resist itself, ancillary chemicals, and technical expertise in the field of molecular film technology. The negative e-beam resist is marketed under the Monoresist name, and initial applications are focused on maskmaking. With such a resist formulation based on the Lanmuir-Blodgett thin film technology, limitations in pattern resolution depend more strongly on the lithography equipment and process parameters than on the resist material itself. Molecular Electronics Corporation claims that 0.1-micron line geometries are easily obtained with its Monoresist negative e-beam resist material.

In addition, the company has developed automated continuous immersion equipment to perform the thin molecular film deposition. The immersion system, marketed as the Monofab, is currently available as a production tool. Molecular Electronics shipped its first mask samples using this technology in the third quarter of 1986.

Optical		Deep-UV	E-Beam		X-Ray	
Pos.	Neg.		Pos.	Neg.	Pos.	Neg.
				*		

Spectrum Resist Products

Spectrum Resist Products (Riddings, Derbyshire, United Kingdom) was formed by Laporte Industries' Electronic Products and Service Division in early 1986. Spectrum Resist Products currently manufactures positive and negative optical resists and markets them under the Spectrum MEGA name. Three resist product ranges have been designed for specific processing applications: MEGA 1 resists for high-resolution lithography; MEGA 2 resists for variable reflective substrates and topography; and MEGA 3 resists for dry etching, aluminium/silicon/copper etching, dielectric etching, and high temperature applications. All resist products have been designed with safe solvents to meet growing demands for ecologically acceptable materials within the semiconductor industry.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
*	*					

Spectrum Resist Products performs no reformulation of photoresists, unlike its sister company, Micro-Image Technology. Spectrum Resist Products, however, does share product distribution networks and billing operations with Micro-Image Technology.

Syn Labs

In June 1987, Syn Labs introduced its first product, a negative resist for e-beam, X-ray, and deep-UV applications. The XLR8 resist, an organo-silicon resist formulation, was developed in cooperation with Intel Corporation. Syn Labs claims that its material has been used by e-beam and X-ray equipment manufacturers, a captive mask shop, and one semiconductor manufacturer. The material has been at beta sites; sampling of the XLR8 negative resist began in June 1987. Syn Labs, a privately held company, was founded in 1985. R&D and administrative activities are located in Sunnyvale, California. Resist manufacturing takes place at Syn Labs' facility in Aguas Calientes, Mexico.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
		*		*		*

UCB Electronics

In 1986, UCB Electronics announced a new negative resist for submicron processing. The material, known by its trade name of PLASMASK, is a component of the DESIRE (Diffusion Enhanced Silylating Resist) process. In the DESIRE process, the PLASMASK resist is used as a conventional single-layer resist. However, with selective silylation of the exposed resist, followed by an anisotropic oxygen etch, researchers have obtained 0.2-micron line geometries with vertical sidewalls even over topography. This is possible because the silylated PLASMASK is converted into silicon dioxide, which acts as a refractory plasma barrier. The DESIRE process was developed as part of a joint research program launched in 1983 between UCB Electronics and IMEC, the Interuniversity Microelectronics Center of Leuven in Belgium.

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In addition to its PLASMASK resist, UCB Electronics also supplies the full resist line of Japan Synthetic Rubber (JSR). The 1986 agreement between UCB Electronics and JSR allows UCB to market and sell JSR's positive and negative optical, deep-UV, e-beam, and X-ray resists in Europe.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x	x	x		x		x

The PLASMASK and JSR resists, as well as processing chemicals, are prepared and bottled at UCB's facilities in Haasrode near Leuven, Belgium. A permanent research team supports the long-term agreement between UCB and IMEC to develop advanced chemical products for the electronics industry. This research program is carried out at the IMEC facility in Leuven.

UCB Electronics is a wholly owned subsidiary of the UCB Group, one of the largest pharmaceutical and chemical concerns in Belgium. The UCB Group was founded in 1928 under the name of Union Chimique Belge. Major product categories for the UCB Group include pharmaceuticals, biotechnology, specialty chemicals, plastic films, and UV-cured resins for the printed circuit board industry.

Departures

Allied Chemical

Allied Chemical announced in August 1985 that its Electronic Chemicals unit was dropping its four-year-old photoresist program. Allied had acquired the exclusive rights to produce a line of positive resists and developers manufactured by Polychrome Corporation (Yonkers, New York) in 1981. Over the following four years, almost $15 million was spent for development and marketing of the new line of positive resist under the trade name, Acculith. The decision to shut down the resist program was attributed to the difficulty encountered in penetrating the photoresist market for the semiconductor industry. Dynamit Nobel acquired Allied's photoresist operations in May 1986, as part of the company's strategy to service the electronic chemicals and materials industries. Dynamit Nobel's new resist operation is located at Dynamit Nobel Chemicals' Microelectronics Center in Bristol, Pennsylvania. Photoresists from Dynamit Nobel Chemicals include the MicroSi MS6000 series of positive optical resists.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x						

Monsanto Company

In September 1986, Monsanto Company sold its photoresist operations to Aspect Systems, a start-up company formed to purchase the operations. Monsanto had focused its photoresist development program on positive optical resists; its first products were developed in 1984. Monsanto's facility in St. Louis, Missouri, performs photoresist manufacturing for Aspect Systems on a contractual basis. The former Photoresist Products division was part of the Monsanto Electronic Materials Company, a Monsanto Company subsidiary whose major products are silicon and epitaxial wafers for the semiconductor industry.

Optical			E-Beam		X-Ray	
Pos.	Neg.	Deep-UV	Pos.	Neg.	Pos.	Neg.
x						

Semiconductor Manufacturers' Photoresist Activities

Over the years, several of the major semiconductor manufacturers have been involved with photoresist R&D. In the United States, these companies include IBM, Motorola, and Texas Instruments. While most internal photoresist programs are focused on developing new proprietary imaging materials, in some instances commercial products are the result. For example, Bell Labs in the United States developed the e-beam resist technology for COP and PBS, which in turn was licensed to Mead Technology in the United States and Chisso in Japan. COP and PBS are two of the major e-beam resists used in maskmaking applications today.

In Japan, several in-house photoresist development programs have produced materials that have since become commercial products. In the case of Hitachi Chemical, photoresist development work is performed in conjunction with the central R&D group at Hitachi, Ltd., the semiconductor manufacturer. Hitachi Chemical then brings the products to the manufacturing environment and is responsible for worldwide sales and marketing. As another example, Toyo Soda developed its Toyobeam CMS series of high-performance resists for VLSI processing in cooperation with NTT's Ibaragi Electrical Communication Laboratory.

Over the past two to three years, several Japanese semiconductor manufacturers have announced new photoresist formulations developed for 4-, 16-, and 64-Mbit device fabrication. Table 5 contains a summary of several of these recent announcements. It is interesting to note that Matsushita Electric has already established an agreement to provide Japan Synthetic Rubber with its new water-soluble polymer technology for 4-Mbit applications. Dataquest believes that the commercialization of new processing materials through such agreements is another example of the benefits derived from close relationships between Japanese semiconductor manufacturers and their vendors.

Table 5

SEMICONDUCTOR MANUFACTURERS' PHOTORESIST ACTIVITIES

Company	Year	Application	Comments
Matsushita Electric	1987	64-Mbit DRAM	Resist employs Langmuir-Blodgett technique for preparing thin molecular films; lithography systems include KrF excimer laser and X-ray exposure sources; circuit patterns of 0.3 microns achieved
Toshiba	1987	16-Mbit DRAM	Positive resist based on chlorosilane and isopropenyl phenol; line width resolution of 0.5 micron
Sanyo Electric	1986	4-Mbit DRAM	Positive e-beam resist for maskmaking applications; e-beam resist, known as SEBR-115, is based on PMMA derivative; marketing program to begin in 1987
Matsushita Electric	1985	4-Mbit DRAM	Jointly developed water-soluble polymer with Hayashibara Biochemical Laboratories, Inc.; polymer system based on polysaccharide compounds and photobleaching agents; would be applied to wafer along with photoresist to produce 0.6-0.7-micron line geometries; agreement established in 1986 to provide JSR with manufacturing technology
Hitachi	1985	4-Mbit DRAM	Collaborated with Kyoto University to develop new positive resist; line width resolution of 0.8 micron

Source: Dataquest
August 1987

Photoresist

MARKET ANALYSIS

Dataquest's analysis of the 1985 worldwide photoresist market focuses on the positive and negative optical photoresist market. Dataquest estimates of company sales (dollar and volume) in the United States, Japan, and Europe are presented in the tables. While specific market share analysis is not included for the ROW countries, estimates of total positive and negative optical resist consumption are presented. All market estimates reflect direct sales of positive and negative photoresist to semiconductor manufacturers. No photoresist sales between resist companies (for reformulation or distribution) or ancillary product sales to semiconductor manufacturers are included in our estimates. Dataquest's analysis of the optical photoresist market does not include ancillary products.

The worldwide positive and negative optical photoresist market was $133 million in 1985. While this study does not contain specific market data for deep-UV, e-beam, or X-ray resists, Dataquest believes that the world market for these materials was between $3 million and $4 million in 1985 and that e-beam resists were the major segment of that market.

Photoresist Pricing

Table 6 contains the regional 1985 average selling price for positive and negative optical photoresist. Positive optical photoresist traditionally commands a price approximately four to five times that of negative resist. Thus, as market demand shifts toward increased positive resist consumption, even with little or no growth in volume, the market size increases.

Table 6

1985 ASPs FOR OPTICAL PHOTORESIST
(Dollars per Gallon)

Region	Positive	Negative
United States	$319	$90
Japan	$305	$58
Europe	$315	$85
Rest of World	$320	$74

ASP = Average Selling Price

Source: Dataquest
August 1987

Dataquest expects that during the next few years, the average selling price of negative optical photoresist will decline slightly, while positive optical photoresist will continue to maintain its current level or increase slightly due to the higher pricing of advanced resist formulations for submicron processing. However, competitive bidding in the market place can force prices lower. For example, in Japan the 1986 average selling price of positive optical resist was ¥65,500 per gallon (¥167 per U.S. dollar), down on the order of 10 percent in yen from 1985's average selling price of ¥72,500 per gallon (¥238 per U.S. dollar). The downward pricing pressure for both positive and negative resists in Japan reflects the aggressive pricing policies of the smaller photoresist companies that are attempting to wrest away a few percentage points of market share from the market leader, Tokyo Ohka Kogyo.

Company Market Share by Region, 1985

United States

Table 7 presents company market shares for the 1985 U.S. positive and negative optical photoresist market. The average selling price for positive optical resist was $319 per gallon, while negative optical resist was approximately $90 per gallon. In 1985, Olin Hunt Specialty Products and Shipley were the two largest suppliers of photoresist to the U.S. semiconductor industry. Olin Hunt was the market leader in negative optical resists, and has a strong position in positive optical photoresists, while Shipley, which manufactures only positive resists, is the market leader in that product segment.

Table 7

1985 U.S. OPTICAL PHOTORESIST MARKET
(Millions of Dollars, Thousands of Gallons)

	Total Market		Positive Optical			Negative Optical		
Company	Sales	Share	Sales	Share	Volume	Sales	Share	Volume
AZ Photoresist	$ 7.8	12.2%	$ 7.8	15.2%	25.0	-	-	-
J.T. Baker	2.4	3.8	1.6	3.0	4.5	$ 0.9	6.9%	10.0
Dynachem	5.3	8.3	4.1	8.0	12.5	1.2	9.7	14.0
KTI Chemicals	5.2	8.2	2.9	5.6	9.0	2.3	19.0	26.0
Olin Hunt Specialty Products	20.7	32.6	13.7	26.8	42.0	7.0	57.1	78.0
Shipley	19.8	31.3	19.8	38.9	63.0	-	-	-
Others*	2.2	3.4	1.3	2.5	4.0	0.9	7.3	8.0
Total	$63.3	100.0%	$51.0	100.0%	160.0	$12.3	100.0%	136.0

*Others include positive optical: EM Chemicals, MacDermid, ROK (Chemtech Industries); negative optical: EM Chemicals, B.F. Goodrich, ROK (Chemtech Industries)

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
August 1987

Japan

Table 8 presents company market share for the Japanese positive and negative optical photoresist market in 1985. The average selling price for positive optical resist was $305 per gallon, while negative optical resist was approximately $58 per gallon. In 1985, Tokyo Ohka Kogyo maintained its majority market share of the Japanese optical resist market with approximately 67.1 percent of the $45.9 million market.

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Table 8

1985 JAPANESE OPTICAL PHOTORESIST MARKET
(Millions of Dollars, Thousands of Gallons)

	Total Market		Positive Optical			Negative Optical		
Company	Sales	Share	Sales	Share	Volume	Sales	Share	Volume
Fuji-Hunt	$ 2.7	5.9%	$ 1.8	5.0%	6.0	$ 0.9	9.1%	15.0
Japan Synthetic Rubber	2.2	4.8	0.5	1.4	1.7	1.7	18.2	30.0
Shipley Far East	6.4	13.9	6.4	17.6	21.0	-	-	-
Tokyo Ohka Kogyo	30.8	67.1	24.4	67.2	80.0	6.4	66.7	110.0
Others*	3.8	8.3	3.2	8.8	10.3	0.6	6.1	10.0
Total	$45.9	100.0%	$36.3	100.0%	119.0	$ 9.6	100.0%	165.0

*Others include positive optical: Dainippon Ink and Chemicals, Hitachi Chemical, Hoechst Japan, Merck Japan, Nagase Chemical, Sumitomo Chemical; negative optical: Dainippon Ink and Chemicals, Hitachi Chemical, Merck Japan, Nagase Chemical

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
August 1987

Europe

Table 9 presents company market share for the European positive and negative optical photoresist market in 1985. The average selling price for positive optical resist was $315 per gallon, while negative optical resist was approximately $85 per gallon. In 1985, Olin Hunt Specialty Products and Hoechst AG were the major suppliers of photoresist to the European market. Olin Hunt had majority market share in both positive and negative optical photoresist segments, while Hoechst AG, which manufactures only positive resists, ranked second in the European positive optical resist market in 1985.

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Table 9

1985 EUROPEAN OPTICAL PHOTORESIST MARKET
(Millions of Dollars, Thousands of Gallons)

Company	Total Market		Positive Optical			Negative Optical		
	Sales	Share	Sales	Share	Volume	Sales	Share	Volume
Hoechst AG	$ 3.9	22.8%	$ 3.9	28.4%	12.5	-	-	-
E. Merck*	2.6	15.3	1.6	11.4	5.0	$ 1.1	31.4%	13.0
Micro-Image Technology**	0.6	3.5	0.3	2.3	1.0	0.3	8.4	3.5
Olin Hunt Specialty Products	7.4	42.9	5.5	39.8	17.5	1.9	55.5	23.0
Shipley	2.2	12.8	2.2	15.9	7.0	-	-	-
Others	0.5	2.7	0.3	2.3	1.0	0.2	4.6	0.5
Total	$17.3	100.0%	$13.9	100.0%	44.0	$ 3.4	100.0%	40.0

*Estimated sales of Hopkin & Williams are included in estimates for E. Merck.

**Estimated sales of Soprelec and M.I.T.-Halbleiterchemie are included in estimates for Micro-Image Technology.

Source: Dataquest
August 1987

Rest of World

Table 10 presents the positive and negative optical photoresist in the ROW countries in 1985. The average selling price for positive optical resist was $320 per gallon, while negative optical resist was approximately $74 per gallon. While Table 10 does not include company market share estimates, Dataquest believes that the major suppliers of photoresist in the ROW region include Olin Hunt Specialty Products, Shipley, and Tokyo Ohka Kogyo.

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Table 10

1985 REST OF WORLD OPTICAL PHOTORESIST MARKET
(Millions of Dollars, Thousands of Gallons)

Total Optical Resist Market	Positive Optical		Negative Optical	
Sales	Sales	Volume	Sales	Volume
$ 6.5	$ 4.8	15.0	$ 1.7	23.0

Source: Dataquest
August 1987

World Photoresist Market

Table 11 presents a summary of sales and market share for the four major suppliers of optical photoresist in the U.S., Japanese, and European markets. For example, Olin Hunt Specialty Products' sales of $30.8 million represent the combined sales of Olin Hunt in the United States and Europe, as well as Fuji-Hunt in Japan. Similarly, Shipley's 1985 sales of $28.5 million represent combined sales in the United States and Europe, as well as Shipley Far East in Japan. For Hoechst AG, European sales as well as sales of AZ Photoresist in the United States have been included in the estimate of $11.7 million. While estimates of Hoechst Japan sales have not been included in this figure, Dataquest believes that this is a small factor and will not significantly change Hoechst's overall market share position in the combined U.S./Japanese/European photoresist marketplace. Similarly, Tokyo Ohka Kogyo's sales of $30.8 million reflect only shipments in Japan. Again, omitting non-Japanese sales will not significantly alter Tokyo Ohka's market share in the U.S./Japanese/European market as Dataquest estimates that greater than 95 percent of the company's optical photoresist sales are in Japan.

In 1985, Tokyo Ohka and Olin Hunt Specialty Products each had market share on the order of 24 percent of the combined U.S./Japanese/European optical photoresist market. Shipley ranked third with approximately 22 percent share, while Hoechst AG ranked fourth with approximately 9 percent share. One important factor that Hoechst AG, Olin Hunt, and Shipley have in common is that each company has a well-established presence in regions other than its home market. In contrast, Tokyo Ohka Kogyo essentially has sold photoresist only in its home market of Japan. Dataquest believes that this situation will change as Japanese semiconductor companies move their manufacturing bases offshore to escape high production costs, alleviate trade friction, and diversify manufacturing operations in a global market. Dataquest expects Japanese semiconductor companies to take their Japanese equipment and material suppliers with them as they move offshore, in order to maintain manufacturing continuity with fabs in Japan.

Table 11

MAJOR COMPANY MARKET SHARE
1985 WORLDWIDE OPTICAL PHOTORESIST MARKET
(Millions of Dollars, Thousands of Gallons)

	Total Market		Positive Optical			Negative Optical		
Company	Sales	Share	Sales	Share	Volume	Sales	Share	Volume
Hoechst AG	$ 11.7	9.2%	$ 11.7	11.5%	37.5	-	-	-
Olin Hunt Specialty Products	30.8	24.3	21.0	20.7	65.5	9.8	38.7%	116.0
Shipley	28.5	22.5	28.5	28.1	91.0	-	-	-
Tokyo Ohka Kogyo	30.8	24.3	24.4	24.1	80.0	6.4	25.3	110.0
Others	24.8	19.6	15.7	15.5	49.0	9.1	36.1	115.0
Total (U.S., Japan, Europe)	$126.5	100.0%	$101.2	100.0%	323.0	$25.3	100.0%	341.0
ROW	6.5		4.8		15.0	1.7		23.0
Total World	$133.0		$106.0		338.0	$27.0		364.0

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
August 1987

In the last two years, Tokyo Ohka has expanded its efforts in photoresist operations outside of Japan. In 1986, Tokyo Ohka opened a new sales office and warehouse center in Livingston, Scotland, for packaging and storage of photoresist materials for distribution to the European market. In a similar move, Tokyo Ohka Kogyo recently established a wholly owned subsidiary in the United States to handle photoresist inquiries from U.S. semiconductor manufacturers. Dataquest believes that part of the impetus for these new ventures is that Tokyo Ohka currently supplies NEC's facilities in Livingston, Scotland, and in Roseville, California. Since Tokyo Ohka has a majority market share in Japan, it is reasonable to expect Japanese semiconductor companies to take their established photoresist vendors with them as they move semiconductor operations to the United States and Europe. Dataquest believes that this practice will increase significantly Tokyo Ohka's market penetration in these heretofore untapped markets.

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Photoresist

OPTICAL RESIST FORECAST

Assumptions

Dataquest's forecast of optical resist consumption is based on the following factors:

- The consumption of silicon by semiconductor manufacturers
- The average photoresist dispense volumes
- The average number of mask levels used in device fabrication
- The other substrate processing (i.e., gallium arsenide) and rework
- The percent positive versus negative resist usage in the industry

Since gallon and liter unit measurements are used extensively and interchangeably in the photoresist industry, Dataquest's forecasts of positive, negative, and total optical resist consumption are presented in both sets of units in the tables.

Silicon Consumption

The optical photoresist forecast is based on Dataquest's silicon consumption forecast. Table 12 presents our estimates of silicon consumption by semiconductor manufacturers in each of the four regions of the world.

Photoresist consumption depends strongly upon the amount of silicon consumed in device fabrication. However, photoresist consumption tracks more effectively with silicon wafer starts rather than silicon consumption as measured in millions of square inches. Therefore, the consumption of silicon in millions of square inches is converted to wafer starts based on Dataquest's estimate and forecast of wafer size distribution in each of the four regions of the world.

Table 12

SILICON CONSUMPTION, 1985-1991
(Millions of Square Inches)

Region	1985	1986	1987	1988	1989	1990	1991	CAGR 1985-1991
United States	490	564	672	867	804	964	1,210	16.3%
Growth	(30.7%)	15.0%	19.3%	28.9%	(7.2%)	19.9%	25.5%	
Japan	594	573	651	814	804	893	1,060	10.1%
Growth	(10.1%)	(3.5%)	13.6%	25.0%	(1.3%)	11.1%	18.8%	
Europe	150	150	182	229	218	266	317	13.3%
Growth	(6.3%)	0	22.4%	26.1%	(5.2%)	22.5%	19.0%	
ROW	66	79	99	146	161	207	254	25.2%
Growth	4.8%	19.7%	38.6%	47.1%	10.3%	28.5%	22.8%	
Worldwide Silicon Market	1,300	1,366	1,605	2,056	1,986	2,330	2,841	13.9%
Growth	(18.3%)	5.1%	17.5%	28.1%	(3.4%)	17.3%	21.9%	

Note: This table was originally published in the "Silicon and Epitaxial Wafer Markets" service section, February 1987.

Source: Dataquest
August 1987

Photoresist Dispense Volume

Dataquest estimates that the average dispense volume of photoresist per mask level per wafer start was approximately 0.60 to 0.75 milliliters (ml) per inch (25.4mm) of wafer diameter in 1985. Newer models of photoresist processing equipment have been designed with dispense volumes of approximately 0.5ml per inch of wafer diameter. Dataquest expects that equipment manufacturers will continue the drive to reduce dispense volumes, since lower manufacturing costs are vital to semiconductor companies in a competitive market. Solitec, a manufacturer of automatic photoresist processing equipment, recently introduced its Series 10200 advanced track system; the company claims that the Series 10200 equipment can effectively coat a 150mm wafer with a photoresist dispense volume of 2ml or less. Due to such equipment advances, Dataquest estimates that the average dispense volume in the industry will be approximately 0.4 to 0.5ml per inch of wafer diameter by 1991. The decrease in average dispense volumes has been incorporated into our photoresist forecast.

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Photoresist

Mask Levels

Photoresist is applied to a wafer for every mask level of device fabrication. Dataquest estimates that the worldwide average number of mask levels ranged from 9.0 to 10.0 in 1985. The photoresist forecast incorporates an increase of 0.5 average mask levels per year.

Other Substrate Processing and Rework

Photoresist is also used in fabricating gallium arsenide devices. Dataquest believes that the consumption of gallium arsenide and other III-V materials (as measured in millions of square inches) represents only a few percent of the total consumption of silicon substrate. In the photoresist forecast, resist material used in gallium arsenide device fabrication is accounted for (along with resist consumed in rework) in an additional corrective factor of approximately 10 percent. This additional factor is in excess of the resist consumption calculated on the basis of silicon consumption, average resist dispense volumes, and average number of mask levels. The 10 percent factor also includes that small portion of photoresist that is left unused in the bottle or container.

Positive versus Negative Resist Usage

Dataquest estimates that in 1985, positive resist represented approximately 48 percent and negative resist 52 percent of the total optical resist market, as measured by volume. Based on an analysis and forecast of line geometries, it is expected that by 1991, positive resist usage will increase to approximately 70 percent of optical resist consumption. Because of the continuing trend toward sub-2-micron processing, positive resist will remain the predominant resist. While new negative resists with sub-2-micron processing capability are being developed, Dataquest does not expect these new resist formulations to turn the tide in positive versus negative resist usage within the industry.

More or Less Resist?

Future consumption of photoresist depends upon the interplay of factors such as wafer size, device complexity, and smaller line geometries. For example, as device complexity increases, the number of mask levels will increase, and, thus, the number of times photoresist is applied to the wafer will also increase. However, as the industry moves to larger wafers, a smaller amount of photoresist is required per square inch to effectively coat the wafer. Table 13 presents a summary of the contributing factors affecting future photoresist demand.

Table 13

FACTORS AFFECTING FUTURE PHOTORESIST CONSUMPTION

Factors Increasing Photoresist Consumption	Factors Decreasing Photoresist Consumption
Increasing consumption of silicon (millions of square inches)	Shift to larger diameter wafers (wafer starts grow at a lesser rate than square inches)
Average number of mask levels increasing with device complexity	Shift to larger diameter wafers (less photoresist consumed per square inch)
Usage of positive resist will increase with sub-2-micron processing	Usage of negative resist will decrease with sub-2-micron processing
	Better designed equipment will reduce dispense volumes per wafer

Source: Dataquest
August 1987

Positive Optical Resist Forecast

Table 14 presents Dataquest's estimates of positive optical resist consumption in the four regions of the world. The estimates are presented in units of thousand gallons and thousand liters because both sets of units are used in the semiconductor industry. Dataquest expects that worldwide positive optical resist consumption will exhibit a healthy growth on the order of 14.1 percent compound annual growth rate (CAGR) between 1985 and 1991. This growth reflects the increased shift from negative optical to positive optical resist usage as manufacturers continue the push below sub-2-micron processing.

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Table 14

POSITIVE OPTICAL PHOTORESIST FORECAST

Region	1985	1986	1987	1988	1989	1990	1991	CAGR 1985-1991
United States								
K gallons	160	175	190	249	232	273	329	12.8%
K liters	606	661	717	941	878	1,033	1,245	
Growth		9.1%	8.5%	31.2%	(6.7%)	17.6%	20.5%	
Japan								
K gallons	119	125	145	191	197	225	272	14.8%
K liters	450	472	549	725	744	852	1,029	
Growth		4.7%	16.4%	32.0%	2.7%	14.4%	20.8%	
Europe								
K gallons	44	43	51	62	59	70	81	10.7%
K liters	167	164	191	234	222	267	306	
Growth		(1.6%)	16.7%	22.2%	(5.0%)	20.1%	14.9%	
ROW								
K gallons	15	19	25	37	41	52	62	26.7%
K liters	57	73	94	140	154	195	233	
Growth		28.1%	28.6%	49.3%	10.3%	26.7%	19.5%	
Worldwide								
K gallons	338	362	410	539	528	620	744	14.1%
K liters	1,279	1,369	1,551	2,039	1,999	2,347	2,814	
Growth		7.0%	13.3%	31.5%	(2.0%)	17.4%	19.9%	

Source: Dataquest
August 1987

Negative Optical Resist Forecast

Table 15 presents Dataquest's forecast of negative optical resist consumption in the four regions of the world. The forecast is presented in units of thousand gallons and thousand liters because both sets of units are used in the semiconductor industry. In contrast to the forecast for positive optical photoresist (Table 14), Dataquest expects the demand for negative optical resist to remain essentially flat or experience a slight decline from 1985 through 1991. Dataquest believes that only the ROW countries will experience modest growth in this product segment over the next few years.

Table 15

NEGATIVE OPTICAL PHOTORESIST FORECAST

Region	1985	1986	1987	1988	1989	1990	1991	CAGR 1985-1991
United States								
K gallons	136	137	137	152	120	123	134	(0.3%)
K liters	515	519	519	577	452	464	509	
Growth		0.9%	0%	11.1%	(21.6%)	2.6%	9.6%	
Japan								
K gallons	165	141	135	147	124	115	111	(6.4%)
K liters	625	532	511	556	468	435	420	
Growth		(14.8%)	(4.0%)	8.8%	(15.8%)	(7.1%)	(3.3%)	
Europe								
K gallons	40	35	40	45	36	36	36	(1.7%)
K liters	151	134	150	169	136	137	138	
Growth		(11.4%)	12.0%	12.6%	(19.6%)	0.9%	0.2%	
ROW								
K gallons	23	24	26	33	31	33	33	6.2%
K liters	87	92	100	126	118	126	126	
Growth		5.2%	8.7%	26.3%	(6.7%)	6.7%	(0.1%)	
Worldwide								
K gallons	364	337	338	377	310	307	315	(2.4%)
K liters	1,378	1,277	1,281	1,428	1,174	1,162	1,192	
Growth		(7.3%)	0.3%	11.5%	(17.8%)	(1.0%)	2.6%	

Source: Dataquest
August 1987

Total Optical Resist Forecast

Table 16 presents Dataquest's forecast of total optical resist consumption in the four regions of the world. The forecast is presented in units of thousand gallons and thousand liters because both sets of units are used in the semiconductor industry. Dataquest expects that the United States, Japan, and Europe will experience modest growth in optical photoresist demand between 1985 and 1991. The ROW countries, however, will experience optical photoresist demand of 16.5 percent CAGR between 1985 and 1991. This growth rate reflects the expected increased level of semiconductor manufacturing

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activities in this region in the years to come. The world demand for optical photoresist is forecast to be approximately 1,059 kilogallons in 1991, of which positive optical photoresist represents 70 percent, and negative optical photoresist represents 30 percent of the volume mix.

Table 16

TOTAL OPTICAL PHOTORESIST FORECAST

Region	1985	1986	1987	1988	1989	1990	1991	CAGR 1985-1991
United States								
K gallons	296	312	327	401	352	396	463	7.7%
K liters	1,120	1,180	1,237	1,518	1,331	1,497	1,754	
Growth		5.4%	4.8%	22.8%	(12.3%)	12.5%	17.1%	
Japan								
K gallons	284	265	280	338	320	340	383	5.1%
K liters	1,075	1,004	1,060	1,280	1,212	1,287	1,450	
Growth		(6.6%)	5.6%	20.8%	(5.3%)	6.1%	12.7%	
Europe								
K gallons	84	79	90	106	95	107	117	5.7%
K liters	318	298	341	403	358	404	444	
Growth		(6.3%)	14.6%	18.0%	(11.2%)	12.8%	9.9%	
ROW								
K gallons	38	43	51	71	71	85	95	16.5%
K liters	144	165	193	266	272	321	359	
Growth		14.2%	17.5%	37.4%	2.2%	18.1%	11.8%	
Worldwide								
K gallons	702	699	748	916	838	927	1,059	7.1%
K liters	2,657	2,647	2,832	3,467	3,173	3,509	4,006	
Growth		(0.4%)	7.0%	22.5%	(8.5%)	10.6%	14.2%	

Source: Dataquest
August 1987

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SUMMARY

In 1984, the gas companies that supply the electronics industry had direct sales of bulk and specialty gases of $205 million to semiconductor manufacturers in the United States. Bulk atmospheric gases (nitrogen, oxygen, hydrogen, and argon) represented $155 million (75.6 percent) of that market. Air Products is the leading supplier of bulk gases in the United States with sales of $72 million (46.4 percent), while the Linde division of Union Carbide is the second largest supplier with sales of $42 million (27.1 percent). Airco and Liquid Air are two other primary bulk gas suppliers to the semiconductor industry and have sales of $21 million (13.6 percent) and $17 million (11.0 percent), respectively.

Nitrogen represented approximately 95 percent by volume or 49.5 billion cubic feet (Bcf) of the bulk atmospheric gases sold in the United States in 1984. Hydrogen and oxygen each represented an additional 2 percent by volume, while argon was approximately 1 percent by volume of the total bulk gas consumption by the U.S. semiconductor industry in 1984.

The nitrogen gas market in 1984 represented a substantial portion of the bulk gas supplied to the semiconductor industry in the United States, in both sales ($118.8 million) and volume (49.5 Bcf). The consumption of nitrogen is dependent not only on wafer starts but also on the installed base of equipment in fabrication facilities. Nitrogen flow is used to maintain the integrity of many pieces of processing equipment during times of nonproduction, and thus the nitrogen market exhibits surprising stability during the economic downturns in the semiconductor industry.

Specialty gas sales to semiconductor manufacturers in the United States represented the remaining $50 million (24.4 percent) of the $205 million gas market in 1984. Four major suppliers of specialty gases (in order of market share) include Airco, Linde, Air Products, and Matheson, with market shares ranging from 21 percent to 15 percent. Suppliers with smaller shares include Scientific Gas Products, Liquid Carbonic, and Liquid Air.

The total worldwide market for bulk and specialty gases supplied to the semiconductor industry in 1984 was $430.5 million. As mentioned above, the U.S. market represented $205 million in sales, or 47.6 percent of the world market. In Japan, bulk and specialty gas sales totaled $157 million (36.5 percent), while the gas market in Europe in 1984 was $32 million (7.4 percent). In Rest of World (ROW), the sales of bulk and specialty gases to the semiconductor industry were $36.5 million (8.5 percent). The ROW gas market may seem surprisingly large for the level of semiconductor production in those areas. However, there is a large nitrogen requirement for assembly operations of devices manufactured in the United States and Europe.

Gases

OVERVIEW

In the semiconductor industry, process gases represent one category of consumable materials that are used throughout the fabrication of semiconductor devices, from the growing of single silicon crystals, through the many steps of wafer fabrication, to the final stages of assembly and packaging. Gases are divided into two general categories: bulk atmospheric gases and specialty gases.

Bulk atmospheric gases (BAG) include nitrogen, oxygen, hydrogen, and argon. Hydrogen is available in only trace amounts in the atmosphere and thus it is generated through hydrocarbon refining rather than through air separation. However, because it is typically supplied in bulk amounts to semiconductor manufacturers, it is included under the bulk atmospheric gases designation. The designation "bulk" refers specifically to a discrete delivery of gas in its liquid state. These gases typically are delivered as cryogenic liquids because of the efficiency of transportation and storage prior to the vaporization stage from the liquid to a gas at the semiconductor fabrication facility. For the purpose of this study, nitrogen gas provided through direct pipeline delivery, as well as customer on-site nitrogen generation plants, are also considered under the bulk atmospheric gases category even though the supply of nitrogen, in this sense, cannot be classified as discrete.

There are a large number of gases (more than 35) that can be classified as specialty gases. For that reason, a further segmentation of this category is necessary, and is based on the chemical reactivity and functionality of the various specialty gases. For the purposes of this study, the specialty gas segmentation is defined as follows:

- Silicon-precursor gases (i.e., silane, dichlorosilane, trichlorosilane, and silicon tetrachloride),
- Dopants (i.e., arsine, phosphine, and diborane)
- Plasma etchants (i.e., carbon tetrafluoride, as well as numerous other halocarbon and fluorine-based gases)
- Reactant gases (i.e., ammonia, hydrogen chloride, nitrous oxide, and carbon dioxide)
- Atmospheric/purge cylinder gases (i.e., nitrogen, hydrogen, oxygen, argon, and helium)
- Others (i.e., tungsten hexafluoride and germane)

Gases

Specialty gases are used in comparatively smaller volumes than the bulk atmospheric gases and thus are delivered to a semiconductor manufacturer in high-pressure cylinders. Note that nitrogen and other atmospheric gases appear in one of the specialty gas categories as well as under the bulk gas designation. The distinction in this case is that these gases are supplied in gas cylinders rather than in discrete deliveries of bulk liquid. These gases are used primarily for purging certain processing systems and equipment in cases when a semiconductor manufacturer is concerned about possible back-contamination of the house lines of nitrogen, hydrogen, argon, etc.

The following section will review the various bulk and specialty gas categories and summarize their applications in the semiconductor manufacturing process. Table 1 contains a comprehensive list of the gases that are used in semiconductor manufacturing.

Table 1

BULK AND SPECIALTY GASES USED IN SEMICONDUCTOR MANUFACTURING

I. BULK ATMOSPHERIC GASES

Nitrogen, N_2	Hydrogen, H_2
Oxygen, O_2	Argon, Ar

II. SPECIALTY GASES

A. Silicon-Precursor Gases

Silane, SiH_4	Dichlorosilane, SiH_2Cl_2
Trichlorosilane, $SiHCl_3$	Silicon Tetrachloride, $SiCl_4$

B. Dopants

Arsine, AsH_3	Boron Trichloride, BCl_3
Phosphine, PH_3	Boron Trifluoride, BF_3
Diborane, B_2H_6	Phosphorous Pentafluoride, PF_5

(Continued)

Table 1 (Continued)

BULK AND SPECIALTY GASES USED IN SEMICONDUCTOR MANUFACTURING

II. SPECIALTY GASES (Continued)

C. Plasma Etchants

Carbon Tetrafluoride, CF_4	(Halocarbon-14)
Fluoroform, CHF_3	(Halocarbon-23)
Hexafluoroethane, C_2F_6	(Halocarbon-116)
Dichlorodifluoromethane, CCl_2F_2	(Halocarbon-12)
Bromotrifluoromethane, $CBrF_3$	(Halocarbon-13B1)
Chlorotrifluoromethane, $CClF_3$	(Halocarbon-13)
Chloropentafluoroethane, C_2ClF_5	(Halocarbon-115)
Methyl Fluoride, CH_3F	(Halocarbon-41)
Trichlorofluoromethane, CCl_3F	(Halocarbon-11)
Perfluoropropane, C_3F_8	
Chlorine, Cl_2	
Carbon Tetrachloride, CCl_4	
Silicon Tetrafluoride, SiF_4	
Sulphur Hexafluoride, SF_6	
Nitrogen Trifluoride, NF_3	
Others	

D. Reactant Gases

Ammonia, NH_3	Nitrous Oxide, N_2O
Hydrogen Chloride, HCl	Carbon Dioxide, CO_2

E. Atmospheric/Purge Cylinder Gases

Nitrogen, N_2	Oxygen, O_2
Hydrogen, H_2	Argon, Ar
Helium, He	

F. Others

Tungsten Hexafluoride, WF_6	Germane, GeH_4
Others	

Source: DATAQUEST

Gases

APPLICATIONS--BULK ATMOSPHERIC GASES

Nitrogen

Nitrogen is the most widely used gas in the semiconductor industry, in both wafer fabrication as well as assembly operations. Its consumption by volume represents approximately 95 percent of all bulk atmospheric gases used in semiconductor manufacturing. Its primary application is in providing an inert atmosphere for the various wafer processing systems such as epitaxial reactors, chemical vapor deposition (CVD) reactors, and diffusion furnaces. Nitrogen is used as a transportation medium in some wafer processing equipment. In addition, it is used as an inert environment during the exposure of negative photoresist in lithography because of the necessity to minimize competitive oxygen side reactions that can lead to film thickness losses. Nitrogen is also used to maintain the integrity of various pieces of processing equipment, such as furnace banks, even while they are not in direct production use. In some facilities, certain clean stations are equipped with constant flows of nitrogen to maintain ultraclean conditions. Many other pieces of equipment in a fab use nitrogen, including blow guns, pneumatic-actuated valves, spin rinse dryers, dessicators, and cryo pumps used for condensing contaminants in vacuum systems. Because of the emphasis on the use of high-purity materials in the semiconductor industry, nitrogen purity is typically "five nines" (99.999 percent) to "six nines" purity.

Oxygen

Oxygen has the capability to form oxides with all elements except inert gases. In wafer fabrication, it is used to form dielectric and passivation layers of silicon dioxide (SiO_2) on silicon substrates (MOS devices, in particular). It is also used as a component in certain halocarbon plasma etch mixtures such as carbon tetrafluoride (CF_4) and oxygen for the etching of silicon dioxide and silicon nitride layers. Its usage represents only a few percent by volume of the bulk atmospheric gases consumed by the semiconductor industry.

Hydrogen

Hydrogen is most commonly used as an ambient environment for the growth of epitaxial layers. It is also used as a carrier gas during diffusion processes to provide a reducing environment in such reactions as the conversion of boron trichloride to atomic boron.

Hydrogen is used with oxygen in oxidation processes to form water vapor at oxidation temperatures in what is called a wet-ox (wet oxidation) process. Typically, silicon and oxygen react directly to form silicon dioxide, but the formation of thicker oxide layers requires prohibitive amounts of production time. When silicon reacts with water vapor to produce silicon dioxide and hydrogen, the oxide layer forms at an increased rate due to the relatively fast diffusion of a hydroxyl species. Hydrogen that has been included in the silicon dioxide film is driven off by subsequent heating steps such as diffusion, and densification of the oxide occurs.

Hydrogen consumption, like that of oxygen, represents only a few percent by volume of the bulk atmospheric gases used in the semiconductor industry.

Argon

Argon is used by the semiconductor industry primarily as an inert environment for the growth of single-crystal silicon, and also has applications in sputtering and ion implantation. There is currently a trend toward increased usage of argon in the annealing process for thin gate oxides because of the truly "inert" nonreactive nature of the gas. Argon costs more than nitrogen, which has been the traditional choice for an inert environment in this process. However, the extra expense at such a late stage of fabrication is considered minimal compared with potential device failure, and hence lower yields, caused by chemical contamination during the annealing process.

Argon consumption represents approximately one percent of the total volume of bulk atmospheric gases consumed by the semiconductor industry, and consumption is split between usage in single silicon crystal growth and fabrication processing.

SPECIALTY GASES

Silicon-Precursor Gases

The silicon-precursor gases such as silane, dichlorosilane, trichlorosilane, and silicon tetrachloride are used in epitaxial and chemical vapor deposition (CVD) processes to deposit layers of silicon or silicon compounds (i.e., silicon dioxide, silicon nitride) onto silicon substrates. Silane, in particular, is used in PECVD (plasma-enhanced CVD) for the deposition of amorphous and polysilicon layers. Dichlorosilane is also a primary source for the deposition of polysilicon.

Silicon epitaxial layers are formed in reactions based on mechanisms of thermal decomposition or reduction by hydrogen, depending on the silicon-precursor reactant gas. Each of the silicon-precursor gases has epitaxial processing advantages and disadvantages, which include the processing temperature range, degree of autodoping, and growth rates. Silane is a pure gaseous source, while silicon trichloride and silicon tetrachloride are both corrosive liquids at room temperature and pressure. Dichlorosilane is in a gaseous state at a pressure of 0.5 atmospheres. The typical epitaxial reactions, temperature ranges, growth rates, and processing advantages and disadvantages are summarized in Table 2.

Table 2

EPITAXIAL SOURCES: ADVANTAGES AND DISADVANTAGES

Reactions

Thermal Decomposition	Temperature Range	Growth Rate
$SiH_4 \longrightarrow Si + 2H_2$	1,000 to 1,050° C	0.2 to 1.0 μ/min
$SiH_2Cl_2 \longrightarrow Si + 2HCl$	1,050 to 1,100° C	$\geq$ 1.0 μ/min

Reduction by Hydrogen	Temperature Range	Growth Rate
$SiHCl_3 + H_2 \longrightarrow Si + 3HCl$	1,150 to 1,200° C	1.0 to 10 μ/min
$SiCl_4 + 2H_2 \longrightarrow Si + 4HCl$	1,150 to 1,200° C	0.5 to 1.5 μ/min

Source	Advantages	Disadvantages
SiH_4	Low-temperature deposition Low autodoping	Pyrophoric gas Moderate growth rates
$SiCl_4$	Moderate to high growth rates Easy to obtain good crystal quality on thick layers	Corrosive liquid High-temperature deposition Moderate autodoping
$SiHCl_3$	Very high growth rates Very high purity epitaxial layers Most common source of poly-Si	Corrosive liquid High-temperature deposition Moderate autodoping
SiH_2Cl_2	Properties intermediate between SiH_4 and $SiCl_4$	

Source: DATAQUEST

Gases

A layer of silicon dioxide is formed when silane and oxygen react together in an oxidation process. The other silicon-precursor gases form oxide layers when they undergo hydrolysis (reaction with water) in a moist atmosphere.

Oxidation

$$SiH_4 + O_2 \longrightarrow SiO_2 + 2H_2$$

Hydrolysis

$$SiH_2Cl_2 + 2H_2O \longrightarrow SiO_2 + 2HCl + 2H_2$$
$$SiHCl_3 + 2H_2O \longrightarrow SiO_2 + 3HCl + H_2$$
$$SiCl_4 + 2H_2O \longrightarrow SiO_2 + 4HCl$$

Silane and dichlorosilane both react with ammonia to form passivation layers of silicon nitride.

$$3SiH_4 + 4NH_3 \longrightarrow Si_3N_4 + 12H_2$$
$$3SiH_2Cl_2 + 4NH_3 \longrightarrow Si_3N_4 + 6HCl + 6H_2$$

As mentioned previously, each of the silicon-precursor gases has processing advantages and disadvantages. The safety issue is particularly important with regard to silane as it is a pyrophoric gas, which means that it will burn upon exposure to air. Silicon tetrachloride (siltet) on the other hand, while corrosive, is not classified as toxic nor does it ignite in air. However, it does require the highest operating temperature of all the silicon-precursor gases for epitaxial deposition ($1{,}200^{o}$ C). In addition, unlike silane, siltet can cause pattern shifts in epitaxial layers due to the formation of chlorine radicals.

The chemical characteristics of dichlorosilane and trichlorosilane fall between those of silane and silicon tetrachloride. Both operate in an intermediate temperature range between silane and siltet. While toxic and corrosive, neither one is considered pyrophoric. In addition, both can cause some degree of pattern shift in epitaxial deposition.

Dopants

Dopants are used as a source of controllable impurities within semiconductor devices. A known concentration and type of impurity (n or p) is introduced into specific regions to modify local electrical properties of the medium. Specifically, an element contributes either an excess hole (p dopant) or electron (n dopant) to the local structure of the crystal lattice, which in turn alters the conductivity of the material. For silicon, the p and n dopants are found in Groups III and V, respectively, of the periodic table. Dopants are available in liquid, solid, and gaseous states. The common gaseous n dopants are arsine and phosphine, while the common gaseous p dopants include diborane and boron trichloride. Boron trichloride is also used in plasma etching, as well as in chemical vapor deposition of BPSG (borophosphosilicate glass). Dopants are utilized in epitaxial deposition, diffusion, and ion implantation.

In diffusion processes, the dopant gas, which is frequently mixed with nitrogen or hydrogen, is introduced into a high-temperature oven (950-1,280° C) and is incorporated into the substrate by a diffusional mechanism. A dopant concentration gradient in the substrate material is established and the depth of diffusion is controlled by process time and temperature.

The common carrier gases for dopants in diffusion processes are nitrogen and hydrogen, as mentioned previously, although argon and helium are also used. Arsine and phosphine may be supplied to a semiconductor manufacturer as pure gases or as premixed dilutions with these atmospheric gases. Arsine and phosphine premixed with silane are also available. As diborane is extremely unstable in its pure form, and decomposes at a rate of 0.5 percent per day at room temperature, it is always supplied to semiconductor manufacturers diluted with other gases; typically, 15 percent diborane in nitrogen, hydrogen, argon, or helium.

Arsine, phosphine, and diborane gases are all highly poisonous materials. Arsine has a disagreeable garlic-like odor, and inhalation of as little as 0.5 parts per million is considered to be dangerous. Phosphine has an unpleasant odor of decaying fish and will react violently in the presence of an oxygen environment. Diborane is described as having a repulsive, sickly sweet odor, and is spontaneously flammable in air above a temperature of 40° C. However, in the presence of certain contaminants, the ignition of diborane/air mixtures may occur at or even below room temperature. For these reasons and other safety issues, primary manufacturing of these gases is limited to only a handful of companies.

Ion implantation, and more recently neutron transmutation, offer a substantial amount of processing control over diffusion. In ion implantation, the dopant atoms are ionized and accelerated to high energies. The ion beam is directed and focused onto the wafer and the high-energy ions penetrate the surface. Ion implantation offers a great deal of process control because ion current and implant time can both be measured, and thus the number (dosage) of dopant ions incorporated into the material as well as the concentration profile can be determined. In ion implantation, room temperature processing minimizes dopant migration in the substrate, particularly beneath critical gate structures. Because the dopant profile can be controlled, smaller line geometries can be achieved. In addition to arsine and phosphine, boron trifluoride and phosphorous pentafluoride are also used as dopant source gases in ion implantation.

One disadvantage to ion implantation compared with diffusion is that as the dopant ions collide with the wafer, a significant amount of damage can occur to the crystal lattice. Most of this damage, however, can be later repaired in subsequent annealing steps.

There is an increasing trend away from diffusion and toward ion implantation as a doping procedure for the small-geometry devices because of the greater degree of process control. This trend will have some impact on the gas industry since the diffusion process consumes large amounts of nitrogen in addition to the dopant source gases. However, it is unlikely that diffusion will completely disappear in the future, but rather, will likely remain a standard technique for introducing dopant materials in the larger-geometry devices.

Neutron transmutation doping (NTD) is a new technique for n-type doping that primarily has been limited to high-power applications. In this process, silicon wafers are placed in a nuclear reactor and a stream of thermal neutrons is passed through them. Some of the silicon atoms in the lattice are altered to phosphorous through a nuclear mechanism. While the technique can only form phosphorous-doped materials, it has its advantages in that it can provide an extremely uniform distribution of phosphorous in silicon. In addition, no external source of dopant material is required, as the silicon provides its own. One disadvantage, however, is that access to a nuclear reactor is required. Currently this technique is still quite limited in its applications and production capability. However, it may prove to be a viable alternative for doping semiconductor devices at some future time.

Plasma Etchants

A wide variety of gases, primarily halocarbons, are used in plasma etching. The choice of gases is strongly dependent on the ability of a given mixture of gases to selectively etch one film in the presence of another with a sufficient degree of profile control. The advantages of plasma etch over wet etching techniques include the ability to generate anistropic (i.e., sharp-walled) as well as isotropic (curved-walled) profiles. In addition, loss of photoresist adhesion is minimized in plasma compared with wet etch. Also, because the etching materials are gases, smaller quantities of reagents are used and thus smaller amounts of waste chemicals are generated.

Gases

From a conceptual point of view, plasma etch is a fairly simple process. A highly reactive gaseous species is generated that reacts with the wafer surface to produce a volatile etch product. For most semiconductor materials and metals, the plasma is used as a source of halogen atoms to generate volatile halide etch products. The etching of organic films is best achieved when the plasma provides a source of oxygen atoms to form volatile products such as carbon monoxide (CO).

It is difficult to establish a quantitative relationship to describe the consumption of halocarbon gases in the plasma etch process, since the physical and chemical mechanisms that determine plasma etch efficiency are still not fully understood. For that reason, plasma etch has been described as more of an art than a science, and most process engineers exercise a great deal of freedom in establishing their own unique plasma etch gas mixtures.

Carbon tetrafluoride (CF_4) is probably the most commonly used plasma etch gas. It is an odorless, colorless gas that is stable and nontoxic. It is capable of etching silicon in both its pure gaseous form and when mixed with oxygen. It is also known as tetrafluoromethane, halocarbon-14, or Freon-14. (Freon is a registered trademark of Dupont.) Fluoroform (CHF_3, trifluoromethane, halocarbon-23) and hexafluoroethane (C_2F_6, halocarbon-116) are also used in large quantities. Please refer to Table 1 for a more comprehensive list of plasma etchants. The following sections give examples of the gases that are used to etch silicon and polysilicon, silicon dioxide and nitride, silicides, metals, and photoresist.

Etching of Silicon and Polysilicon

For any given plasma etch mixture, it is very important to be able to selectively etch one film in the presence of another. Selectivity for isotropic etching of silicon and polysilicon in the presence of oxide is very high when using the fluorine-source plasmas (such as CF_4/O_2, SiF_4, SF_6, and NF_3). Typically, anistropic profiles are difficult to achieve when using fluorine sources; however, a high degree of anistropy can be obtained with plasmas that produce chlorine and bromine atoms (Cl_2, Cl_2 C_2F_6, CF_3Cl C_2F_6, Br_2, and CF_3Br).

It is believed that the underlying mechanism for achieving such anistropic profiles may be the physical ion bombardment of the surface. Isotropic profiles are easier to obtain when etching silicon and polysilicon with fluorine sources, and are believed to be due to chemical etching by fluorine atoms.

Gases

Etching of Silicon Dioxide and Nitride

The plasma gases that are used to etch silicon dioxide and nitride in the presence of silicon include CF_4/H_2, CHF_3, and C_2F_6. It has been established empirically that high degrees of selectivity for etching oxide and nitride layers are achieved by the addition of fluorine scavengers such as methane, ethylene, and hydrogen, thereby establishing a fluorine-deficient chemical environment. The underlying chemistry is not clearly understood, and the fine-tuning of feed gases to the plasma discharge is still empirical in nature.

Etching of Silicides

Silicides of titanium (Ti), tantalum (Ta), molybdenum (Mo), and tungsten (W) are commonly etched with a mixture of CF_4 and O_2. Highly volatile silicon tetrafluoride (SiF_4) is produced, as well as moderately volatile metal fluorides. Isotropic as well as anistropic profiles have been reported. We expect this area of plasma etch to continue to receive attention with the increasing trend toward CVD-tungsten silicide applications in MOS devices.

Etching of Metals

In etching metal layers, it is critical that water vapor and oxygen be excluded from the plasma reactor (or possibly scavenged) because of the formation of native metal oxides at the surface. Chlorocarbon and fluorocarbon gases are typically used to etch metal films rather than pure halogens, because of their ability to reduce the native oxides chemically. Nitrogen trifluoride (NF_3) is helpful in increasing selectivity over silicon dioxide films.

Aluminum and chromium do not form volatile metal fluorides, and therefore, etching of these metals is best carried out in plasmas that generate chlorine atoms. Gases that efficiently scavenge oxygen and moisture include boron trichloride (BCl_3) and silicon tetrachloride ($SiCl_4$). In addition, they form radicals that react with the native oxide. Once the native oxide has been removed, aluminum may be etched spontaneously in a pure chlorine environment. Both anistropic and isotropic etches can be achieved depending upon the amount of molecular chlorine in the plasma mixture.

Etching of Photoresist

Photoresist and organic films are often stripped by plasma systems that generate atomic oxygen. Rare gases and CF_4 are added to stabilize the discharge and enhance the reactivity of the organic material. The discharge produces such etch products as carbon monoxide, carbon dioxide, and water. If the plasma is rich in atomic oxygen, high selectivities over silicon dioxide, silicon nitride, and metals can be achieved.

Reactant Gases

Reactant gases include ammonia, hydrogen chloride, nitrous oxide, and carbon dioxide. Ammonia is typically used with either silane or dichlorosilane to produce silicon nitride layers in chemical vapor deposition. Silicon nitride films are used as passivation layers or interlayer dielectrics in semiconductor devices. Ammonia is a corrosive, alkaline gas that is considered toxic. It is generally regarded as nonflammable, and has a distinctive pungent odor.

Hydrogen chloride is used to polish and etch wafers prior to deposition steps by removing defects on the wafer surface due to mechanical polishing and handling of the wafer. A significant development in thermal oxidation has been the use of hydrogen chloride in combination with oxygen. Hydrogen chloride is particularly effective in gettering mobile sodium ions and other impurities in the wafer, which in turn helps minimize leakage in the MOS gate threshold voltage. Hydrogen chloride is a colorless, corrosive, nonflammable, acidic gas that has a repulsive odor. Because of its corrosive nature, special attention must be focused to maintain the purity of the gas. In particular, contamination can result from the interaction between hydrogen chloride and the walls of gas cylinders.

Nitrous oxide and carbon dioxide are both used as sources of oxygen in silicon oxide films formed in chemical vapor deposition processes. Nitrous oxide is available as a liquefied gas. It has a sweet odor and is generally used as an anesthetic. It is commonly known as "laughing gas." However, nitrous oxide becomes a strong oxidizing agent at temperatures greater than 300° C. Carbon dioxide is a colorless, odorless, noncombustible gas.

Atmospheric/Purge Cylinder Gases

As mentioned previously, nitrogen and other atmospheric gases are also supplied to semiconductor manufacturers in cylinders as well as in discrete deliveries of bulk liquids. They are classified under the specialty gas designation because they represent cylinder deliveries. These gases are used primarily for purging certain processing systems and equipment in cases when a semiconductor manufacturer is concerned about possible back-contamination of the house lines. In addition, there are some processes, such as sputtering, that require small amounts of gas, and thus single-cylinder usage is more economical. In the case of sputtering, the process is run under vacuum conditions and argon ions are accelerated in an electric field. Through physical bombardment, the argon ions knock molecules off the surface of a solid target. The ejected material from the target is deposited onto the surface of a wafer, in addition to the walls of the sputtering chamber. Typically, a cylinder of argon can last for three months or more in a sputtering system before it requires replacement.

Other Specialty Gases

In this specialty gas category can be found such gases as tungsten hexafluoride and germane. Germane, GeH_4, is used in epitaxial chemical vapor deposition for the manufacturing of LEDs. Germane must be used with great caution as it is a hemolytic gas, and thus has the ability to dissolve red blood cells.

Tungsten hexafluoride, WF_6, is used as a source of tungsten for the deposition of tungsten silicide as an alternative interconnect material in VLSI devices. The deposition of refractory metal silicides is an area that is receiving increased attention as semiconductor manufacturers design IC devices with higher packing densities and higher device speeds. The problem is that while scaling improves overall device performance, a reduction in device geometries also results in a corresponding reduction of the thickness of interconnect lines. In addition, the larger die sizes used in VLSI devices typically require longer interconnect lines. This combination of thinner and longer interconnect lines results in an increase in the interconnect resistivity and hence, in the RC time delay of the circuit.

Tungsten silicide, as well as other refractory metal silicides based on molybdenum, tantalum, and titanium, have been developed as interconnect materials for VLSI devices because they exhibit considerably reduced resistivities. When these refractory metal silicides are deposited at the gate level on a layer of doped polysilicon, the resulting structure is called a "polycide" shunt. The polycide structure has the advantage of the reduced resistivity of the refractory metal silicide and yet retains the good performance characteristics of polysilicon, such as the stable polysilicon/oxide interface.

The techniques of deposition of refractory metal silicides include sputtering, coevaporation, and chemical vapor deposition. The source materials for molybdenum, titanium, and tungsten are molybdenum hexafluoride, titanium tetrachloride, and tungsten hexafluoride, respectively.

These materials are all liquids at 25° C that have sufficient vapor pressure to allow for source flow to be controlled with a mass flow controller. Tungsten hexafluoride, in particular, is a yellow liquid at room temperature. In its gaseous state, it forms a white mist of hydrogen fluorine gas in moist air. In an inert environment, tungsten hexafluoride is a colorless, odorless gas.

DATAQUEST believes that tungsten silicide is the most widely used refractory metal silicide in the United States. Genus, a CVD manufacturer, was the first to develop a dedicated tungsten silicide reactor for liquid phase chemical vapor deposition, and the success of the Genus reactor has done much to stimulate interest in tungsten hexafluoride as a source material.

SUMMARY OF PHYSICAL CONVERSION FACTORS

Gas, by its very nature, is available in a variety of different volumes and quantities depending on the temperature and pressure of the system. The associated nomenclature used to describe a given amount of gas is likewise as varied. The following section presents a summary of the different units of temperature, pressure, volume, and weight that are commonly used in the gas industry, as well as a set of conversion factors between the different units.

Any amount or quantity of gas has a temperature and pressure dependence that in its simplest form is governed by the Ideal Gas Law, $PV = nRT$. This law states that the pressure of any gas, P (measured in atmospheres), multiplied by its volume, V (liters), is equal to the product of the number of moles of the gas, n, multiplied by the temperature of the system, T (in kelvins), and the universal gas constant, R. One convenient way to remember the appropriate factors is that one mole of gas at one atmosphere pressure at 0° C (273 K) will occupy 22.4 liters.

STP is the designation that is used to indicate standard temperature and pressure; by definition, one atmosphere, 0° C (273 K). The more common specification is that of NTP, which stands for normal temperature and pressure, and corresponds to one atmosphere, 70° F. One atmosphere of pressure can also be defined in units of pounds per square inch; specifically, one atmosphere of pressure is equal to 14.7 psi. An alternative designation is gauge pressure, or psig (pounds per square inch gauge), which does not include ambient pressure conditions. Finally, psia (pounds per square inch absolute) is the sum of gauge pressure as well as the atmospheric pressure, typically 14.7 psi.

Gases

Common units for volume include liters, cubic feet (cf), and cubic meters (cm, not to be confused with centimeters). In some cases, cubic feet will be specifically identified as standard cubic feet (scf) which defines the temperature and pressure values at NTP. However, while "scf" may not be directly stated, in general it is assumed that NTP conditions hold unless otherwise specified. Large quantities of gas are usually described in units of hundred cubic feet (hcf), billion cubic feet (Bcf), or hundred cubic meters (hcm); this last designation is pronounced "nook-ems."

The units of kilograms, pounds, and tons are also used to designate a given quantity of gas under normal temperature and pressure. The definition of a ton, and thus the conversion factor from tons to pounds, takes on a different value in the United States compared with Europe and Japan. In the United States, one ton is equal to 2,000 pounds. In Europe and Japan, the designation of metric tons is assumed, in which case one metric ton is equal to 2,204 pounds (1,000 kg). Table 3 contains a summary of temperature, volume, and weight conversion factors.

Table 3

PHYSICAL CONVERSION FACTORS

Temperature

Fahrenheit ($^\circ$ F) = 1.8 * $^\circ$ C + 32
Celsius ($^\circ$ C) = (5/9) * ($^\circ$ F-32)
Kelvin (K) = $^\circ$ C + 273

Volume

1 liter = 1,000 cubic centimeters
1 cubic foot = 28.32 liters
1 cubic meter = 35.31 cubic feet = 1,000 liters
1 hcm = 100 cubic meters = 3,531 cubic feet
100 Bcf = 28.32 million hcm (million hundred cubic meters)

Weight

1 kg = 2.204 pounds
1 ton = 1,000 pounds
1 metric ton = 1,000 kg = 2,204 pounds

Source: DATAQUEST

Gases

GAS COMPANIES SUPPLYING THE SEMICONDUCTOR INDUSTRY

Table 4 contains a listing of the major bulk and specialty gas companies that directly supply the semiconductor industry in the United States, Japan, and Europe. The companies are listed in alphabetical order rather than by regional market share. The individual companies and their regional trading partners and joint ventures will be discussed in the following sections.

Table 4

GAS COMPANIES BY REGION

United States	Japan	Europe
Air Products	Daido Sanso	Air Products
Airco	Iwatani	B.O.C., Ltd.
Liquid Air	Nippon Sanso	L'Air Liquide
Liquid Carbonic	Osaka Sanso	Linde AG
Matheson	Seitetsu Kagaku	Matheson
Scientific Gas Products	Showa Denko	Messer Griesheim
Union Carbide (Linde)	Taiyo Sanso	Union Carbide (Linde)
	Takachiho	
	Teisan	

Source: DATAQUEST

United States

In the United States, there are essentially only four companies that supply bulk atmospheric gases to the semiconductor industry: Air Products & Chemicals, Airco Industrial Gases, Liquid Air Corporation, and the Linde division of Union Carbide Corporation. While all four companies serve the industrial gas market in addition to the semiconductor industry, Air Products and Union Carbide have a diverse range of business operations beyond gases. Air Products supplies chemicals and engineering services in addition to industrial gases and related equipment. In 1984, Air Products acquired a minority interest in UTI Instruments Company, an analytical instrumentation firm, as well as an interest in Benzing Technologies, a plasma processing equipment company that utilizes nitrogen trifluoride gas to clean CVD reactors. To complement its acquisitions in high-technology firms, Air Products has also formed a joint venture with Celltech, Ltd., one of the leading biotechnology companies in Great Britain.

Union Carbide Corporation is a large, multinational corporation with business divisions in chemicals, plastics, and metals as well as its industrial gas operations. In addition, Union Carbide has polysilicon facilities in the United States and owns KTI Chemicals, Inc., a photoresist company that also supplies pellicles to the semiconductor industry. In 1984, Union Carbide purchased Phoenix Research, a primary manufacturer of high-purity arsine, phosphine, and gaseous hydrogen chloride. Phoenix Research is one of only three companies that has primary arsine manufacturing capability. Air Products and Union Carbide rank first and second in sales of total bulk and specialty gases to the semiconductor industry in the United States with a combined market share of more than 60 percent.

Liquid Air is an operating company that is 90 percent-owned by L'Air Liquide, a French gas company that is the largest industrial gas company in the world. Airco is owned by British Oxygen Company, B.O.C., Ltd., which is headquartered in the United Kingdom.

All four companies provide on-site nitrogen facilities as well as bulk liquid deliveries of nitrogen, oxygen, argon, and hydrogen. Both Air Products and Linde have nitrogen pipeline systems, though the two Air Products networks (Silicon Valley and Chandler, Arizona) are much more extensive than the new Linde system (San Jose, California). Air Products and Linde also have liquid hydrogen manufacturing facilities.

The major specialty gas suppliers to the semiconductor industry include Air Products, Airco, and Linde. Liquid Air's new specialty gases division, Alphagaz, is a recent entrant in the market and currently represents a percent or less of sales to the semiconductor industry. Ideal Gas Products is part of the Alphagaz Specialty Gases Division of Liquid Air.

Other specialty gas companies include Liquid Carbonic, Matheson Gas Products, and Scientific Gas Products. Matheson was purchased in 1983 in a joint venture between Amerigas and the Japanese industrial gas company, Nippon Sanso. Matheson's European operations were purchased at the same time by Union Carbide Corporation. Scientific Gas Products is part of the Ashland Chemical Company, a major supplier of wet chemicals and acids to the semiconductor industry. Ashland Chemical Company, in turn, is part of Ashland Oil.

Gases

Europe

The major gas companies that supply the European semiconductor industry include Air Products, B.O.C., L'Air Liquide, Linde AG, Matheson, Messer Griesheim, and Union Carbide.

Union Carbide does not use the Linde name for its gas operations in Europe because the West German gas company, Linde AG, has rights to worldwide use of the Linde name outside of North America. (Dr. Karl von Linde was the German scientist who developed and patented the technique of cryogenic air separation in 1895.) Linde AG, one of the world leaders in air liquefaction plants, has recently started to focus on the electronic gases market. It has a new specialty gas handling facility outside of Munich, which is expected to be on-line in late 1985.

In addition to its other international facilities, Union Carbide owns the European operations of Matheson (headquartered in Belgium). Union Carbide also has a joint venture with Enichem, a sector of ENI, the Italian state energy group, to market, distribute, and produce industrial and specialty gases in Italy (operational mid-1985). The name of the company is Italiana Gas Industriali S.p.A. (IGI), and it is headquartered in Milan. Union Carbide has plans for a specialty gas manufacturing facility in Scotland; however, final approval for the facility has been postponed for further evaluation in light of the fatal toxic gas leak at the Union Carbide facility in Bhopal, India, in December 1984.

Messer Griesheim is a new entrant in the specialty gas market for the semiconductor industry. It represents a joint venture between Swedish AGA and L'Air Liquide of France.

In the United Kingdom, the major gas suppliers are B.O.C. and Air Products. In France, L'Air Liquide has a large majority of the market, with Air Products and Matheson representing the bulk of the remainder. In West Germany, the major gas suppliers include Air Products, Messer Griesheim, L'Air Liquide, Linde AG, and Union Carbide/Matheson. In Belgium, Air Products and Union Carbide/Matheson are the two major suppliers, while in the Netherlands, there are several gas company suppliers to the Phillips semiconductor operations.

Japan

The major gas suppliers to the Japanese semiconductor industry include Daido Sanso, Iwatani, Nippon Sanso, Osaka Sanso, Seitetsu Kagaku, Showa Denko, Taiyo Sanso, Takachiho, and Teisan. The word "sanso" is the Japanese word for oxygen, and thus many of these companies will be listed in the press or in publications as, for example, Daido or Osaka Oxygen.

Gases

Nippon Sanso is the largest oxygen manufacturer in Japan as well as the largest bulk gas supplier to the Japanese semiconductor industry. Nippon Sanso, as well as Showa Denko, a specialty gas supplier to the semiconductor industry, are both part of the Fuyo group. The Fuyo group is one of the large industrial entities under which many Japanese businesses are organized, and has as its focus the Fuji Bank. Nippon Sanso, in a joint venture with Amerigas, purchased Matheson Gas Products in 1983. In a second joint venture with Amerigas, Nippon Sanso also acquired an interest in Ansutech, a manufacturer of air separation plants in the United States.

Teisan is a major bulk gas supplier in Japan and is owned by L'Air Liquide of France (major stockholder with 64.2 percent of shares). Teisan currently ranks second behind Nippon Sanso in sales of bulk gases to the Japanese semiconductor industry. While Teisan is currently a small player in the specialty gas market, they have plans to promote sales of these gases to the semiconductor and laser industries.

Daido Sanso, a major supplier of oxygen to Japan's steel industry, is experiencing growth in the area of sales of bulk gases to the Japanese semiconductor industry. Air Products is the major stockholder in Daido Sanso with 10 percent ownership of shares. Daido Sanso is part of the Sumitomo group.

Osaka Sanso also supplies bulk atmospheric gases to the Japanese semiconductor industry. B.O.C. of the United Kingdom, through B.O.C. Japan, is the largest stockholder in Osaka Sanso with 23.5 percent of shares. Osaka Sanso is part of the Mitsubishi group.

Taiyo Sanso is a bulk gas supplier to the Japanese semiconductor industry and has Mitsubishi Chemical Industries as its parent company (36.3 percent of shares). Taiyo Sanso is also a member of the Mitsubishi group.

Seitetsu Kagaku is a specialty gas supplier to the Japanese semiconductor industry and is related to Sumitomo Chemical and Nippon Steel through the Sumitomo group.

Takachiho is a specialty gas supplier to the Japanese semiconductor industry and is the trading partner of Synthatron, a New Jersey-based specialty gas manufacturer. Synthatron is a primary manufacturer of arsine, and is a major supplier of dopants to the Japanese market.

Iwatani & Co., Ltd., has formed a joint venture with Union Carbide under the name Iwatani Industrial Gases (IIG) to produce helium, hydrogen, argon, nitrogen, and specialty gases for the Japanese market. The facilities are expected to be operational by late 1985, and technology transfer has already been underway for some time. Union Carbide's commitment under the joint venture was more than $10 million, and it will take up to 25 percent in the venture over the next few years. Iwatani & Co. is part of the Sanwa group that has the Sanwa Bank as its focus.

In summary, the major bulk gas suppliers for Japan's semiconductor industry are Nippon Sanso and Teisan with approximately 70 percent of the market. Daido Sanso, Osaka Sanso, and Taiyo Sanso combined represent an additional 24 percent or so of bulk gas sales. In the specialty gas market, Nippon Sanso and Seitetsu are identified as major suppliers to the semiconductor industry, while Showa Denko, Teisan, and Takachiho maintain a smaller portion of market share. Iwatani did not represent any significant share of the specialty gas market in 1985.

ROW

The countries with significant semiconductor fabrication under the Rest of World heading include South Korea and Taiwan, while Malaysia, Hong Kong, and Singapore have substantial assembly operations. The major gas suppliers include B.O.C., L'Air Liquide, Nippon Sanso, and Union Carbide either through direct sales or joint venture agreements. Union Gas Co. in Korea is part of the Union Carbide operations, while, for example, Hong Kong Oxygen represents a joint venture between B.O.C. and L'Air Liquide. Because of the large volume of assembly that is conducted in Pacific Rim countries, nitrogen consumption is disproportionately larger than would be expected from nitrogen requirements in semiconductor fabrication operations.

Gas Company Interrelationships

It is clear that while there are half a dozen or more gas companies that supply the semiconductor industry in each of the various regions of the world, there is a large degree of interrelations between the various companies. Two of the major gas companies in the United States, Airco and Liquid Air, are owned by their European counterparts, B.O.C. and L'Air Liquide, respectively. The remaining two major gas companies in the United States, Air Products and Union Carbide, both have major operations established in Western Europe. In Japan, it has been particularly important for the major American and European gas companies to have a Japanese firm as a trading partner or co-joint venturer because of the difficulty of establishing a presence in the Japanese market. Table 5 presents a summary of the regional interrelationships that exist between the major gas suppliers to the worldwide semiconductor industry.

Table 5

GAS COMPANY INTERRELATIONSHIPS

Japan		United States		Europe
Daido Sanso	← Joint Venture —	Air Products	— Overseas Operations →	Air Products
Osaka Sanso	← Joint Venture —	Airco	← Parent Company of Airco —	B.O.C., Ltd.
Osaka Sanso	← (Joint Venture) —			B.O.C., Ltd.
Teisan	← Same Parent Company →	Liquid Air	← Parent Company of Liquid Air —	L'Air Liquide
Teisan	← (Parent Company of Teisan) —			L'Air Liquide
Iwatani	← Joint Venture —	Linde / UCC	— Overseas Operations →	Matheson/UCC
Nippon Sanso	— Joint Venture →	Matheson		

Source: DATAQUEST

BULK ATMOSPHERIC GAS MANUFACTURING

Nitrogen, Oxygen, and Argon

Nitrogen, oxygen, and argon are obtained directly from the air by a technique of cryogenic air separation and distillation. Essentially, the process entails cooling air close to its liquefaction point and then utilizing the physical difference in volatilities of components of air to distill and separate them. Table 6 contains a list of the fixed components of air by percent composition, as well as the variable components. The fixed components are numbered (in parentheses) in decreasing order of volatility. Those gases in the same volatility range will become impurities of one another. Therefore, helium and neon will sometimes be found in nitrogen, but not in oxygen or argon. Similarly, krypton and xenon will always occur in oxygen, but not in argon or nitrogen. The extent to which any components become impurities in the others is dependent on the separation capacity of the distillation system.

Table 6

COMPONENTS OF THE ATMOSPHERE

Gas	Order of Volatility	Symbol	Concentration-Dry Basis Volume %	Concentration-Dry Basis ppm
Fixed				
Nitrogen	(3)	N_2	78.084	
Oxygen	(5)	O_2	20.9476	
Argon	(4)	Ar	0.934	
Neon	(2)	Ne		18.18
Helium	(1)	He		5.24
Krypton	(6)	Kr		1.14
Xenon	(7)	Xe		0.087
Variable				
Carbon Dioxide		CO_2		300 to 400
Nitrous Oxide		N_2O		0.5
Nitrogen Dioxide		NO_2		0 to 0.02
Water		H_2O	1.25*	
Hydrogen		H_2		0.5 Typ
Carbon Monoxide		CO		1 Typ
Methane		CH_4		2 Typ
Ethane		C_2H_6		$<$0.1 Typ
Other Hydrocarbons		C_xH_y		$<$0.1 Typ

*At 70° F and 50 percent relative humidity

Source: Linde Division
Union Carbide Corporation

It is interesting to note that the level of the variable components of the air may differ, depending on the geographical location of a given air separation plant because of the local levels of smog and humidity. Additional purification of the bulk atmospheric gases is necessary in areas that have substandard air quality.

Once the different components of air have been separated, the cryogenic liquids are transported to a customer's site from the gas company's air separation facility in specially equipped tank trucks and tube trailers. Upon arrival at a semiconductor facility, the liquid is transferred to cryogenic storage tanks located "on the pad," close to the vaporization equipment. The transportation and storage advantages associated with cryogenic liquids are clearly demonstrated by the fact that a single volume of liquid nitrogen upon vaporization translates to an equivalent of approximately 750 volumes of nitrogen gas.

Atmospheric gases obtained from air separation facilities, such as nitrogen, oxygen, and argon, are available to semiconductor manufacturers in discrete deliveries of bulk liquid. Other alternative delivery modes for nitrogen include multicustomer nitrogen gas pipeline networks, as well as on-site nitrogen generation facilities at a semiconductor manufacturing location. It is essentially not economical to produce any gas other than nitrogen on-site because of insufficient volume demand. The alternative modes of nitrogen delivery will be discussed in detail in a later section.

Hydrogen

Hydrogen is obtained in the industrial processes of thermal cracking or steam reforming of hydrocarbons (i.e., natural gas) or in the reduction of water by carbon. The hydrogen is liquefied and transported in the same manner as the other bulk atmospheric gases.

Bulk Gas Manufacturers--United States

Gas companies in the United States that supply bulk atmospheric gases to semiconductor manufacturers include Air Products, Airco, Liquid Air, and the Linde division of Union Carbide. DATAQUEST estimates that these four companies supply approximately 98 percent of bulk gases, by sales, to the semiconductor industry. All four major players in this market provide on-site nitrogen generation facilities to semiconductor manufacturers. Air Products has two established multicustomer pipeline networks, and Union Carbide brought a new multicustomer pipeline system on-line in early 1985. There are relatively few companies that comprise the remaining 1 to 2 percent of the bulk gas market in the United States; companies in this category include Liquid Carbonic and MG Industries (Scientific Gases Division).

Of the four major suppliers to the semiconductor industry, only Air Products and Union Carbide have liquid hydrogen manufacturing facilities. Union Carbide has one manufacturing plant in Ontario, California, another in Niagara Falls, New York, and a third in Ashtabula, Ohio. Air Products' hydrogen facilities are in the New Orleans area, a plant in the Great Lakes region, another near Los Angeles, and a new facility planned for Sacramento, California. Since Air Products does not sell any of its hydrogen to competitors, other gas companies must purchase the liquid hydrogen that they supply to semiconductor manufacturers from Union Carbide.

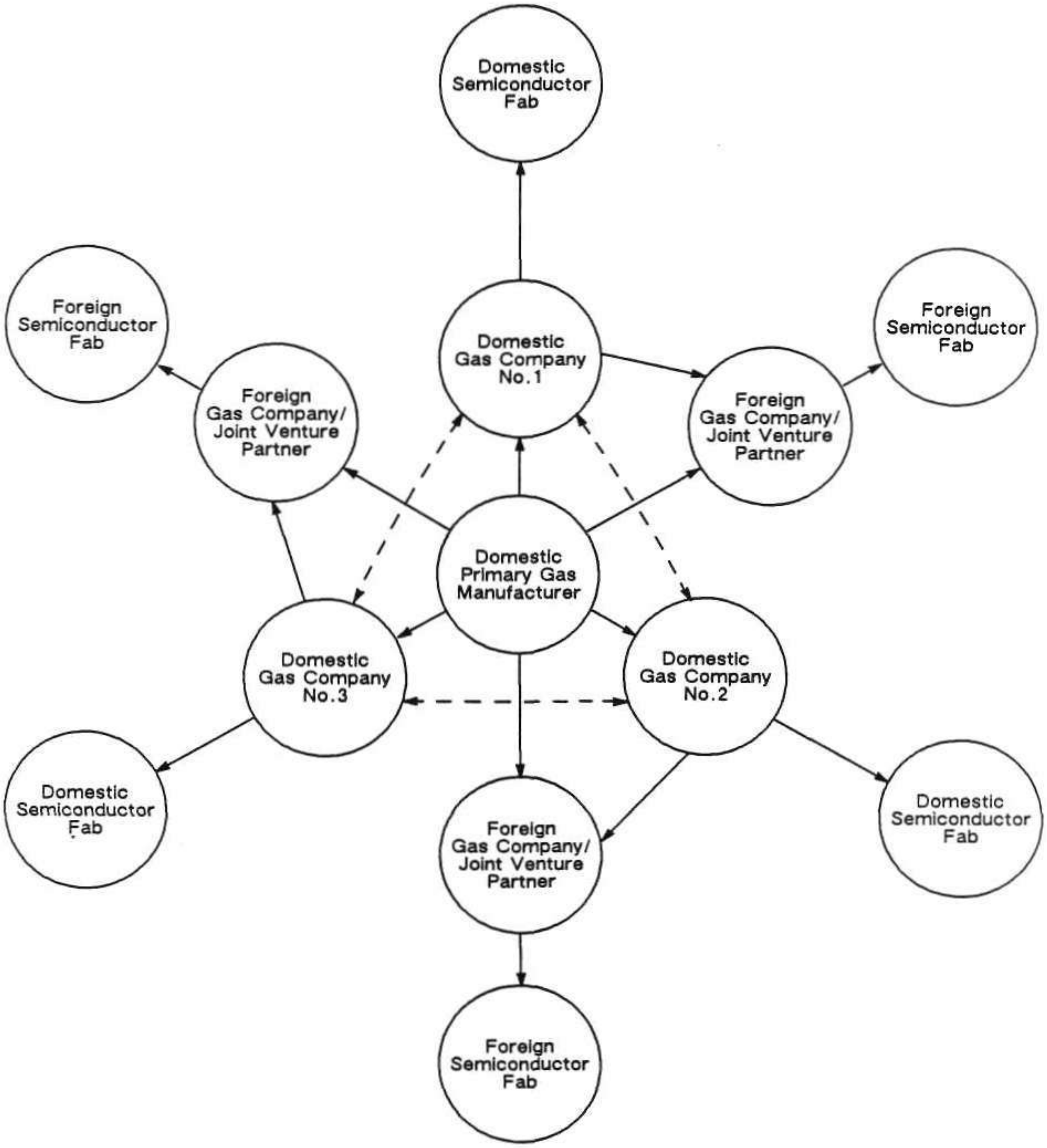
SPECIALTY GAS MANUFACTURING

There are a large number of specialty gases (more than 35) used in semiconductor manufacturing. While all specialty gas companies essentially supply the entire range of gases, it is interesting to note that no one company has complete manufacturing capability. Therefore, in the specialty gas industry, it is necessary that companies sell product between themselves. It is therefore possible for a gas manufactured by one company to be purchased, remixed, filtered, and repackaged by another company, and in some cases exchange hands a second time, before finally being sold to a semiconductor manufacturer. For that reason, it is very difficult to establish the exact size of the specialty gas market from within the industry because of possible double- and triple-counting of product. As mentioned, many of the specialty gases are remixed to provide different dilution mixtures with gases such as nitrogen, argon, hydrogen, or helium. This can also be a source of confusion when following the distribution network of gas produced by primary manufacturers to their final semiconductor manufacturing destination.

Figure 1 presents a schematic of different possible distribution networks for specialty gases from a primary manufacturer to a final destination at a semiconductor manufacturing facility. For example, Synthatron, a primary manufacturer of arsine, may supply one or more gas companies in the United States with the dopant. Typically, these gas companies would refilter and repackage the material, and sell the product directly to a semiconductor manufacturer. However, they may also sell some amount of the gas to another gas company in the United States, possibly to a joint venture partner, or to their overseas gas operations. In addition, Synthatron also supplies dopant directly to foreign gas companies, who in turn supply foreign semiconductor fabrication facilities.

Figure 1

POSSIBLE DISTRIBUTION NETWORKS FOR SPECIALTY GASES FROM POINT OF MANUFACTURING TO POINT OF USE



Source: DATAQUEST

Gases

Silicon-Precursor Gases

Union Carbide is a leading supplier of silicon-precursor gases, since it is the only company in the United States with primary manufacturing capability for silane, dichlorosilane, trichlorosilane, and silicon tetrachloride. Other basic manufacturers in one or more of the silicon-precursor gases include Air Products, Matheson, Scientific Gas Products, and Synthatron. In addition, Texas Instruments, a semiconductor manufacturer, is also a primary manufacturer of silicon tetrachloride.

Dopants

One example of limited primary manufacturing capability is that of the gaseous dopants. There are only three primary manufacturers of arsine, all located in the United States: Matheson Gas Products, Phoenix Research (purchased in 1984 by Union Carbide), and Synthatron. While Matheson and Phoenix Research are also primary manufacturers of phosphine, Synthatron obtains low-grade phosphine from American Cyanamid.

DATAQUEST believes that Europe presently has no arsine and phosphine manufacturing capability, nor does Japan. DATAQUEST estimates that in 1984, Synthatron supplied essentially all of Europe's arsine/phosphine needs, and approximately 70 percent of Japan's requirements. It is believed that Japan may be establishing dopant manufacturing capability in arsine and phosphine in the near future.

In addition, there is only one primary manufacturer in the United States for diborane, Callery Chemical Company (Callery, PA). Callery has no direct sales to semiconductor manufacturers, but sells its product to the different gas companies who then purify and repackage it for semiconductor industry consumption. Some primary manufacturing capability of diborane does exist in Europe and Japan; .however, it is unclear what amount of diborane is exported from the United States to these regions.

Plasma Etchants

Carbon tetrafluoride is the gas that is most commonly used in the plasma etching process. Both Linde and Air Products have primary manufacturing capability for carbon tetrafluoride. Other suppliers obtain carbon tetrafluoride from Dupont and then filter, purify, and repackage the material prior to providing it to a semiconductor manufacturer.

Gases

Matheson and Scientific Gas Products are both licensed by LFE Corporation to manufacture proprietary plasma etchant gas mixtures. A 35 percent royalty is charged on the etchant mixtures which are protected under a "composition of matter" patent.

In addition to Air Products, Linde, Matheson, and Scientific Gas Products, other manufacturers of plasma etch gases include Liquid Carbonic and Synthatron.

Air Products, in particular, has a wide range of primary manufacturing capability in fluorine-based gases, including nitrogen trifluoride and tungsten hexafluoride. These two gases have received a good deal of attention recently. Nitrogen trifluoride is used in a system developed by Benzing Technologies to clean horizontal-tube LPCVD (low pressure CVD) reactors. Tungsten hexafluoride, which is classified in the "Other Specialty Gases" category, is used in a CVD reactor system developed by Genus for the deposition of tungsten silicide.

Reactant Gases

DATAQUEST believes that none of the gas suppliers has primary manufacturing capability for gaseous hydrogen chloride, except Union Carbide through its recent acquisition of Phoenix Research. The gas suppliers typically purchase liquid hydrochloric acid and then repackage the material as a gas under high-pressure conditions.

The emphasis on ultrahigh-purity materials has led gas suppliers to develop special passivated cylinders to minimize contamination and particulate generation, particularly for the corrosive gases. Airco was the first to introduce aluminum cylinders for electronic gases under the "Spectra Seal" name. Airco later announced a line of specially prepared carbon steel cylinder linings, under the "Spectra Steel" name, for those materials that are chemically incompatible with an aluminum cylinder. This type of cylinder is particularly effective in maintaining purity levels for hydrogen chloride.

Atmospheric/Purge Cylinder Gases

The manufacturing process for obtaining nitrogen, oxygen, argon, and hydrogen has been discussed in previous sections. Helium is a fixed component in air separation; however, it is usually obtained in concentration from gas reserves located in some natural gas fields. Helium is used as an inert carrier gas in some applications in semiconductor processing. However, helium is primarily used in the electronics industry as an inert carrier gas for dopants in the production of glasses in fiber optics.

Other Specialty Gases

DATAQUEST believes that Air Products is the only primary manufacturer of tungsten hexafluoride in the United States. Tungsten hexafluoride is used as a source of tungsten for tungsten silicide deposition. Genus was the first to develop a dedicated tungsten silicide reactor for liquid phase chemical vapor deposition. Genus is also a supplier of high-purity, moisture-free tungsten hexafluoride for exclusive use in its reactor system. The Japanese have traditionally used molybdenum hexafluoride as a source material for molybdenum silicide, but with the advent of the Genus reactor, the Japanese market has shifted toward the use of tungsten hexafluoride as a source material in refractory metal silicide deposition.

Airco and Matheson are primary suppliers of germane to the semiconductor industry.

SAFETY ISSUES

The previous section has emphasized the manufacturing capability for specialty gases of the various gas suppliers. There are relatively few sites of primary manufacturing of specialty gases in the United States. One reason is that due to the toxic and corrosive nature of most of the specialty gases, it is a very involved, costly procedure to certify manufacturing facilities to the safety standards of local and state officials, the EPA (Environmental Protection Agency), and OSHA (Occupational Safety and Health Agency). In light of the December 1984 toxic gas leak at the Union Carbide facility in Bhopal, India, industrial development agencies around the world are quite concerned about potentially hazardous leaks that might arise at a specialty gas manufacturing plant. One example of the fallout from Bhopal is that plans for a Union Carbide specialty gas facility in Scotland have been postponed until further evaluation can be completed.

Specialty gas manufacturers are very aware of the safety issues surrounding their products and have gone to special efforts to ensure reliable handling of the gases. Linde has worked jointly with Veriflow Corporation in the development and testing of a new remote-controlled valve for the control of hazardous gases. This new valve would allow personnel to stay at a distance to safely handle flammable, toxic, or corrosive gases under high pressure. It includes a special flow-limiting restrictor in the outlet to prevent the chance of uncontrollable gas flow in the event of a leak downstream. It also maintains a secondary self-sealing system to prevent leaks to the atmosphere in case the primary outlet becomes disconnected with the valve left open. The cost of the new valve will be included as part of the cylinder rental charge.

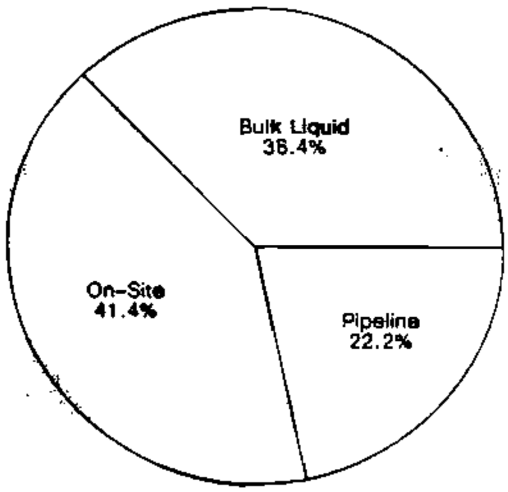
While safety is foremost in the minds of many semiconductor manufacturers, the associated cost for including the new Linde valve on specialty gas cylinders will be a factor of six to seven times the standard cylinder charge, and this may deter widespread usage in the industry.

NITROGEN DELIVERY SYSTEMS

There are three different modes of delivering high-purity nitrogen to a semiconductor fabrication facility: an on-site air separation plant, a single-customer or multicustomer pipeline network, and merchant deliveries of liquid nitrogen. DATAQUEST estimates that approximately 49.5 billion cubic feet (Bcf) of nitrogen were supplied to the semiconductor industry in the United States in 1984. The volume percentage associated with each type of delivery mode is presented in Figure 2. For the purpose of this study, only multicustomer pipeline systems are considered under the pipeline category. Single-customer pipelines are considered delivery extensions of dedicated merchant air separation facilities, and thus in some ways are analogous to customer on-site facilities. Each of the three delivery modes has economic and logistical advantages and disadvantages which will be reviewed in the following sections. In particular, such issues as the amount of nitrogen required, the location of the fabrication facility, and the existing infrastructure must be considered in each case.

Figure 2

NITROGEN DELIVERY MODE BY VOLUME--UNITED STATES
1984



Volume--49.5 Bcf

Source: DATAQUEST

On-Site Nitrogen Generation Plants

Semiconductor manufacturers consider an on-site nitrogen generation facility when sufficiently large volumes of nitrogen are required for a given fabrication facility. This occurs when a new facility with large nitrogen consumption requirements comes on-line, or when the consumption of nitrogen has grown beyond the point of economic justification for merchant delivery of liquid nitrogen. Because the consumption rate of nitrogen is substantially larger than that of the other bulk gases, it is the only gas that is economical for a semiconductor manufacturer to produce on-site. One exception, however, is a Texas Instruments facility in Dallas that is supplied via a single-customer pipeline network with high-purity nitrogen, oxygen, argon, and hydrogen generated at a nearby plant operated by Liquid Air.

Typically, the gas company responsible for installation of the plant retains ownership and supervises its operation. There are several reasons why this is the case. First, a semiconductor manufacturer has other more pressing demands for capital expenditure than a nitrogen generation plant. In addition, personnel at a fabrication facility are usually not knowledgable about gas production or maintenance of such a facility. Finally, if it becomes necessary to expand nitrogen capacity, existing plant equipment will have to be removed and a larger facility installed in its place, since smaller plants cannot be directly upgraded.

There are several factors that influence the choice for on-site nitrogen generation, but foremost is the wafer production level, and thus nitrogen consumption rate, of a fabrication facility. However, nitrogen consumption in a fab depends on more than just wafer starts, since a certain amount of nitrogen is always required to maintain the processing equipment and environment even when wafer production levels drop. Typically in the industry, it is estimated that 500 to 700 cubic feet of nitrogen are consumed per wafer start, on the average. This figure, which includes both fabrication and maintenance requirements, allows one to calculate the nitrogen consumption rate of a fabrication facility on the basis of wafer starts. If wafer production levels at a given facility decrease, however, the reduction in nitrogen will not drop at the same rate because of the amount of gas that is needed to maintain the integrity of the processing environment.

The consumption rate of nitrogen that economically justifies conversion to an on-site facility is 22,000 to 26,000 cubic feet/hour. This corresponds to approximately 25,000 to 30,000 wafer starts/month if one assumes an average consumption rate of 625 cubic feet of nitrogen/wafer start for 720 hours/month of production operation. By the time a semiconductor manufacturer has reached a nitrogen consumption rate of 28,000 to 30,000 cubic feet/hour (32,000 to 35,000 wafer starts/month), the conversion to on-site nitrogen generation has usually been made.

Several issues that may affect a lower break-even point for the conversion to an on-site facility include the location of the fabrication facility and the condition of the existing infrastructure. If a semiconductor fab is located in an area that is quite a distance from a merchant source of liquid nitrogen, the additional costs for transporting bulk liquids may become prohibitive when compared with the alternative of on-site nitrogen generation. In addition, if the existing infrastructure (communications and transportation network) is poor, regular and reliable delivery of bulk liquid nitrogen may not be possible, and again, on-site nitrogen generation may be the only alternative. On-site plants at semiconductor fabrication locations have been identified in Israel, Malaysia, and South Korea. In these cases, the infrastructure that would allow for merchant delivery of liquid nitrogen is poor. At the facility in Israel, oxygen and hydrogen as well as nitrogen are produced on-site, which is unusual since these gases are required in much smaller volumes than nitrogen in the semiconductor processing environment. Hydrogen, oxygen, and argon are rarely produced on-site in the United States because the existing infrastructure is sufficient to make bulk delivery economically viable.

The cost to a semiconductor manufacturer for on-site nitrogen is approximately $0.10 to $0.12/hundred cubic feet (hcf) for an average-size facility (typically 30,000 to 80,000 cubic feet/hour). For a larger facility, the cost may be more like $0.08 to $0.09/hcf. The charge usually includes a regular fixed fee that covers the equipment and facility and the cost of maintaining the plant, as well as the gas itself.

The customer typically pays the power costs for the generation of nitrogen; this can vary considerably, depending on the source of electricity. For example, the energy costs in the Pacific Northwest are several mils per kW-hour (about $0.002 to 0.003/kW-hour) up to $0.01 to $0.02/kW-hour because of the abundant source of cheap hydroelectric power. In the San Francisco Bay Area, however, Pacific Gas & Electric charges $0.07 to $0.10/kW-hour, which makes the overall cost of a customer on-site generation plant prohibitive when compared with the existing pipeline network and liquid bulk deliveries. (Certain discounts on energy rates apply for large-volume users that maintain power consumption at a specified capacity.)

The amount of energy required to generate 100 cubic feet of nitrogen (in liquid form) is approximately 3 kW-hours, some of which may be recovered from heat exchangers when the liquid is vaporized. Because there is such a wide range in the cost of power, it is very difficult to establish an average selling price for on-site nitrogen that includes these additional on-site fees. For the purpose of this study, the average selling price of nitrogen is reported as $0.11/hcf, with the understanding that power charges are not included.

The current short-term trend is that the number of on-site locations will increase, and that existing locations will continue to add nitrogen generation capacity. However, several industry sources believe that the long-term trend will be away from the large fabrication facilities toward small production centers, and thus the number of new on-site locations will drop dramatically. One disadvantage to on-site nitrogen production that should be mentioned is that regardless of the amount of nitrogen produced at the facility, the fixed fee payments are unaffected. In an economic downturn, such as the industry has recently endured, those fees can become an economic liability for facilities that are required to cut back or shut down production lines.

DATAQUEST estimates that there are more than 50 semiconductor fab locations in the United States that have on-site nitrogen generation facilities, and they account for 20.5 Bcf, or 41.4 percent of total nitrogen consumption in 1984. The major gas companies that provide on-site nitrogen generation facilities in the United States include Air Products, Airco, Liquid Air, and the Linde division of Union Carbide.

On-site nitrogen generation facilities are also found at more than a dozen Japanese semiconductor facilities. Several that have been identified include Fujitsu (Aizu), Matsushita (Arai), Motorola (Aizu), Oki (Miyazaki), a Sharp facility, and Toshiba (Iwate). The companies that supply the nitrogen generation systems include Daido Sanso, Nippon Sanso, Osaka Sanso, and Teisan.

In the European gas market, several on-site nitrogen generation facilities have been identified in the United Kingdom; generator suppliers for these sites include Air Products, B.O.C., and Petrocarbon (a British supplier of air separation facilities). Limited activity in the area of on-site nitrogen generation plants has also been reported in France and West Germany. Nitrogen on-sites have also been identified in Israel, South Korea, Malaysia, and Singapore. Currently, there is no information available regarding the volume percentage that is accounted for by this mode of nitrogen delivery in Europe, Japan, or countries in ROW.

Pipeline Delivery of Nitrogen

Gaseous nitrogen is supplied to semiconductor facilities via single-customer and multicustomer pipeline networks. For the purpose of this study, however, only multicustomer pipeline systems are considered under the pipeline designation. Single-customer pipelines are considered delivery extensions of dedicated merchant air separation facilities, and thus are analogous to customer on-site facilities.

At this time, there are only three multicustomer pipeline systems that supply semiconductor manufacturers in the United States with nitrogen. While single-customer pipelines exist in Europe as well as Japan, there are currently no multicustomer pipeline networks in those regions. The following discussion, therefore, is limited to the two Air Products pipelines located in the Silicon Valley and Chandler, Arizona, and the new Linde pipeline, located in San Jose, California.

The driving force for establishing a multicustomer pipeline system is the strategic location of a network that has the ability to serve an expanding geographical region of semiconductor production activity. Air Products established its first pipeline system in 1971, located in the Silicon Valley. Over the years, the low-carbon steel pipeline has been expanded to a system that is 25 miles long, including a recent 3-mile extension that is made of electropolished stainless steel. The pipeline network supplies high-purity gaseous nitrogen to more than 45 semiconductor manufacturers in the Silicon Valley, from Mountain View to San Jose, with the recent 3-mile extension into Milpitas. Several major manufacturers that are hooked up to the Air Products' nitrogen pipeline network include Advanced Micro Devices, Fairchild, Hewlett-Packard, Intel, Monolithic Memories, and National Semiconductor. A second Air Products pipeline, also low-carbon steel, was established in Chandler, Arizona, in the late 1970s. It is approximately 25 miles long and serves approximately 10 semiconductor manufacturers, including GTE, General Instruments, Intel, and Motorola.

The Linde division of Union Carbide brought a high-purity nitrogen pipeline system on-line in early 1985. It is a two-mile long stainless steel system that serves the International Business Park in San Jose. There are currently four semiconductor manufacturers that are being supplied with nitrogen from the Linde pipeline network. Linde chose a stainless steel pipeline system rather than low carbon steel because of its ability to provide an ultrahigh-purity, low-contaminant environment for gaseous nitrogen delivery.

DATAQUEST estimates that the volume of nitrogen supplied by multicustomer pipeline networks in the United States was approximately 11.0 Bcf, or 22.2 percent of the total nitrogen volume consumed by semiconductor manufacturers in 1984. This volume is totally attributable to the Air Products' pipeline systems in the Silicon Valley and in Chandler, Arizona, since the Linde pipeline did not come on-line until early 1985. (The Silicon Valley pipeline accounted for 80 percent, or 8.8 Bcf, while the Chandler network supplied the remaining 20 percent, or 2.2 Bcf, of pipeline-delivered nitrogen.) Even for pipeline nitrogen volumes in 1985, the Linde pipeline's contribution to the total amount supplied by multicustomer pipeline systems will be negligible. The cost for nitrogen provided by the pipeline systems varies from $0.20 to $0.24/hcf, with an average selling price of $0.22/hcf.

Merchant Liquid Nitrogen Delivery

Liquid nitrogen is delivered via tube trailers and tanker trucks to cryogenic holding tanks located "on the pad" at semiconductor manufacturing facilities. This is the only option available for nitrogen supply when a semiconductor manufacturer is not strategically located to take advantage of a multicustomer pipeline system, or if the account is of insufficient size to warrant on-site nitrogen generation. The overwhelming advantage for shipping discrete amounts of bulk liquid rather than gaseous nitrogen is that a single volume of liquid corresponds to an equivalent of 750 volumes of gas after vaporization. Vaporizers are installed on the pad by the gas supplier for on-site conversion from liquid to gas as needed.

The pricing system for merchant delivery of liquid nitrogen can vary considerably depending on the size of the account and the distance of the fab facility from vendor-owned air-separation plants. The basic cost of bulk liquid nitrogen delivery includes the power costs to liquefy and separate out the nitrogen, transportation costs (based on round-trip mileage) to move a discrete volume of liquid by tube trailer to a fabrication facility, as well as a hook-up charge. In addition, there is typically an escalation clause built into the contracts for liquid nitrogen delivery that increases the price of nitrogen as time goes on. (For example, pricing for bulk liquids can in some cases follow the Producer Price Index for Industrial Commodities set by the Bureau of Labor Statistics.) However, as the account grows, appropriate reductions in price are also considered. Thus, taking these many factors into account, the price of bulk liquid nitrogen delivered to a semiconductor manufacturer can vary from as low as $0.17 to $0.19/hcf to $0.50 to $0.60/hcf. In some cases, liquid nitrogen prices in the United States are even greater than $1.00/hcf because of the size/distance factors.

While prices vary considerably, an average selling price of $0.40/hcf is assumed in this study. This cost factor includes delivery of the bulk liquid as well as the leasing fee for vaporization equipment and storage tanks. Because of very aggressive pricing practices within the gas industry for semiconductor manufacturer accounts, the pricing distribution for liquid nitrogen will continue to span a wide range of values in the future.

The merchant liquid nitrogen delivery prices can be higher overall than either pipeline delivery or on-site generation, even when power costs are included. One reason is that some of the power cost for air liquefaction and separation can be recovered through heat exchange equipment when the liquid is vaporized to a gas. The gas company is responsible for the operation of customer on-site facilities, as well as their own plants, and thus can pass the savings in power costs directly on to the semiconductor manufacturer through prices for on-site nitrogen and pipeline-delivered nitrogen. However, with liquid nitrogen delivery, the semiconductor manufacturer is paying for a liquid supply of nitrogen, and thus the cost up front does not reflect any eventual recovery of power charges that may be generated through vaporization.

DATAQUEST estimates that the volume of nitrogen supplied to semiconductor manufacturers in the United States in 1984 from bulk liquid merchant deliveries was 18.0 Bcf, which corresponds to 36.4 percent of the total nitrogen volume consumption.

MARKET ANALYSIS

Worldwide Semiconductor Gas Market

Table 7 presents the worldwide semiconductor gas market in 1984 by regional sales of bulk and specialty gases.

Table 7

1984 WORLDWIDE SEMICONDUCTOR GAS MARKET

	Bulk Atmospheric Gases		Specialty Gases		Total	
Region	$M	Percent	$M	Percent	$M	Percent
United States	$155.0	46.9%	$ 50.0	50.0%	$205.0	47.6%
Japan	115.0	34.8	42.0	42.0	157.0	36.5
Europe	25.0	7.6	7.0	7.0	32.0	7.4
ROW	35.5	10.7	1.0	1.0	36.5	8.5
Total	$330.5	100.0%	$100.0	100.0%	$430.5	100.0%

Source: DATAQUEST

Gases

DATAQUEST believes that specialty gas costs for Japan, Europe, and the ROW are proportionately higher than for the United States because regional gas suppliers do not have full specialty gas manufacturing capability. Thus it is necessary for a variety of different gases to be shipped in cylinders to these areas. For example, DATAQUEST believes that Europe has no dopant manufacturing capability, and that Japan as well may still not have established primary dopant manufacturing. The interrelationships between the various gas companies in different regions of the world provide the necessary distribution networks for such gases.

Table 8 presents the total bulk gas market and the portion of the market represented by nitrogen (revenues, volumes, and average selling prices) for the different regions of the world. Nitrogen is singled out because it is consumed by the semiconductor industry in substantially larger volumes than any of the other gases, and thus represents the majority of the bulk gas market in any given region.

Table 8

COMPARISON OF 1984 WORLDWIDE BULK GAS AND NITROGEN GAS MARKET

	Bulk Gas		Nitrogen				
Region	$M	Percent	$M	Percent	Vol(Bcf)	Percent	ASP/hcf
United States	$155.0	46.9%	$118.8	45.6%	49.5	55.6%	$0.24
Japan	115.0	34.8	88.0	33.8	22.0	24.7	0.40
Europe	25.0	7.6	20.0	7.7	10.0	11.3	0.20
ROW	35.5	10.7	33.8	12.9	7.5	8.4	0.45
	$330.5	100.0%	$260.6	100.0%	89.0	100.0%	

Source: DATAQUEST

Several factors influence the different prices for nitrogen in the different regions of the world, including mode of delivery, infrastructure, and power costs. Nitrogen prices may vary, depending on the mode of delivery, with higher costs for bulk liquid and lower costs for pipeline or on-site nitrogen. DATAQUEST estimates that when the pricing structures for the various modes of delivery have been accounted for, the average selling price of nitrogen in the United States is $0.24/hcf. Specific information on the percent of nitrogen supplied by different delivery modes is not available for the other regions.

Prices for bulk liquid and on-site nitrogen are strongly influenced by the variable cost factors associated with distance and quantity for the delivery of liquid, and the power costs associated with operating an on-site plant. DATAQUEST believes that the average selling price for nitrogen in Europe is about $0.20/hcf, strongly influenced by excellent infrastructure, while for Japan and ROW the estimated prices are $0.40/hcf and $0.45/hcf, respectively. Total bulk atmospheric gas costs for the ROW, therefore, are influenced by not only a relatively larger volume of nitrogen because of assembly operations, but a relatively higher cost for the gas as well.

U.S. Semiconductor Gas Market by Product

Table 9 presents the dollar/volume distribution for the bulk atmospheric gases (nitrogen, oxygen, hydrogen, and argon) consumed by the semiconductor industry in the United States in 1984. Nitrogen volumes and average selling prices are also presented by mode of delivery. The revenues represent direct sales of gas to semiconductor manufacturers.

Table 9

1984 BULK ATMOSPHERIC GAS SALES IN THE UNITED STATES BY PRODUCT

Gas	Volume (Bcf)	Vol %	ASP/hcf	$M	$%
Nitrogen					
On-Site	20.50	41.4%	$0.11	$ 22.6	19.0%
Pipeline	11.00	22.2	$0.22	24.2	20.4
Bulk Liquid	18.00	36.4	$0.40	72.0	60.6
Total	49.50	100.0%		$118.8	100.0%
Nitrogen	49.50	94.9%	$0.24	$118.8	76.6%
Oxygen	1.00	1.9	$0.60	6.0	3.9
Hydrogen	1.10	2.1	$1.50	16.5	10.6
Argon	0.55	1.1	$2.50	13.7	8.9
Total	52.15	100.0%		$155.0	100.0%

Source: DATAQUEST

Gases

Average selling prices for the bulk atmospheric gases have a wide range in values because of variable cost factors. These factors include the cost of power to produce the gases through cryogenic air separation and distribution costs that are distance dependent. In addition, there are the delivery and quantity terms, which depend on the relative size and age of the account. In general, average selling prices for nitrogen (per hundred cubic feet) are approximately $0.11 for on-site nitrogen generation facilities (customer pays power), $0.22 for nitrogen pipeline delivery, and $0.40 for bulk liquid nitrogen delivery. The average selling price for oxygen corresponds to $0.60/hcf, but can be as high as $1.00/hcf or more. Hydrogen typically costs $1.50/hcf, but the price may range from $1.00 to $2.50/hcf and is highly distance dependent, since there are only a limited number of facilities in the country that produce liquid hydrogen. The average selling price for argon is approximately $2.50/hcf, but again may vary over a large range of prices from $2.00 to $3.50/hcf, depending on a variety of variable cost factors.

Table 10 shows the specialty gas sales to the semiconductor industry in the United States in 1984 by gas category: silicon-precursors, dopants, plasma etchants, reactant gases, atmospheric purge/cylinder gases, and others. Please refer to Table 1 for the specific gases that are members of each category. The volumes of the different gases consumed in fabrication, as well as their average selling prices, vary considerably. In this study, only revenues associated with each specialty gas category are reported.

Table 10

1984 SPECIALTY GAS SALES IN THE UNITED STATES BY PRODUCT

Gas Category	$M	Percent
Silicon-Precursors	$17.5	35.0%
Dopants	8.0	16.0
Plasma Etchants	12.5	25.0
Reactant Gases	5.0	10.0
Atmo/Purge & Others	7.0	14.0
	$50.0	100.0%

Source: DATAQUEST

Gases

U.S. Semiconductor Gas Market by Company

Table 11 ranks the leading bulk gas suppliers by 1984 sales in the United States. Air Products has a substantial share of the bulk gas market with $72 million in sales (46.4 percent share). Air Products' two pipeline networks (in the Silicon Valley and Chandler, Arizona) account for $24.2 million of that $72 million, or 33.6 percent of Air Products' gas revenues from the semiconductor industry. The pipeline systems evaluated on their own correspond to 20.4 percent of the total industry nitrogen revenues, and 15.6 percent of the total bulk gas revenues. Linde is a strong second with 27.1 percent share of the market. Airco and Liquid Air come in at a close tie for third with 13.6 percent and 11.0 percent, respectively. Of the four major gas companies in the United States, only Air Products and Linde have merchant liquid hydrogen manufacturing facilities.

Table 11

1984 BULK ATMOSPHERIC GAS SALES IN THE UNITED STATES BY COMPANY

Company	Sales ($M)	Percent
Air Products	$ 72.0	46.4%
Linde	42.0	27.1
Airco	21.0	13.6
Liquid Air	17.0	11.0
Others	3.0	1.9
Total	$155.0	100.0%

Source: DATAQUEST

Gases

Table 12 shows the specialty gas sales in the United States in 1984. The major suppliers of specialty gases to the semiconductor industry include Airco, Union Carbide, Air Products, and Matheson. DATAQUEST estimates that they account for 70 percent of sales directly to semiconductor manufacturers in 1984. Other smaller suppliers include Scientific Gas Products, Liquid Carbonic, and Alphagaz (the specialty gas division of Liquid Air). DATAQUEST estimates that their participation in the market accounts for an additional 16 percent of direct sales to the semiconductor industry in 1984. The remaining 14 percent of sales in 1984 is spread among several companies that typically supply only one or perhaps a handful of the full complement of specialty gases.

Table 12

1984 SPECIALTY GAS SALES IN THE UNITED STATES BY COMPANY

Company	Sales ($M)	Percent
Airco	$10.5	21.0%
Linde	9.0	18.0
Air Products	8.0	16.0
Matheson	7.5	15.0
Scientific Gas Products	5.0	10.0
Liquid Carbonic	2.5	5.0
Liquid Air	0.5	1.0
Others	7.0	14.0
Total	$50.0	100.0%

Source: DATAQUEST

Table 13 presents total sales of semiconductor gases (bulk and specialty) in the United States in 1984, and overall market shares for the various suppliers.

Gases

Table 13

1984 TOTAL SEMICONDUCTOR GAS SALES BY COMPANY

Company	Sales ($M)	Percent
Air Products	$ 80.0	39.0%
Linde	51.0	24.9
Airco	31.5	15.4
Liquid Air	17.5	8.5
Matheson	7.5	3.7
Scientific Gas Products	5.0	2.4
Liquid Carbonic	2.5	1.2
Others	10.0	4.9
Total	$205.0	100.0%

Source: DATAQUEST

Japanese Semiconductor Gas Market

The total gas market in Japan in 1984 was $157 million, of which $115 million in sales (73.2 percent) were bulk gases and $42 million in sales (26.8 percent) were specialty gases. The major bulk gas suppliers to Japan's semiconductor industry are Nippon Sanso, Teisan, Daido Sanso, Osaka Sanso, and Taiyo Sanso. Table 14 shows bulk atmospheric gas sales in Japan in 1984 for these companies.

Table 14

1984 BULK ATMOSPHERIC GAS SALES IN JAPAN BY COMPANY

Company	Sales ($M)	Percent
Nippon Sanso	$ 52.0	45%
Teisan	29.0	25
Daido Sanso	8.0	7
Osaka Sanso	8.0	7
Taiyo Sanso	8.0	7
Others	10.0	9
Total	$115.0	100%

Source: DATAQUEST

In the specialty gas market, the major suppliers are Nippon Sanso and Seitetsu. Smaller suppliers of specialty gases in Japan in 1984 include Showa Denko, Teisan, and Takachiho. Iwatani, a new entrant in the specialty gas market, did not participate in sales of specialty gases to the Japanese semiconductor industry in 1984. Estimates of market share for the specialty gas suppliers are not presented at this time.

European Semiconductor Gas Market

In Europe, the total 1984 semiconductor gas market was $32 million, of which $25 million in sales (78.1 percent) were bulk gases and $7 million in sales (21.9 percent) were specialty gases. The major gas companies that supply the European semiconductor industry include Air Products, B.O.C, L'Air Liquide, Linde AG, Matheson-UCC, Messer Griesheim, and Union Carbide. (The European operations of Matheson Gas Products are owned by Union Carbide Corporation; thus the designation Matheson-UCC refers to their joint operations.)

The major gas suppliers that serve semiconductor manufacturers in the United Kingdom are B.O.C. and Air Products. In France, L'Air Liquide is the major supplier, while Air Products and Matheson-UCC have smaller shares. In West Germany, the major gas suppliers include Air Products, L'Air Liquide, Linde AG, Matheson-UCC, and Messer Griesheim. In the Benelux region, Air Products and Matheson-UCC are the two major suppliers of semiconductor gases to the area. Estimates of market share by company for the bulk and specialty gas suppliers are not presented at this time.

ROW Semiconductor Gas Market

In 1984, the semiconductor gas market in the ROW was $36.5 million, of which $35.5 million of sales (97.3 percent) were bulk gases and $1 million in sales (2.7 percent) were specialty gases. The ROW countries with significant semiconductor fabrication operations include South Korea and Taiwan, while Malaysia, Hong Kong, and Singapore have substantial assembly operations. The major gas suppliers to these regions, either through direct sales or joint venture agreements, include Nippon Sanso, Teisan, Union Carbide, B.O.C., and L'Air Liquide. Estimates of market share by company for the bulk and specialty gas suppliers are not presented at this time.

Worldwide Nitrogen Market

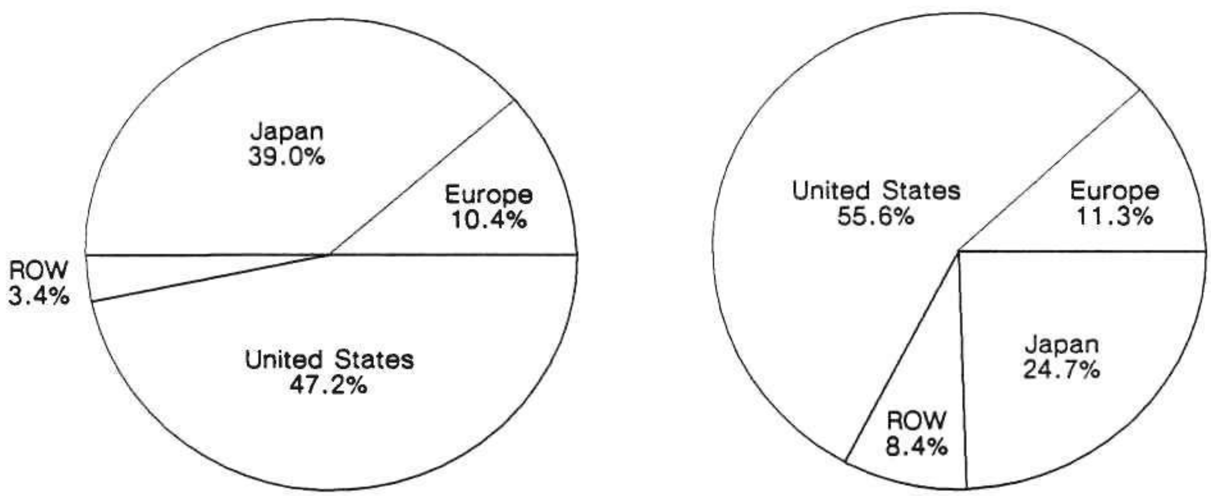
Nitrogen is consumed by the semiconductor industry in substantially larger volumes than any other gas. It is important to understand that nitrogen is used by a semiconductor manufacturer not only in wafer fabrication and assembly, but also to maintain the integrity of the fabrication equipment and processing environment. For example, such equipment as furnace banks and some lithography tools, as well as certain types of clean stations, are supplied with a continuous flow of nitrogen, whether wafers are present or not. Therefore, the amount of nitrogen consumed by a semiconductor manufacturer is dependent in some manner on the amount of equipment in a fab as well as on the amount of wafers produced at the facility.

Total worldwide nitrogen consumption by the semiconductor industry in 1984 amounted to 89.0 Bcf (see Table 8). Figure 3 presents worldwide nitrogen consumption as well as worldwide silicon consumption by region for 1984. (Silicon consumption in the United States includes captive as well as merchant manufacturers.)

At first glance, the distribution of nitrogen by region presented in Figure 3 does not appear to correlate with total semiconductor production as measured by million square inches of processed silicon, particularly in a comparison between the United States and Japan. It appears that Japan uses quite a bit less nitrogen relative to its silicon consumption than the United States. In addition, assembly operations, which consume nitrogen, are retained onshore in Japan, while DATAQUEST estimates that 85 percent or more of assembly operations for U.S. semiconductor manufacturers are performed offshore (in the ROW).

Figure 3

1984 WORLDWIDE NITROGEN AND SILICON CONSUMPTION



Total Silicon—1,769 Million Square Inches **Total Nitrogen Volume—89.0 Bcf**

Source: DATAQUEST

DATAQUEST believes that the difference in nitrogen consumption can be accounted for in part by a difference in philosophy of manufacturing operations. DATAQUEST believes that Japanese semiconductor manufacturers follow very tight regulations in nitrogen flow rates for processing equipment, whether in wafer fabrication production or in maintenance mode. In the United States, however, DATAQUEST believes that there is a tendency for a larger acceptable tolerance in nitrogen flow rates, in particular for flow rates to slowly increase over time. When it is recognized that nitrogen consumption has become unacceptably high in a given fabrication facility, flow rates are reduced to acceptable levels. However, the gradual increase in nitrogen consumption may be repeated in the absence of strict supervision in the processing environment.

There are other factors that may also account for the difference in nitrogen consumption in Japan and the United States relative to semiconductor production. The first factor to consider is product mix and its influence on consumption of nitrogen. The Japanese semiconductor industry produces a relatively larger number of discrete and linear devices than the United States. These devices do not require the same level of processing as some of the more advanced devices, and therefore do not require as much nitrogen per wafer.

A decrease in nitrogen consumption is influenced by the trend toward the usage of clean dry air (CDA) in those applications that do not require a nitrogen environment. The substitution of CDA for nitrogen in certain applications (dessicators, pneumatic-actuated valves, some lithography tools) has been adopted by some semiconductor manufacturers in the United States; however, the trend can at best be described as gradual. DATAQUEST is uncertain of the amount of CDA that is currently being used in Japanese facilities.

Other trends that correlate with a decrease in nitrogen consumption include an increase in the use of argon for annealing, as well as an increase in ion implantation over diffusion. DATAQUEST believes that Japanese semiconductor manufacturers purchased more ion implantation equipment than the United States in both 1983 and 1984. The Japanese therefore have a substantially larger focus on ion implantation than U.S. manufacturers when taken in comparison with the amount of silicon processed in each region. DATAQUEST believes that a combination of these factors account for the difference in nitrogen consumption in Japan compared with the United States, relative to their respective levels of semiconductor production.

The large consumption of nitrogen in the ROW includes not only that area's semiconductor production but the substantial assembly operations in Pacific Rim countries. DATAQUEST estimates that 85 percent or more of U.S. assembly and 90 percent of European assembly occurs offshore, and the nitrogen consumed in ROW takes into account those assembly-related nitrogen requirements.

The various factors that we believe will affect future nitrogen consumption by semiconductor manufacturers in addition to wafer starts are summarized in Table 15.

Table 15

FACTORS INFLUENCING FUTURE NITROGEN CONSUMPTION

Increases in Nitrogen Usage

- Shift toward larger-sized wafers
- Increase in nitrogen consumption for United States and Europe as assembly operations return onshore
- Increase in the installed equipment base with accompanying requirement for nitrogen to maintain integrity of processing equipment and environment

Decreases in Nitrogen Usage

- Trend toward ion implantation and away from diffusion
- Increased use of clean dry air for noncritical applications such as dessicators, pneumatic-actuated valves, and lithography equipment (e.g., aligners and track equipment)
- Trend toward use of argon in annealing rather than nitrogen (in particular for thin gate oxides)
- Decrease in nitrogen in ROW as assembly operations return onshore for the United States and Europe

Trends in Nitrogen Delivery Mode

- Areas with traditionally poor infrastructure, such as ROW, will continue to go to on-site nitrogen facilities
- U.S. in general experiencing trend toward smaller fabs; thus, trend will be toward more bulk liquid delivery of nitrogen
- Geographical concentrations of existing and future semiconductor production will be advantageous sites for multicustomer pipeline networks

Source: DATAQUEST

Since nitrogen flow is used to maintain the integrity of many pieces of processing equipment during times of nonproduction, the nitrogen market exhibits surprising stability during economic downturns in the semiconductor industry. DATAQUEST estimates that nitrogen consumption in the United States is only down 10 percent by volume in 1985, from 49.5 Bcf in 1984 to 44.5 Bcf. The corresponding decrease in million square inches of processed silicon from 1984 to 1985 is 35 percent from 834 million square inches to 542 million square inches. DATAQUEST believes that because nitrogen is such a large portion of the bulk gases market, both by volume and dollar value, that gas companies, in general, represent one of the few industries with the ability to weather the economic roller coaster of the semiconductor industry.

Worldwide Semiconductor Gas Market Forecast

Table 16 contains DATAQUEST's forecast for bulk and specialty gas sales by region from 1985 through 1990. The sales of semiconductor gases in 1984 are also included in the table. CAGR refers to compound annual growth rate.

DATAQUEST believes that in general, the consumption of the bulk atmospheric gases oxygen, argon, and hydrogen, as well as the specialty gases, will follow the trend in consumption of silicon by the semiconductor industry. However, as mentioned previously, the consumption of nitrogen is dependent not only on wafer starts but also on the installed base of equipment in fabrication facilities. The nitrogen market therefore is not as sensitive to the economic cycles of the semiconductor industry as the other gases, which are considered as direct consumable materials in wafer fabrication.

The pricing forecast for all of the bulk atmospheric gases will be influenced by the cost of power to produce them and transportation costs to distribute them. In addition, argon pricing will continue to rise in response to decreased oxygen production by the gas companies for industries outside of the semiconductor industry, in particular the steel industry. Argon is a byproduct in oxygen separation, and when oxygen demand from the steel industry was high, sufficient amounts of argon were produced to amply supply the semiconductor industry. With decreased oxygen requirements from a declining steel industry, gas manufacturers have found it necessary to run facilities for argon production alone, which is reflected in higher argon prices.

Table 16

WORLDWIDE SEMICONDUCTOR GAS MARKET FORECAST
1984-1990
(Millions of Dollars)

Region	1984	1985	1986	1987	1988	1989	1990	CAGR 1984-1990
United States								
BAG*	$155.0	$131	$153	$195	$244	$261	$ 318	12.7%
SPG**	50.0	34	44	62	81	79	101	12.4%
Japan								
BAG	115.0	108	124	167	218	237	293	16.9%
SPG	42.0	36	44	64	90	97	127	20.2%
Europe								
BAG	25.0	24	29	37	50	57	72	19.3%
SPG	7.0	6	8	12	17	20	26	24.4%
ROW								
BAG	35.5	33	41	58	79	90	114	21.5%
SPG	1.0	1.4	1.9	3.2	5.0	6.3	9.0	44.2%
Total								
BAG	$330.5	$296	$347	$457	$591	$645	$ 797	15.8%
SPG	$100.0	$ 77	$ 98	$141	$193	$202	$ 263	17.5%
Total	$430.5	$373	$445	$598	$784	$847	$1,060	16.2%

*Bulk atmospheric gases
**Specialty gases

Source: DATAQUEST

A system for argon reclamation has recently been developed by Coke Process Systems, Inc. (Westborough, Massachusetts) for efficient recovery and purification of argon used in silicon crystal growing operations. ARCO Solar (Camarillo, California), which manufactures silicon for solar cell applications, will have one of the first systems installed and operational by April 1986. If the claims of 80 percent recovery and higher-purity argon are realized, argon reclamation systems could have a substantial impact on the gas industry in the coming years.

Gases

In the forecast for specialty gases, the costs associated with the different specialty gas categories have not been assigned. The use of plasma etchants, however, will continue to increase as the industry focuses on dry etching for smaller geometry devices. The dopant market will see some decrease in usage over time as the trend continues toward ion implantation, which uses less material than the alternative method of diffusion. Tungsten hexafluoride usage will continue to gain a share of the specialty gas market because of the development of the Genus CVD reactor for the deposition of tunsten silicide.

<u>Semiconductor Gas Market Regional Comparison, 1984 and 1990</u>

Figures 4 and 5 represent percent bulk and specialty gas sales by region for 1984 and 1990, respectively. The United States and Japan are expected to have equal shares of the worldwide semiconductor gas market in 1990, with each region responsible for approximately $420 million in gas sales. However, DATAQUEST expects that Japan will overtake the United States in consumption of silicon by 1987, and that the equal size of the respective gas markets in 1990 can be accounted for by the continued efficient utilization of nitrogen in Japan, as described previously. Europe and ROW will have also increased their share of the semiconductor gas market in 1990 over their respective shares in 1984 at the expense of the U.S. market. The increase in the Japanese, European, and ROW gas markets reflect increased silicon consumption and production of semiconductor devices relative to the U.S. semiconductor industry.

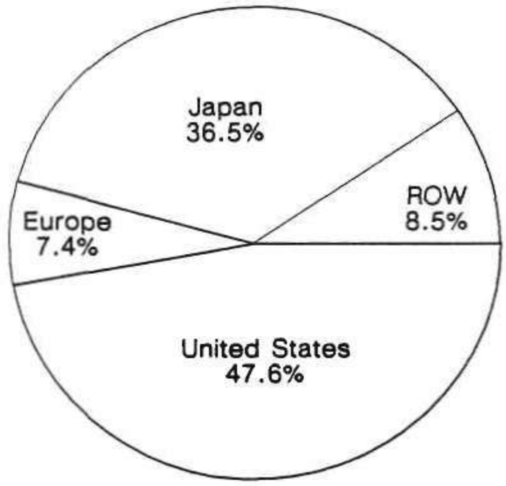
In 1984, specialty gas costs in Japan, Europe, and ROW for a given volume of gas were comparatively higher than those for the United States because of the necessity to ship gases into those regions lacking primary manufacturing capability. DATAQUEST believes that primary manufacturing of specialty gases will become more prevalent in Japan, Europe, and ROW, and therefore prices for specialty gases will become more comparable with those in the United States by 1990.

The bulk gas market in the ROW will still reflect the additional nitrogen required for assembly operations of U.S. and European devices. However, DATAQUEST believes that onshore assembly operations will continue to grow in these two regions.

Gases

Figure 4

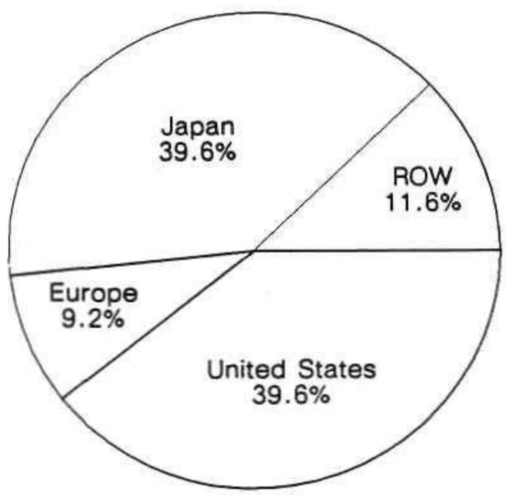
1984 WORLDWIDE SEMICONDUCTOR GAS MARKET BY REGION



Total Sales—$430.5 Million

Figure 5

ESTIMATED 1990 WORLDWIDE SEMICONDUCTOR GAS MARKET BY REGION



Total Sales—$1,060 Million

Source: DATAQUEST

Gases

GENERAL CONCLUSIONS

DATAQUEST believes that the semiconductor gas market will continue to remain price and quality competitive. There are few players in the market, and each is determined to maintain its customer base within the semiconductor industry because of the perceived importance of participating in the growth of high-technology industries. As each new semiconductor fab comes on-line, all major suppliers will participate in bidding for new contracts, and thus pricing structures will reflect the competitive drive for future market share.

In addition to competing on the basis of price, the gas companies are also focusing on the timely issues of quality control and customer support. The gas industry no longer supplies just one of the many consumable materials used in wafer fabrication, but rather offers a complete package from the gas itself to the associated gas-handling equipment to technical support at the semiconductor manufacturer's facility. The gas companies are developing integrated quality control systems from point of manufacturing to point of delivery to point of use. We believe that purity, efficient filtration systems, and quality control for gases will remain of paramount importance as semiconductor manufacturers continue to emphasize reduced particulate and contamination levels in their quest for VLSI devices and beyond.

SEMICONDUCTOR GAS INDUSTRY

Market Definitions

- Semiconductor Bulk Gases
  - Nitrogen (On-Site, Pipeline, Liquid)
  - Oxygen, Hydrogen, Argon
- Semiconductor Specialty Gases
  - Silicon Precursors
  - Dopants
  - Etchants
  - Reactant Gases
  - Atmospheric/Purge Cylinder Gases
  - Others

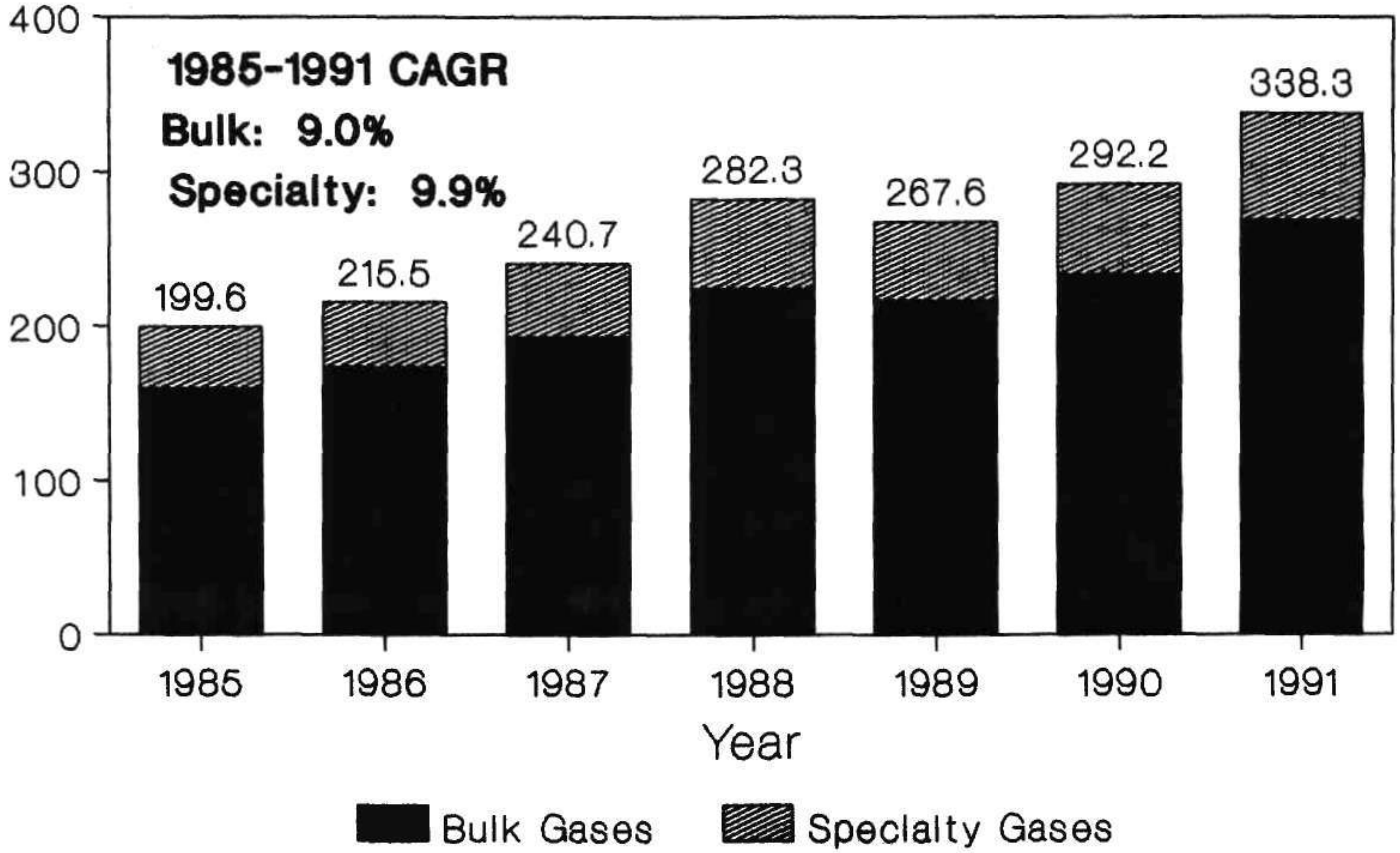
U.S. BULK AND SPECIALTY GAS

(Millions of Dollars)

GAS CATEGORY	1985	1986
Bulk Gases	$160.4	$173.8
Growth		8.4%
Specialty Gases	$ 39.2	$ 41.7
Growth		6.4%
Total	$199.6 M	$215.5
Growth		8.0%

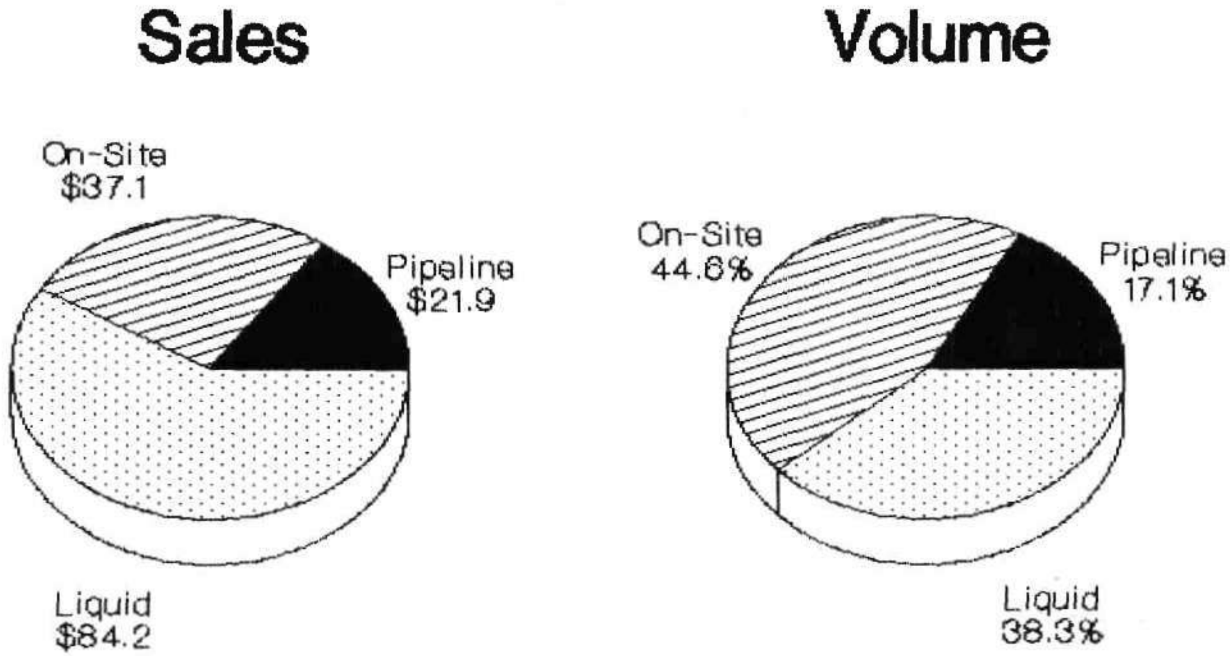
Source: Dataquest

U.S. SEMICONDUCTOR GAS MARKET
(Millions of Dollars)



Source: Dataquest

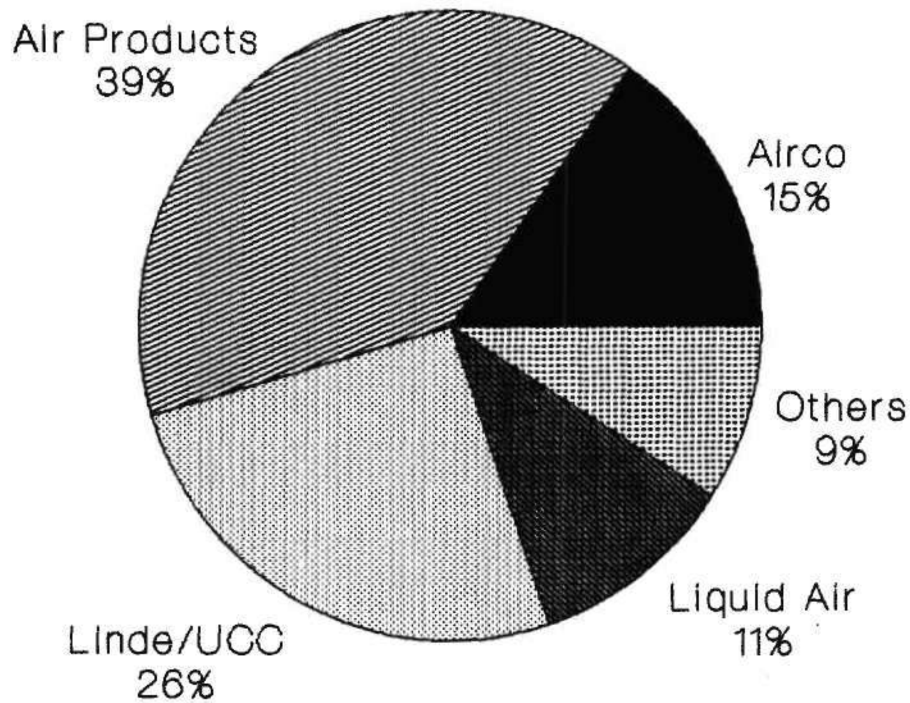
1986 NITROGEN MARKETS
UNITED STATES



$143.1 M **55.4 Bcf**

Source: Dataquest

1986 BULK & SPECIALTY GAS MARKET
United States



$215.5 Million

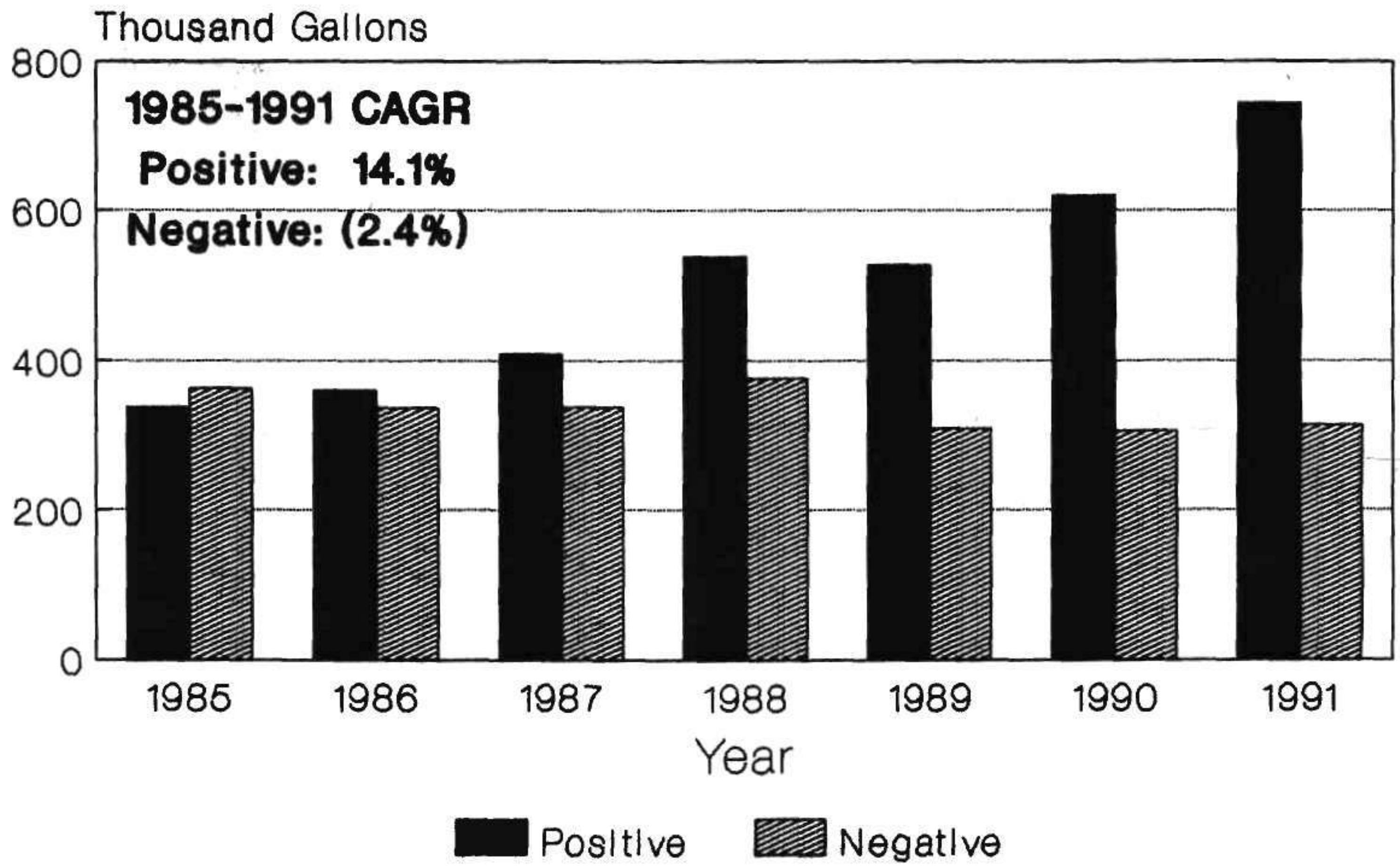
Source: Dataquest

1985 OPTICAL PHOTORESIST MARKET
(Millions of Dollars)

REGION	Positive	Negative
United States	$ 51.0 M	$12.3 M
Japan	36.3	9.6
Europe	13.9	3.4
ROW	4.8	1.7
Total	$106.0 M	$27.0 M

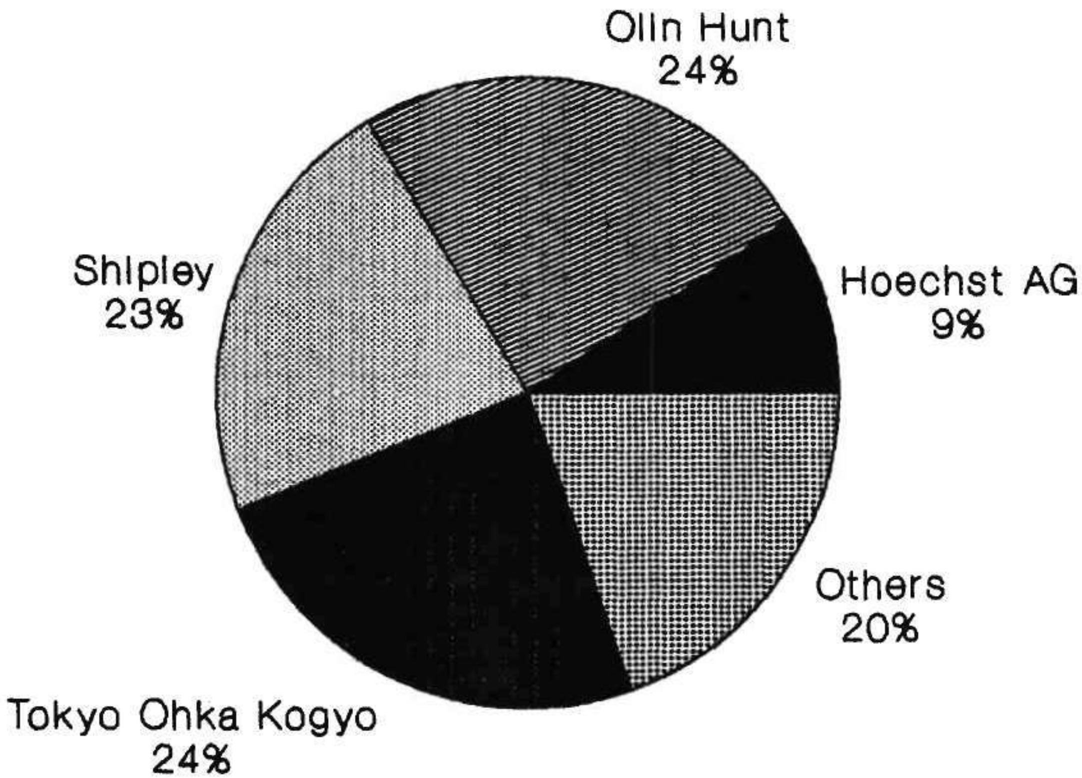
Source: Dataquest

OPTICAL PHOTORESIST CONSUMPTION
Worldwide



Source: Dataquest

1985 WORLD OPTICAL RESIST MARKET
MAJOR PLAYERS



$133.0 Million

Source: Dataquest

Silicon and Epitaxial Wafer Markets

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Silicon and Epitaxial Wafer Markets

Silicon and Epitaxial Wafer Markets

SUMMARY

In 1985, silicon and epitaxial wafer sales to the worldwide semiconductor industry by merchant silicon companies was $1,266.5 million. Silicon wafers accounted for $1,020.9 million (80.6 percent) of this figure, and epitaxial wafer sales accounted for $245.6 million (19.4 percent). These sales represented 1,038 million square inches of silicon wafers and 85 million square inches of epitaxial wafers. The average selling price of silicon wafers ranged from $0.90 to $1.00 per square inch as compared with $2.80 to $2.90 per square inch for epitaxial wafers. Several semiconductor manufacturers have captive production of silicon material, which accounted for an additional 177 million square inches of silicon that year. When merchant wafer sales are added to captive silicon production, total silicon consumption amounted to 1,300 million square inches in 1985.

Table 1 summarizes worldwide silicon and epitaxial wafer sales (and market share) for the top six merchant silicon companies in 1985. The market is strongly dominated by four Japan-based silicon companies, Monsanto of the United States, and Wacker of West Germany.

Table 1

WORLDWIDE MERCHANT SILICON COMPANY MARKET SHARE, 1985
(Millions of Dollars)

Company	Silicon and Epitaxial Wafer Sales	Percent Share
Shin-Etsu Handotai	$ 310.0	24.5%
Wacker	205.0	16.2
Osaka Titanium Company	160.0	12.6
Monsanto	137.0	10.8
Japan Silicon	128.0	10.1
Komatsu Electronic Metals	116.0	9.2
Others	210.5	16.6
Total	$1,266.5	100.0%

Source: Dataquest
February 1987

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Silicon and Epitaxial Wafer Markets

INTRODUCTION

This study is Dataquest's analysis of the worldwide silicon and epitaxial wafer markets. It presents an overview of merchant silicon company products, market focus, and manufacturing activities. Market share for merchant silicon companies is tabulated by region of silicon and epitaxial wafer sales in 1985. The sales of these companies are estimated in U.S. dollars and converted to millions of square inches using an average selling price for each region. Captive silicon production is included in Dataquest's estimate of worldwide silicon consumption. Historical and forecast semiconductor device production revenue and silicon consumption are summarized by region. The study also presents Dataquest's historical and forecast wafer size distribution for the United States. Please note that the regional designation "United States" includes Canadian semiconductor manufacturing activities.

Definitions and Conventions

Silicon Producers

Dataquest defines companies that produce silicon and epitaxial wafers as either merchant silicon companies or captive silicon producers. Merchant silicon companies are suppliers such as Monsanto Electronic Materials Company in the United States, Shin-Etsu Handotai (also known as SEH) in Japan, and Wacker in Western Europe. These three merchant silicon companies, along with about 20 more companies worldwide, produce most of the silicon consumed by the semiconductor industry today. The name Monsanto is used throughout this study to represent Monsanto Electronic Materials Company, unless otherwise noted.

Silicon is also produced to a lesser extent by both merchant and captive semiconductor manufacturers. Dataquest refers to these semiconductor manufacturers collectively as captive silicon producers because they grow single-crystal silicon to produce wafers for their own internal consumption. Captive producers with significant internal silicon production include AT&T, IBM, Motorola, and Texas Instruments in the United States, Philips in Europe, and Hitachi in Japan. Dataquest estimates that the U.S. captive silicon producers meet from 50 to 75 percent of their silicon requirements with captive silicon operations, whereas this amount is approximately 30 percent for Hitachi and Philips.

Semiconductor manufacturers with captive silicon production tend to be established, vertically integrated companies. In the early years of the semiconductor industry, the high cost of silicon provided sufficient economic justification for some semiconductor manufacturers to develop this internal capability. However, high-quality, low-cost silicon wafers have become readily available from a number of merchant silicon companies, and in response to such competitive factors, some semiconductor manufacturers have shut down their silicon operations. Fairchild closed its silicon wafer plant in Healdsburg, California, in June 1985, and later sold its silicon production equipment to Pentagood Training, Ltd., a Hong Kong firm, for $3.5 million. This equipment, in turn, was sold to the People's Republic of China. Delco, another semiconductor manufacturer with internal silicon production, discontinued its captive silicon operations in the spring of 1986. Although Motorola continues to produce single-crystal silicon, the company closed its polysilicon facility in the fall of 1986. Dataquest believes that this 100-metric-ton plant has not as yet been sold.

Merchant or Captive? - Some captive silicon producers, such as Motorola and Fairchild (when it was actively producing silicon), have sold small amounts of material on the merchant silicon market. Dataquest estimates that merchant sales for these companies in 1985 amounted to less than 10 percent of their total captive silicon production, and thus continues to identify these companies as captive rather than merchant silicon producers.

Dataquest identifies Toshiba Ceramics, a subsidiary of Toshiba Corporation, as a merchant silicon company even though a substantial amount of its silicon production is consumed by its semiconductor parent. However, because Toshiba Ceramics is actively marketing its material on the merchant market, Dataquest considers Toshiba Ceramics to be a merchant rather than a captive silicon producer. Toshiba Corporation is considered to be a customer of Toshiba Ceramics.

Silicon Products

Dataquest defines the merchant silicon wafer market in two product segments: silicon wafers and silicon epitaxial wafers. (Silicon wafers grown by both Czochralski and float zone methods are included.) In the silicon and epitaxial wafer markets analysis, Dataquest does not include sales of polysilicon, single-crystal silicon ingots, silicon materials used in solar applications, or compound semiconductor material substrates such as gallium arsenide.

Several different units are used to describe silicon wafers, including million square inches (MSI), million square centimeters, and wafer or slice equivalents. For the purpose of comparison, all silicon and epitaxial wafer quantities in this study will be defined in units of MSI. The conversion factor between square centimeters and square inches is 6.45 square centimeters per square inch. Wafer or slice equivalents can be translated into MSI by multiplying the number of wafers of a given size by the area of that wafer size as measured in square inches. As an example, 150,000 100mm equivalents are equal to 1.83 MSI.

Although polysilicon production is not a topic of this study, several merchant silicon companies produce polysilicon in addition to single-crystal silicon ingots and wafers. Information regarding poly plant locations and capacities for these companies is included in the merchant silicon company profiles.

SILICON AND EPITAXIAL WAFERS

Silicon Wafers

In the early days of the semiconductor industry, silicon was considered to be one of several materials with semiconductor potential. With the development of planar processing in 1960, polysilicon price reductions, and inexpensive plastic packaging for silicon transistors, silicon took the market from germanium as the basic element used to manufacture semiconductor devices. The history of silicon manufacturing in the United States, and the technology of single crystal growth and wafer production can be found in two service sections located behind the Wafer Fabrication Materials tab in this binder. These sections are entitled "Silicon History" and "Silicon Technology."

Epitaxial Wafers

Epitaxial processing produces a layer of single-crystal material that has the same crystallographic orientation as the underlying substrate. It is possible to design the epitaxial layer to meet well-defined chemical, physical, and electrical specifications. The epitaxial layer of material is produced by a chemical vapor phase deposition reaction upon a polished substrate, which also has been manufactured to tightly controlled specifications. The epitaxial layer is typically the electrically active layer of transistors, diodes, and other discrete devices. Epi layers are an important part of bipolar device fabrication, and are used for isolation and buried layers. Epi is also increasingly being utilized in MOS integrated circuits.

CMOS Epi

An area where epitaxy has become important is in CMOS device fabrication. CMOS circuits are especially vulnerable to a condition known as latch-up. In CMOS construction, n-type and p-type wells are in sufficiently close proximity to create parasitic n-p-n-p (silicon-controlled rectifier type) switching structures. Latch-up occurs when such parasitic devices turn on due to a transient condition such as forward biasing produced by a voltage spike. In latch-up, the CMOS device presents a near short-circuit condition across the power supply. The adverse effects of this can range from the interruption of further circuit operation until the condition is removed to physical destruction of the chip. With CMOS design rules approaching the 1 micron regime and gate oxide thicknesses approaching 100 angstroms, latch-up becomes more of a problem. High-resistivity epi layers on low-resistivity substrates is now used as a technique for latch-up hardening (prevention).

Although CMOS epi has been touted as a solution to the problem of latch-up, most semiconductor manufacturers have found the additional cost of an epitaxial wafer (typically 2.5 to 3.0 times the cost of a silicon wafer) prohibitive. To meet the market prices of low-end products, a manufacturer using epi material would have to give up considerable margin and hence profitability. This may be one of the reasons that Texas Instruments reportedly began its 256K DRAM production on epitaxial wafers and later converted to a non-epi process. Although it has been reported that AT&T and IBM have shown new designs in CMOS epi, Japanese semiconductor manufacturers continue to design without epi for their advanced CMOS devices. Dataquest estimates that epitaxial wafer consumption in Japan by application is approximately 60 percent for discrete devices, 35 percent for bipolar ICs, and 5 percent for MOS integrated circuits.

<u>Epitaxial Services--Japanese Style</u>

Semiconductor manufacturers in the United States have three sources of epitaxial silicon wafers: larger merchant silicon companies (such as Monsanto, SEH America, and Wacker), small custom epitaxial houses, or internal epitaxial wafer production. Japan has no equivalent to the United States' small custom epitaxial houses, so Japanese silicon companies have taken on the responsibility for providing custom epitaxial wafer specifications. For example, in the case of buried layers for bipolar IC applications, a Japanese silicon wafer company will obtain the photomask from a customer and perform the lithography, selective diffusion, and deposition of the epitaxial layer. This "fabricated" epitaxial wafer with its buried layer is then returned to the customer. This allows the Japanese semiconductor manufacturer to minimize investment in equipment and processes, and instead devote resources to design and new process development. Dataquest believes that the practice of providing photomasks to silicon manufacturers for buried layer processing is far more prevalent in Japan than in the United States because of the close relationship between vendor and customer in Japan.

Silicon and Epitaxial Wafer Markets

WORLDWIDE MERCHANT SILICON MARKET

Table 2 contains a list of merchant silicon manufacturers that were active in the world market in 1985. This list, organized by region in which the company headquarters are based, summarizes whether a company offers silicon and/or epitaxial wafers. Fifteen of the 23 companies are located in the United States, 3 in Europe, and 5 in Japan. (The acquisition by Japanese manufacturers of U.S. silicon companies NBK, Siltec, and U.S. Semiconductor will be discussed in a later section.) Fourteen manufacturers supply epitaxial wafers, 16 supply silicon wafers, and 7 provide both types of wafers. (Dynamit Nobel began manufacturing epitaxial wafers in late 1986, so is not included in the count of epitaxial wafer suppliers for 1985.) Table 2 also includes five new merchant silicon companies that entered the market in 1986/1987; two are located in Japan, two in Europe, and one in Korea.

Table 2 shows the percentage of silicon substrate material (based on square inches) each company produces internally and the percentage purchased from other silicon vendors. This is an important distinction since several United States-based epitaxial wafer manufacturers purchase some or all of their silicon substrate from other companies. For example, in 1985, Cincinnati-Milacron, an epitaxial silicon wafer company, internally produced 60 percent of its silicon substrate and purchased 40 percent from other merchant silicon companies. This practice must be noted when evaluating total wafer consumption because of the potential problem of double-counting million square inches of silicon based on company sales alone.

Two U.S. captive silicon companies, Fairchild and Motorola, also sold a small amount of their internally produced wafers on the merchant market in 1985. Dataquest estimates that Fairchild's merchant silicon wafer sales were approximately $0.2 million, whereas Motorola's Semiconductor Materials Group sold approximately $2.1 million of silicon and epitaxial wafers. Both companies have sold material on the merchant market in order to ensure that internal production methods continue to produce material of competitive quality and cost. Although these companies are not listed in Table 2, their sales have been included as part of the total United States-based silicon manufacturers' sales during 1985 that are presented in the next section. (Note: As mentioned previously, Fairchild closed its silicon operations in June 1985.)

Table 2

WORLDWIDE MERCHANT SILICON COMPANIES

	Substrate Grown	Substrate Purchased	Silicon Wafers	Epitaxial Wafers
U.S. Companies				
Cincinnati Milacron	60%	40%		X
Crysteco, Inc.	100%	0	X	
Epitaxy, Inc.	0	100%		X
General Instruments Power Semiconductor Div.	0	100%		X
Gensil	100%	0	X	
M/A-Com	50%	50%		X
Monsanto Electronic Materials Company	100%	0	X	X
NBK Corporation	100%	0	X	
Pensilco	100%	0	X	
Recticon	100%	0	X	
Silicon Services	0	100%		X
Siltec	100%	0	X	
Spire Corporation	0	100%		X
U.S. Semiconductor	0	100%		X
Virginia Semiconductor	100%	0	X	
Japanese Companies				
Japan Silicon	100%	0	X	X
Komatsu Electronic Metals	100%	0	X	X
Osaka Titanium Company	100%	0	X	X
Shin-Etsu Handotai	100%	0	X	X
Toshiba Ceramics	100%	0	X	X
European Companies				
Dynamit Nobel Silicon	100%	0	X	(X-1986)
Topsil Semiconductor Materials A/S	100%	0	X	
Wacker	100%	0	X	X
New Entrants--1986				
Lucky Advanced Materials (Korea)	100%	0	X	
Nittetsu Denshi (Japan)	100%	0	X	
Okmetic (Finland)	100%		(X-1987)	
Rhone-Siltec (France)	100%	0	X	
Showa Denko (Japan)	100%	0	X	

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

Tables 3, 4, and 5 present the combined and separate sales of silicon and epitaxial wafers by regionally based merchant companies to given regions of the world. For example, in these tables, Shin-Etsu Handotai's worldwide sales, which include the sales of Shin-Etsu's U.S. subsidiary, SEH America, are included under the heading "Japan-Based Companies." Similarly, the worldwide sales of Europe-based Wacker Chemitronic include the sales of its U.S. affiliate, Wacker Siltronic. The activities of each of the regionally based merchant silicon companies are discussed in the sections to follow. Market share analysis for silicon and epitaxial wafer sales in each of the four regions of the world are presented in a later section.

Table 3

WORLDWIDE MERCHANT SILICON AND EPITAXIAL WAFER MARKET, 1985
(Millions of Dollars)

Region of Sales	United States-Based Company Sales	Japan-Based Company Sales	Europe-Based Company Sales	Total
United States	$216.3	$ 84.9	$ 86.7	$ 387.9
Japan	7.9	632.1	8.6	648.6
Europe	18.8	10.4	130.0	159.2
Rest of World	12.7	26.6	31.5	70.8
Total	$255.7	$754.0	$256.8	$1,266.5
Percent	20.2%	59.5%	20.3%	100.0%

Source: Dataquest
February 1987

Table 4

WORLDWIDE MERCHANT SILICON WAFER MARKET, 1985
(Millions of Dollars)

Region of Sales	United States-Based Company Sales	Japan-Based Company Sales	Europe-Based Company Sales	Total
United States	$150.5	$ 74.6	$ 79.4	$ 304.5
Japan	7.7	502.6	8.1	518.4
Europe	13.2	8.1	116.0	137.3
Rest of World	7.7	22.7	30.3	60.7
Total	$179.1	$608.0	$233.8	$1,020.9
Percent	17.5%	59.6%	22.9%	100.0%

Source: Dataquest
February 1987

Table 5

WORLDWIDE MERCHANT EPITAXIAL WAFER MARKET, 1985
(Millions of Dollars)

Region of Sales	United States-Based Company Sales	Japan-Based Company Sales	Europe-Based Company Sales	Total
United States	$65.8	$ 10.3	$ 7.3	$ 83.4
Japan	0.2	129.5	0.5	130.2
Europe	5.6	2.3	14.0	21.9
Rest of World	5.0	3.9	1.2	10.1
Total	$76.6	$146.0	$23.0	$245.6
Percent	31.2%	59.4%	9.4%	100.0%

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

MERCHANT SILICON COMPANY ACTIVITIES

United States Silicon Companies

Fifteen United States-based merchant silicon companies (and two captive silicon producers) supplied the semiconductor industry with wafers in 1985. These manufacturers accounted for $255.7 million in silicon and epitaxial wafer sales, or 20.2 percent of the world's $1,266.5 million silicon and epitaxial wafer market in 1985. Three of the fifteen merchants account for almost 80 percent of the United States-based silicon and epitaxial wafer manufacturers' sales; these are Monsanto, Cincinnati Milacron, and Siltec. The remaining 12 companies are of two categories: small silicon wafer manufacturers and small custom epitaxial houses. (Note: Monsanto is the only United States-based silicon manufacturer to supply both silicon and epitaxial wafers to the semiconductor industry.) In particular, these smaller silicon and epitaxial houses are pursuing niche markets by providing relatively small quantities of material that meet customers' specific requirements. The smaller companies, for the most part, have chosen not to compete with the larger silicon companies for commodity wafer sales.

Cincinnati Milacron

Cincinnati Milacron is the largest epitaxial wafer supplier in the United States, with epi wafer sales of approximately $42 million in 1985. Cincinnati Milacron's manufacturing facility is in Maineville, Ohio. Dataquest estimates that approximately 70 percent of the company's epi business is for discrete semiconductor devices, with the remaining 30 percent directed at CMOS applications. Cincinnati Milacron builds its own epitaxial reactors, which are not for sale on the commercial epitaxial reactor market. In 1985, the Maineville manufacturing facility was expanded. It now has production capacity to generate $125 million in epitaxial wafer sales per year. The company is also a major manufacturer of processing systems for the metalworking and plastics industries. It also builds robots and metrology and inspection systems for industrial automation applications. In 1985, total sales for the company and its subsidiaries were $732.2 million.

Crysteco, Inc.

Crysteco, Inc., of Wilmington, Ohio, supplies silicon wafers to the semiconductor industry. The company grows 100 percent of its substrate material. All material grown is Czochralski silicon, though Dataquest believes that Crysteco provides some slice and polish services for float zone ingots. Dataquest's estimate for Crysteco's wafer sales in 1985 is $9 million, which places Crysteco as the third-largest United States-based supplier of silicon wafers (after Monsanto and Siltec).

Epitaxy, Inc.

Epitaxy, Inc., is an epitaxial wafer company in Santa Clara, California; the company was established in 1972. Dataquest estimates that Epitaxy, Inc., had epitaxial wafer sales of about $6 million in 1985, of which 55 percent was outside of the United States. Epitaxy, Inc., does not grow any substrate material, but rather purchases it from other merchant silicon manufacturers. Like the other small custom epi houses, it is pursuing niche market applications and has opted not to compete in the CMOS epi wafer market.

General Instruments--Power Semiconductor Division

The Power Semiconductor Division of General Instruments (Westbury, New York) manufactures epitaxial wafers. Most of its epi wafers are used in-house, but a small number are sold on the merchant market. Dataquest estimates that the Power Semiconductor Division sold approximately $2.5 million worth of epitaxial wafers in 1985. Major applications for its epitaxial wafers include microwave and radio frequency (RF) discrete devices.

Gensil

Gensil is a small silicon wafer company located in Garland, Texas. It manufactures silicon wafers to custom specifications for discrete device applications (such as zener diodes, which require tight resistivity profiles), and provides silicon substrate suitable for epitaxial deposition. Wafers are available from 1 inch to 100mm diameter. Gensil is owned by General Semiconductor Industries, a Tempe, Arizona, semiconductor device company that manufactures discrete devices such as diodes, and switching and power transistors. Dataquest estimates that Gensil's 1985 worldwide silicon wafer sales were $2.5 million. Approximately 50 percent of Gensil's wafers are sold to its parent company.

M/A-COM

M/A-Com Semiconductor Products (Burlington, Massachusetts) produces epitaxial silicon wafers for the semiconductor industry. It offers epi wafers up to 125mm diameter. These wafers are used in a wide range of device products including MOS (including DRAMs and MOSFETs), linear and digital ICs, RF power transistors, Schottky rectifiers, microwave diodes, transistors, and photovoltaic devices.

In 1985, M/A-COM produced 50 percent of its silicon substrate wafer material, and purchased 50 percent from other companies. In 1986, however, M/A-COM decided to curtail its single crystal growth operations and purchase all of its silicon substrate. Dataquest estimates that M/A-COM's 1985 worldwide epitaxial wafer sales were $6.0 million.

Monsanto Electronic Materials Company

Monsanto Electronic Materials Company (headquartered in Palo Alto, California) is the largest United States-based silicon company, with silicon and epitaxial wafer sales of $137 million in 1985, or 10.8 percent of the $1,266.5 million world market. Monsanto Electronic Materials Company is one of the operating groups of the Monsanto Company, a St. Louis-based chemical giant with sales of $6.75 billion in 1985. (Please note that the name Monsanto is used throughout this study to represent Monsanto Electronic Materials Company, unless otherwise noted.) Table 6 summarizes Monsanto's silicon facilities and plant activities. In Table 6, polysilicon refers to the location of a polysilicon plant; single-crystal ingot refers to the growth of silicon ingots at a given location; and wafers refers to the slicing, lapping, and polishing activities associated with wafer preparation.

Monsanto's polysilicon and single crystal operations are United States-based. Polysilicon capacity (as of January 1987) is approximately 210 metric tons at the Saint Peters plant. Both the Saint Peters plant and the newer Spartanburg facility grow single-crystal silicon ingots and produce wafers; epitaxial wafer production is done in Spartanburg. Wafer capacity at Monsanto's U.S. facilities is approximately 325 MSI. Monsanto's overseas facilities obtain single-crystal silicon from the U.S. plants to produce wafers for their respective local markets.

Three new offshore wafer facilities, in Korea, Japan, and the United Kingdom, became operational in 1986. Each new plant has a 20 MSI wafer capacity, which can be expanded for future requirements. This offshore wafer manufacturing is part of Monsanto's strategy to better penetrate overseas markets.

Table 6

MONSANTO ELECTRONIC MATERIALS COMPANY SILICON PLANT LOCATIONS

Location	Country	Polysilicon	Single-Crystal Ingots	Wafers	Technical Center
Saint Peters, Missouri	United States	X	X	X	X
Spartanburg, South Carolina	United States		X	X	
Kuala Lumpur	Malaysia			X	
Gumi	South Korea			X	
Utsonomiya, Tochigi	Japan			X	X
Milton Keynes	United Kingdom			X	X

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

Korean Activities - In Korea, Monsanto's manufacturing facility for silicon wafers is at Gumi, adjacent to the country's developing semiconductor industry. The silicon facility, a 50-50 joint venture between Monsanto and Dongbu Industrial Company, is named Korsil Co., Ltd. Other Monsanto activities in Korea include an agreement with Samsung to increase silicon wafer sales to Samsung in the latter half of 1986. Monsanto has been working with Samsung engineers to customize wafer specifications to Samsung's processing requirements.

Japanese Activities - Monsanto and Hitachi announced an agreement in July 1986 for a cooperative program in which Monsanto would begin to supply wafers to Hitachi. Both companies would work together to customize the wafers to Hitachi's specific requirements. This agreement represents the first volume sales of Monsanto wafers to Hitachi; prior to April 1986, the company had supplied only test wafers. Dataquest believes that this is a significant move toward opening up the Japanese silicon market to foreign companies. Dataquest estimates that foreign silicon company wafer market share was approximately 2.5 percent of 1985's $648.6 million merchant silicon sales in Japan. However, with the political pressures of trade imbalance between the United States and Japan, U.S. government officials have urged Japan to buy more wafers from the United States. Dataquest expects that the Japanese government will respond favorably, and foreign-based silicon company market share in Japan will increase, albeit slowly, over the next few years.

NBK Corporation

NBK Corporation (Santa Clara, California) is a small silicon wafer manufacturer located in the Silicon Valley. Although NBK does not produce epitaxial wafers directly, the company supplies a small amount to customers through subcontractors. NBK was purchased by Kawasaki Steel for $9.36 million in the third quarter of 1985. The acquisition is part of the Japanese steelmaker's strategy for diversification into electronic materials. Kawasaki Steel invested $8.3 million in NBK in 1986 to upgrade to 150mm capability and improve silicon wafer quality control with a class 10 clean room environment; as a result, an incremental amount of capacity was added, on the order of 10 to 15 percent. Dataquest estimates that NBK's wafer sales in 1985 were $7 million, of which more than 95 percent were in the United States.

In 1986, Kawasaki Steel sent samples of NBK's wafers to Japanese semiconductor manufacturers. Dataquest expects that with Kawasaki Steel's backing, NBK's wafer sales to Japan will increase as a percent of total sales.

Pensilco

Pensilco is a small silicon wafer manufacturer in Bradford, Pennsylvania. It specializes in small-diameter wafers, which range from 1 inch to 100mm in diameter. It provides customized silicon wafers, especially for zener diode fabrication. The company started its silicon operations in 1958 under the name of Allegheny Electronics; the Pensilco name was adopted in 1976. Dataquest estimates that Pensilco's worldwide silicon wafer sales were $3.3 million in 1985.

Recticon

Recticon is a small merchant silicon company in Pottstown, Pennsylvania. Dataquest estimates that Recticon's 1985 worldwide silicon wafer sales were $5.0 million. Rockwell International sold Recticon to Walker International in the first quarter of 1986. (Walker plans to use the acquisition to move out of its traditional business, photo processing.) Recticon has established a niche business supplying very thin and smaller-size wafers, but currently can produce from 1-inch to 125mm diameter wafers. In addition, Recticon specializes in growing single-crystal silicon with unusual crystal orientations. At the Semicon Southwest show in Dallas (October 1986), Recticon displayed a single-crystal ingot of 2-1-1 orientation. Recticon has attracted interest from semiconductor R&D groups that want to use silicon wafers with this orientation as a substrate for gallium arsenide-on-silicon processing.

Silicon Services

Silicon Services (Santa Clara, California) is a small, epitaxial wafer supplier in the Silicon Valley. Its primary product is epitaxial wafers for power transistors; other application markets include epitaxial wafers for bipolar processing and a small amount of CMOS. Silicon Services does not grow its substrate material. Instead, it purchases from other merchant silicon companies or obtains the material directly from its customers (as in the case of bipolar applications where the customer has already prepared a buried layer, followed by ion implantation). Silicon Services supplies epitaxial wafers between 2 inches and 125mm. Dataquest estimates that Silicon Services' epitaxial wafer sales were $1.0 million in 1985.

Siltec

Siltec Silicon is a merchant silicon wafer company with manufacturing facilities in Salem, Oregon. Dataquest estimates that its 1985 worldwide silicon wafer sales were $24.8 million. In mid-1985, Siltec's silicon production facilities were relocated and consolidated in Salem from operations in Menlo Park and Mountain View, California. Siltec Silicon is one of two business units that make up Siltec Corporation,

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headquartered in Menlo Park, California. (Siltec Corporation's second business unit is Cybeq Systems, which manufactures production, transport, and test equipment used in silicon production operations.) Siltec has polished wafer capacity of 70 MSI per year. The company was founded in 1969 by Robert Lorenzini, a recognized pioneer in the field of crystal growing.

Overseas Activities - Over the past several years, Siltec expanded its activities overseas through joint venture and technology licensing strategies. In 1984, Siltec entered into an agreement with Rhone-Poulenc of France to manufacture silicon wafers in France for distribution to semiconductor manufacturers in Western Europe. The joint venture, Rhone-Siltec, began pilot production in September 1985 at a facility near Mantes-la-Jolie (100 kilometers west of Paris.) Rhone-Siltec has single crystal growth and polished wafer operations; current wafer capacity is approximately 20 MSI.

In October 1985, Siltec announced the licensing of its silicon technology to Lucky Advanced Materials of Korea, an affiliate of the Lucky-Goldstar group. Lucky Advanced Materials agreed to pay Siltec $4 million plus royalties for the technology. The Lucky Advanced Materials silicon facility is in Gumi and started production in February 1987. Wafer capacity at this facility is on the order of 20 MSI. The Lucky Advanced Materials plant is the only facility in Korea that has single crystal silicon growth and wafer production operations.

Siltec announced plans in mid-1985 to form a joint venture with Toyo Soda Manufacturing Co. of Japan to market silicon wafers in that region. However, plans were canceled at the end of 1985 in response to the deepening recession in the industry and weak demand for wafers in Japan.

Acquisition - In September 1986, Siltec agreed to an acquisition by Mitsubishi Metal Corporation of Japan for approximately $33 million. The acquisition includes both Siltec Silicon and Cybeq Systems. Mitsubishi Metal Corporation is a multibillion dollar, multinational corporation headquartered in Tokyo. (Mitsubishi Metal and Mitsubishi Electric Corporation, the semiconductor manufacturer, are both members of the same industrial group, the Mitsubishi Group.) Mitsubishi Metal's wholly owned subsidiary, Japan Silicon (also known as Nippon Silicon or JASIL), is a major silicon manufacturer in Japan. The Siltec acquisition is being financed 60 percent by Mitsubishi Metal, 30 percent by Mitsubishi Mining and Cement, and 10 percent by Mitsubishi Corporation. Mitsubishi Metal is also a major supplier of gallium arsenide wafers to the semiconductor industry.

Spire Corporation

Spire Corporation is a small epitaxial silicon company in Bedford, Massachusetts. Dataquest estimates that Spire Corporation had epitaxial wafer sales of $0.6 million in 1985. Spire provides 2-inch, 3-inch, and 100mm epi wafers and focuses on meeting custom epitaxial specifications for microwave devices and discretes. The company has chosen not to pursue the MOS epitaxial wafer market. Spire is currently designing its own silicon epitaxial reactor, based on experience and technology developed in the production of its gallium arsenide epitaxial reactor. Spire's silicon epitaxial reactor will handle 200mm wafers and is expected to be available by March 1987. (Spire also supplies gallium arsenide epitaxial wafers to the semiconductor industry.)

U.S Semiconductor

U.S. Semiconductor (Fremont, California) manufactures epitaxial wafers in the Silicon Valley. U.S. Semiconductor started its production with 125mm epitaxial wafers in April 1984 and currently supplies the semiconductor industry with 3-inch to 125mm epitaxial wafers. The company, founded in 1984, was privately held until its recently announced acquisition by Japanese silicon manufacturer Osaka Titanium Co., Ltd. (OTC). The acquisition took place in December 1986 for an undisclosed sum. Dataquest estimates that U.S. Semiconductor had epitaxial wafer sales of $5.2 million in 1985.

Virginia Semiconductor

Virginia Semiconductor, a small silicon wafer manufacturer in Fredericksburg, Virginia, specializes in small-diameter wafers (from 1 to 3 inches) and offers very thin wafers of three-mil (0.003 inch) thickness. Founded in 1978, Virginia Semiconductor started production of float zone and Czochralski single-crystal ingots in June 1979. Dataquest estimates that Virginia Semiconductor's 1985 silicon wafer sales were $1.5 million.

Japanese Silicon Companies

Five Japan-based merchant silicon companies supplied the semiconductor industry with wafers in 1985. These five manufacturers accounted for $754.0 million in silicon and epitaxial wafers sales. This amounted to 59.5 percent of the world's $1266.5 million silicon and epitaxial wafer market that year. Dataquest estimates that Shin-Etsu Handotai's worldwide silicon and epitaxial sales were $310 million, or approximately 41 percent of the Japan-based silicon company sales. Japanese merchant silicon companies differ from the majority of their Europe- and United States-based competitors in that all five silicon companies provide the semiconductor industry with both epitaxial and silicon wafers.

Japan Silicon

Japan Silicon is a major Japanese silicon and epitaxial wafer manufacturer. Dataquest estimates that Japan Silicon ranks as the world's fifth largest silicon company with worldwide sales of $128 million (10.1 percent of the world market) in 1985. Japan Silicon is a subsidiary of Mitsubishi Metal Corporation, the Japanese company that recently acquired the United States-based firm, Siltec Corporation.

Japan Silicon is known by several names in the industry: Nippon Silicon, Nihon Silicon, and JASIL. The history of Japan Silicon is thus: Japan Electronic, then part of Mitsubishi Metal, merged with Chisso Denshi to form a silicon operation called Toyo Silicon (Toyo means Asia in Japanese). Seven or eight years ago, Toyo Silicon's name was changed to Japan Silicon, which is often shortened to JASIL. Japan Silicon has been active in the sales and promotion of its products in the United States for the last 18 months to two years.

Table 7 gives the location of Japan Silicon's manufacturing facilities and plant activities. Both the Ikuno and Noda facilities have single crystal silicon operations and wafer production. The Noda Plant produces 3-inch to 200mm wafers, whereas the Ikuno Plant produces 125mm and 150mm wafers. Yamagata Silicon obtains ingots of single-crystal silicon from its sister plants and produces 100mm to 150mm diameter wafers. Epitaxial wafer activity takes place at the Noda Plant. Japan Silicon wafer capacity for polished wafers (3 inches to 200mm) is 20 MSI per month, diffused wafer capacity (3 inches to 125mm) is 900,000 square inches per month, and epitaxial wafer capacity (3 inches to 150mm) is 2 MSI per month.

Table 7

JAPAN SILICON PLANT LOCATIONS

Location	Polysilicon	Single-Crystal Ingots	Wafers
Ikuno Plant			
Asaki District, Hyogo Prefecture		X	X
Noda Plant			
Noda City, Chiba Prefecture		X	X
Yamagata Silicon			
Yonezawa City, Yamagata Prefecture			X

Source: Dataquest
February 1987

Japan Silicon obtains most of its polysilicon materials from Hi-Silicon Co., Ltd., located in Yokkaichi City, Mie Prefecture. Hi-Silicon was formed in 1967 as a joint venture between Mitsubishi Metal and Osaka Titanium Company. Through this joint venture, Japan Silicon and OTC are entitled to equal amounts of polysilicon capacity at the Hi-Silicon facility, which has a total capacity of 1,080 metric tons. Mitsubishi Metal Corporation (Japan Silicon's parent) also has a 12.25 percent equity position in Dow Corning's polysilicon subsidiary, Hemlock Semiconductor.

Komatsu Electronic Metals Co., Ltd.

Komatsu Electronic Metals, ranking sixth overall in worldwide sales, is a major supplier of silicon and epitaxial wafers to the Japanese market. Its 1985 sales were $116 million (9.2 percent worldwide market share). Komatsu Electronic Metals was incorporated in 1960 as an affiliate of Komatsu, Ltd.

Table 8 contains the locations and plant activities of Komatsu's silicon facilities. The Hiratsuka facility produces polysilicon, single-crystal silicon, and some wafers. The Kyushu Komatsu plant in Miyazaki produces most of the company's polished wafers. Komatsu's Nagasaki Plant was opened in 1985 and produces epitaxial wafers. Expansion to produce single-crystal silicon at Nagasaki is to be completed in the spring of 1987. Komatsu supplies both Czochralski and float zone material to the semiconductor industry. It ranks as one of the three major float zone suppliers in the world (Shin-Etsu Handotai and Wacker are the others).

Komatsu both produces polysilicon for its own needs and purchases it from the merchant market to supplement its supply. Its polysilicon capacity is approximately 100 metric tons as of January 1987. Komatsu manufactures polysilicon by a proprietary method that employes monosilane gas. This method, known as the Komatsu method, uses crude silica as a source of silane gas that is refined to high purity, then decomposed into very high-purity polycrystalline silicon material. Union Carbide Corporation is the only polysilicon producer in the world that has licensed the Komatsu method. In addition to its internal usage of silane in polysilicon production, Komatsu Electronic Metals is also a major supplier of high-purity silane to the semiconductor industry for processing applications such as epitaxy and chemical vapor deposition.

Table 8

KOMATSU ELECTRONIC METALS SILICON PLANT LOCATIONS

Location	Polysilicon	Single-Crystal Ingots	Wafers
Head Office and Plant			
Hiratsuka City, Kanagawa Prefecture	X	X	X
Nagasaki Plant			
Omura City, Nagasaki Prefecture			X
Kyushu Komatsu Electric Co., Ltd.			
Kiyotake City, Miyazaki Prefecture			X

Source: Dataquest
February 1987

Osaka Titanium Company

Osaka Titanium Company (OTC) is the Japanese semiconductor industry's second largest silicon supplier and ranks third in the world with sales of $160 million (12.6 percent of the world market) in 1985. OTC is part of the Osaka Titanium Group along with Hi-Silicon Co. and Kyushu Electronic Metals Co. OTC started research on silicon for semiconductor applications in 1957 and built its first polysilicon facility in 1960. Hi-Silicon was established in 1967 as a joint venture between Mitsubishi Metal and Osaka Titanium Company in which both companies share equally the polysilicon capacity of the Hi-Silicon plant. (Hi-Silicon currently has poly capacity of 1,080 metric tons per year.) In 1984, OTC completed a new poly facility in Amagasaki with a current capacity of 720 metric tons per year. Between these two facilities, OTC's effective polysilicon capacity is 1,260 (540 + 720) metric tons per year.

Kyushu Electronic Metals was established in 1973 with OTC and Sumitomo Metal Industries as the major stockholders. All of OTC's wafers are produced at the Kyushu Electronic Metals facilities in the Saga Prefecture. Kyushu Electronic Metal's first wafer facility was built in 1975; its newest silicon plant, in Imari City, was completed in 1984. The Imari Plant is manufacturing 125mm, 150mm, and 200mm wafers.

OTC produces both silicon (Czochralski and float zone) and epitaxial wafers. Its epitaxial wafer capacity is on the order of 22 MSI per year; its total wafer capacity is about 250 MSI per year. Table 9 shows the plant locations and activities of silicon facilities within the Osaka Titanium Group.

Table 9

OSAKA TITANIUM GROUP SILICON PLANT LOCATIONS

Location	Polysilicon	Single-Crystal Ingots	Wafers
Osaka Titanium Company			
Head Office and Plant	X	X	
Amagasaki, Hyogo Prefecture			
Kyushu Electronic Metal Co., Ltd.			
Head Office and Plant		X	X
Kishima District, Saga Prefecture			
Imari Plant			
Imari City, Saga Prefecture			X
Hi-Silicon Co., Ltd.			
Head Office and Plant	X		
Yokkaichi City, Mie Prefecture			

Source: Dataquest
February 1987

Shin-Etsu Handotai

Shin-Etsu Handotai (also known as SEH) is the largest silicon and epitaxial wafer company in the world with 1985 sales of $310 million, or 24.5 percent of the $1,266.5 million market. SEH is also the largest merchant silicon company in Japan with 1985 silicon and epitaxial wafer sales of $226.6 million, or 34.9 percent of the $648.6 million market. Shin-Etsu Handotai was formed as a joint venture between Shin-Etsu Chemical and Dow Corning in 1967. In 1979, Shin-Etsu Chemical acquired full ownership of Shin-Etsu Handotai. Shin-Etsu Handotai's subsidiaries and affiliates include SEH America, SEH Europe, and SEH Malaysia.

Like several of the major silicon merchant companies, Shin-Etsu Handotai's silicon manufacturing is vertically integrated, from polysilicon to polished wafers. Polysilicon facilities are at the Naoetsu factory (part of Shin-Etsu Chemical) and the Isobe factory. Polysilicon capacity is currently about 150 metric tons per year. Shin-Etsu Handotai has a 24.5 percent equity position in Hemlock Semiconductor, the Dow Corning polysilicon subsidiary, and obtains additional polysilicon from other vendors to supplement its needs.

Shin-Etsu Handotai is a major manufacturer of both Czochralski and float zone material. Float zone ingots are grown at the Isobe and Saigata facilities; Czochralski ingots, at Isobe, Shirakawa, and Takefu, as well as Vancouver, Washington, and Livingston, Scotland. Shin-Etsu Handotai produces epitaxial wafers at the Isobe and Shirakawa factories in Japan, and overseas at Vancouver and Livingston. Shin-Etsu Handotai's world headquarters are in Tokyo, and its R&D centers are at Isobe and Vancouver. In addition to silicon products, Shin-Etsu Handotai manufactures gallium arsenide and gallium phosphide through a joint venture with Furukawa Mining known as Iwaki Handotai. Table 10 summarizes Shin-Etsu Handotai's silicon plant locations and activities.

Table 10

SHIN-ETSU HANDOTAI SILICON PLANT LOCATIONS

Location	Polysilicon	Single-Crystal Ingots	Wafers
Isobe Plant			
Annaka City, Gunma Prefecture	X	X	X
Nagano Plant			X
Naoetsu Plant			
Jyoetsu City, Niigata Prefecture	X		X
Saigata Plant			
Kubiki Town, Niigata Prefecture		X	
Shirakawa Plant			
Nishishirakawa, Fukushima Prefecture		X	X
Takefu Plant			
Takefu District, Fukui Prefecture		X	
Kuala Lumpur, Malaysia			X
Vancouver, Washington, United States		X	X
Livingston, Scotland, United Kingdom		X	X

Source: Dataquest
February 1987

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Toshiba Ceramics

Toshiba Ceramics supplies both silicon and epitaxial wafers to the semiconductor industry. Dataquest estimates that Toshiba Ceramics had worldwide wafer sales of $40 million in 1985, of which 98 percent were to Japanese semiconductor manufacturers. Toshiba Ceramics makes major sales of silicon and epitaxial wafers to its parent company, Toshiba Corporation, the semiconductor manufacturer. However, Dataquest still considers Toshiba Ceramics to be a merchant silicon manufacturer because the company has active marketing and sales of wafers to the merchant market in addition to supplying its semiconductor parent.

Toshiba Ceramics has a silicon manufacturing facility (Oguni Plant) in the Nishiokitama District, Yamagata Prefecture. Activities at this facility include the growth of Czochralski single-crystal silicon ingots and wafer production. Toshiba Ceramics has a joint venture with the polysilicon manufacturer, Tokuyama Soda, known as Tokuyama Ceramics (Tokuyama, Yamaguchi Prefecture). This facility produces all of Toshiba Ceramics' epitaxial wafers. In addition to silicon and epitaxial wafers, Toshiba Ceramics manufactures a diverse product mix for the semiconductor industry including ceramic materials and quartz, graphite, and silicon carbide products. Table 11 shows Toshiba Ceramics' silicon plant locations and activities.

Table 11

TOSHIBA CERAMICS SILICON PLANT LOCATIONS

Location	Polysilicon	Single-Crystal Ingots	Wafers
Oguni Plant Nishiokitama District, Yamagata Prefecture		X	X
Tokuyama Ceramics Tokuyama, Yamaguchi Prefecture			X

Source: Dataquest
February 1987

European Silicon Companies

Three Europe-based merchant silicon companies supplied the semiconductor industry with wafers in 1985. During that year, these manufacturers accounted for $256.8 million in silicon and epitaxial wafer sales, or 20.3 percent of the world's $1,266.5 million market for those products. (This is very close to 1985 United States-based silicon company sales of $255.7 million.) Dataquest estimates that Wacker had worldwide silicon and epitaxial sales of $205 million, or approximately 80 percent of the Europe-based silicon company sales. Of the three Europe-based silicon companies, only Wacker supplied both silicon and epitaxial wafers. (Dynamit Nobel began epitaxial wafer production in the latter half of 1986 at its Novara facility.)

Dynamit Nobel Silicon

Dynamit Nobel Silicon (also known as DNS) is a subsidiary of Dynamit Nobel AG, one of West Germany's largest chemical and plastics producers. Dynamit Nobel AG was established by the Swedish engineer Alfred Nobel, the inventor of dynamite and founder of the Nobel Foundation.

Prior to DNS becoming a wholly owned subsidiary of Dynamit Nobel AG in October 1980, it had been known as Smiel and was owned by Montedison. Today the company is completely dedicated to the merchant manufacture of silicon for the semiconductor industry. Corporate headquarters are in Novara, Italy. Table 12 presents a summary of DNS plant locations and activities.

Table 12

DYNAMIT NOBEL SILICON PLANT LOCATIONS

Location	Country	Polysilicon	Single-Crystal Ingots	Wafers	Technical Center
Merano	Italy	X	X		
Novara	Italy			X	
Research Triangle Park, North Carolina	United States			X	
Sunnyvale, California	United States				X

Source: Dataquest
February 1987

Dynamit Nobel Silicon reported that polysilicon capacity at Merano, Italy, was expanded from 450 to 700 metric tons per year at the end of 1985. Dataquest believes that current polysilicon capacity is still on the order of 700 metric tons per year. Both Czochralski and float zone ingots are grown at the Merano facility. Dynamit Nobel Silicon's European silicon wafer operations are at Novara, Italy, where epitaxial wafer production started in the latter half of 1986.

DNS' North Carolina facility was originally a joint venture between Dynamit Nobel Silicon and W.R. Grace. The two companies formed Dynamit Nobel Grace Silicon in late 1984 to produce silicon wafers, polysilicon and single-crystal ingots at a new facility in North Carolina. They initially invested $35 million in the Research Triangle Park plant, which was opened in May 1985; this facility began wafer production in January 1986. In March 1986, Dynamit Nobel Silicon bought out the one-third interest held by Grace for approximately $10.8 million. The North Carolina facility currently produces Czochralski polished wafers.

In addition to supplying both float zone and Czochralski silicon wafers to the semiconductor industry, DNS sells some single-crystal ingots and polysilicon. Dataquest believes that Dynamit Nobel Silicon's sales of poly are split almost equally between Japan and the United States. Dataquest estimates that the company's 1985 worldwide wafer sales were $43 million.

Topsil Semiconductor Materials A/S

Topsil is a merchant silicon manufacturer in Frederikssund, Denmark. Topsil produces its own polysilicon, grows float zone single-crystal ingots, and manufactures wafers. The company pioneered the neutron transmutation doping (NTD) technique in 1974. This technique transforms silicon atoms into phosphorous by exposing a wafer to a flux of thermal neutrons. Although the technique can form only phosphorous-doped materials, its advantage is that it can provide an extremely uniform distribution of phosphorous, thus producing wafers with well-defined resistivity profiles.

Wacker

Wacker is the world's second largest supplier of silicon and epitaxial wafers to the semiconductor industry with 1985 sales of $205 million, or 16.2 percent of the world market share. Wacker is the name used in this study to refer to the collective silicon operations of Wacker-Chemie GmbH of West Germany, which is owned equally by Hoechst AG and Dr. Alexander Wacker Familien Gesselschaft mbH. Wacker-Chemie first started its research into high-purity silicon materials in 1953 and established Wacker-Chemitronic at Burghausen, West Germany, in 1968.

Wacker Siltronic, established in 1978, is a U.S. subsidiary of Wacker-Chemie and an affiliate of Wacker-Chemitronic. Wacker's silicon plant locations and activities are shown in Table 13.

Table 13

WACKER SILICON PLANT LOCATIONS

Location	Polysilicon	Single-Crystal Ingots	Wafers
Wacker Chemitronic Burghausen, West Germany	X	X	X
Wacker Siltronic Portland, Oregon		X	X

Source: Dataquest
February 1987

Wacker's Burghausen facility has a polysilicon capacity of approximately 3,200 metric tons per year. In addition, extensive single crystal growth operations, both Czochralski and float zone, and wafer production, silicon and epitaxial, occur at Burghausen. Wacker is a recognized leader in the field of float zone silicon material. In addition to producing semiconductor substrate materials (silicon and gallium arsenide), Wacker-Chemitronic established a subsidiary, Heliotronic GmbH, in 1977, to research and manufacture solar-grade silicon.

Wacker Siltronic produces silicon crystal ingots and wafers at its Portland facility. Plans to build a polysilicon facility there have been put on hold due to the poor economic conditions within the semiconductor industry.

Wacker Chemicals East Asia, established in Tokyo in 1982, serves as a marketing and sales arm for Wacker-Chemie in Japan and the Pacific Rim. Dataquest estimates that Wacker's Japanese silicon and epitaxial wafer sales were $5.5 million in 1985. This represents 0.9 percent of the Japanese silicon market. Dataquest believes that Wacker's presence in Rest of World (ROW) is substantially larger, with silicon and epitaxial wafer sales of $28.5 million, or 40.2 percent of the ROW silicon market.

New Entrants

Japan

Two new Japanese companies entered the merchant silicon market in 1986, Nittetsu Denshi (a subsidiary of Nippon Steel) and Showa Denko. Both Showa Denko and Nittetsu Denshi started sampling 125mm polished wafers in the third quarter of 1986, and industry sources expect both companies to be significantly competive by late 1987 or 1988.

Nittetsu Denshi - Nittetsu Denshi (also referred to as Nittetsu Shoji, Nittetsu Electronics, and NSC Electron) was established as a wholly owned subsidiary of Nippon Steel in June 1985. The silicon wafer facility is in Hikari City, Yamaguchi Prefecture. Sampling began in the fall of 1986, and production-level wafers are expected in the second quarter of 1987. Nippon Steel, Nittetsu Denshi's parent, is one of several Japanese steel manufacturers diversifying from its traditional sunset industry, steel, into the sunrise industries, such as electronic materials. In addition to financial backing, the steelmaker can provide its new venture with a strong background in support technologies for silicon manufacturing, such as crystal growth control and precision measurement. To speed its entry into the silicon market, Nippon Steel agreed to provide Hitachi with a stable supply of silicon wafers from its new subsidiary in exchange for technological assistance.

Showa Denko - Showa Denko began actively sampling silicon wafers in 1986. In addition to its new venture into silicon wafers, Showa Denko provides a broad mix of electronic materials to semiconductor manufacturers, including compound semiconductor materials (gallium arsenide, gallium phosphide, and indium phosphide) and high-purity specialty gases (such as silane, hydrogen chloride, boron trichloride, nitrogen trifluoride, and fluorocarbon etchants).

Showa Denko manufactures silicon at its Chichibu City facility in Saitama Prefecture. (Single-crystal ingots of gallium arsenide are also produced at this facility.) Dataquest estimates that Showa Denko's wafer capacity was approximately 9.0 million square inches at the end of 1986. The company's expansion plans call for wafer capacity of approximately 35 to 40 MSI by late 1987 or early 1988. Showa Denko manufactures both Czochralski and magnetic Czochralski (MCZ) material. The company obtained its MCZ technology from Sony Corporation, a pioneer in this field. The MCZ growth method has received much attention the last few years because of its ability to provide very high-purity material with tight oxygen control.

Showa Denko has ten years of experience in compound semiconductor material manufacturing and an existing distribution network in electronic materials, factors that Showa Denko hopes will provide a competitive advantage.

Europe

Okmetic - Okmetic is a new merchant silicon company in Espoo, Finland. The company was founded in 1985. Production of 3-inch through 125mm Czochralski wafers will begin in 1987.

Rhone-Siltec - In 1984, Siltec entered into an agreement with Rhone-Poulenc of France to manufacture silicon wafers in France for distribution to semiconductor manufacturers in Western Europe. Rhone-Poulenc is one of the world's largest chemical companies, and its entrance into the silicon wafer business is another indication of the growing interest of chemical manufacturers in the field of electronic materials. The joint venture, Rhone-Siltec, began pilot production in September 1985 at a facility near Mantes-la-Jolie (100 kilometers west of Paris). Rhone-Siltec has single crystal growth and polished wafer operations; current wafer capacity is approximately 20 MSI.

Korea

Lucky Advanced Materials - In October 1985, Siltec announced the licensing of its silicon technology to Lucky Advanced Materials of Korea, an affiliate of the Lucky-Goldstar group. Lucky Advanced Materials agreed to pay Siltec $4 million plus royalties for the technology. The Lucky Advanced Materials silicon facility is located in Gumi and began production in February 1987. Wafer capacity at this facility is on the order of 20 MSI. The Lucky Advanced Materials plant is the only facility in Korea that has single crystal silicon growth and wafer production operations.

MARKET ANALYSIS--COMPANY MARKET SHARE BY REGION

This section presents Dataquest's estimates of worldwide and regional silicon and epitaxial wafer shipments by the merchant silicon companies in 1985. Our estimates of company sales include wafers sold directly to semiconductor manufacturers and those sold to epitaxial silicon wafer houses that do not grow all of their own material. The potential problem of double-counting million square inches that arises from sales to epi houses is corrected in our final analysis of total million square inch consumption by the semiconductor industry. The company market share that we publish, however, reflects sales to both sets of customers: semiconductor manufacturers and epitaxial silicon wafer companies.

Silicon and Epitaxial Wafer Markets

Tables 14 through 18 present 1985 merchant silicon and epitaxial wafer sales. Tables 14 through 17 are each devoted to silicon and epitaxial wafer sales in a given region of the world. Table 18 presents merchant silicon company market share for wafer sales worldwide. The total market for silicon and epitaxial wafers in 1985 was $1,266.5 million. Of this total, $255.7 million or 20.2 percent was produced by United States-based merchant silicon manufacturers, $754.0 million or 59.5 percent was produced by Japan-based merchant silicon manufacturers, and $256.8 million or 20.3 percent was produced by Europe-based merchant silicon manufacturers.

Silicon and Epitaxial Wafer Markets

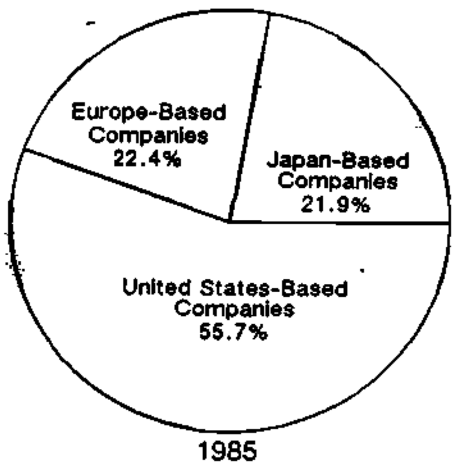
United States

Figure 1 shows the market share of the regionally based silicon companies in the $387.9 million U.S. wafer market in 1985. Dataquest estimates that United States-based companies supplied approximately 56 percent ($216.3 million) of the silicon and epitaxial wafers sold in the United States in 1985. In particular, United States-based epitaxial manufacturing accounted for almost 79 percent of epitaxial wafer sales. This, in part, is due to the presence of the many U.S. small epitaxial silicon manufacturers. In 1985, Europe-based and Japan-based silicon companies had essentially equal share of the U.S. market; Wacker and Shin-Etsu Handotai sales dominated each of these groups. Additional sales of epitaxial and silicon wafers by United States-based companies outside of the United States amounted to $39.4 million, or 15.4 percent of total United States-based company sales of $255.7 million.

Table 14 presents figures for silicon and epitaxial wafer sales to semiconductor manufacturers in the United States in 1985.

Figure 1

REGIONALLY BASED SILICON COMPANY MARKET SHARE IN THE UNITED STATES, 1985



Source: Dataquest
February 1987

Table 14

U.S. SILICON AND EPITAXIAL WAFER MARKET, 1985
(Millions of Dollars)

Company	Silicon Wafers	Percent Share	Epitaxial Wafers	Percent Share	Total Sales	Percent Share
U.S.-Based Companies						
Cincinnati Milacron	-	-	$39.1	46.8%	$ 39.1	10.1%
Crysteco	$ 8.6	2.8%	-	-	8.6	2.2
Epitaxy, Inc.	-	-	2.7	3.2	2.7	0.7
General Instruments Power Semicond. Div.	-	-	2.1	2.5	2.1	0.5
Gensil	1.8	0.6	-	-	1.8	0.5
Fairchild	0.2	0.1	-	-	0.2	0.1
M/A-COM	-	-	4.8	5.8	4.8	1.2
Monsanto	98.0	32.2	10.4	12.5	108.4	27.9
Motorola	1.8	0.6	0.3	0.4	2.1	0.5
NBK Corporation	6.7	2.2	-	-	6.7	1.7
Pensilco	3.3	1.1	-	-	3.3	0.9
Recticon	5.0	1.6	-	-	5.0	1.3
Silicon Services	-	-	0.8	1.0	0.8	0.2
Siltec	23.8	7.8	-	-	23.8	6.1
Spire Corporation	-	-	0.6	0.7	0.6	0.2
U.S. Semiconductor	-	-	5.0	6.0	5.0	1.3
Virginia Semiconductor	1.4	0.4	-	-	1.4	0.3
Total	$150.5	49.5%	$65.8	78.9%	$216.3	55.7%
Japan-Based Companies						
Japan Silicon	$ 0.9	0.3%	$ 0.4	0.4%	$ 1.3	0.3%
Komatsu Electronic Metals	4.6	1.5	1.0	1.2	5.6	1.4
Osaka Titanium Company	14.5	4.8	1.1	1.3	15.6	4.0
Shin-Etsu Handotai	53.9	17.7	7.8	9.4	61.7	15.9
Toshiba Ceramics	0.7	0.2	0.1	0.1	0.7	0.2
Total	$ 74.6	24.5%	$10.3	12.3%	$ 84.9	21.9%
Europe-Based Companies						
Dynamit Nobel Silicon	$ 18.9	6.2%	-	-	$ 18.9	4.9%
Topsil	2.2	0.7	-	-	2.2	0.6
Wacker	58.2	19.1	$ 7.4	8.8%	65.6	16.9
Total	$ 79.4	26.0%	$ 7.3	8.8%	$ 86.7	22.4%
Total Sales--United States	$304.5	100.0%	$83.4	100.0%	$387.9	100.0%

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

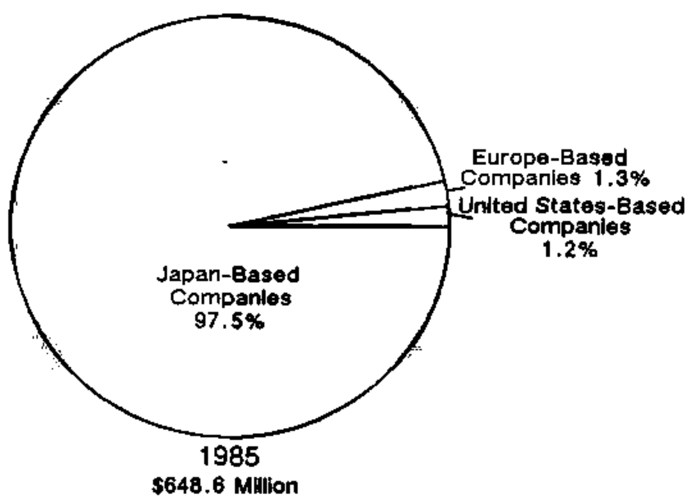
Japan

Figure 2 shows the market share of the regionally based silicon companies in the $648.6 million Japanese wafer market in 1985. Dataquest estimates that Japan-based companies sold $632.1 million worth of silicon and epitaxial wafers, with non-Japanese silicon companies accounting for only 2.5 percent of the Japanese market in 1985. This is partly because silicon specifications are much tighter in Japan than in other regions, and thus local vendors can work closely with their customers to meet these requirements. In addition, Japan-based silicon companies have a tendency to develop long-term relationships with their semiconductor manufacturer customers, making it difficult for an outside vendor to penetrate the market. Additional sales of epitaxial and silicon wafers by Japan-based silicon companies in other regions of the world amounted to $121.9 million, or 16.2 percent of total Japan-based silicon and epitaxial wafer sales in 1985.

Table 15 presents figures for silicon and epitaxial wafer sales by merchant silicon companies to semiconductor manufacturers in Japan in 1985.

Figure 2

REGIONALLY BASED SILICON COMPANY MARKET SHARE IN JAPAN, 1985



Source: Dataquest
February 1987

Table 15

JAPANESE SILICON AND EPITAXIAL WAFER MARKET, 1985
(Millions of Dollars)

Company	Silicon Wafers	Percent Share	Epitaxial Wafers	Percent Share	Total Sales	Percent Share
U.S.-Based Companies						
Cincinnati Milacron	-	-	-	-	-	-
Crysteco	$ 0.1	0.0	-	-	$ 0.1	0.0
Epitaxy, Inc.	-	-	-	-	-	-
General Instruments Power Semicond. Div.	-	-	$ 0.1	0.0	0.1	0.0
Gensil	-	-	-	-	-	-
Fairchild	-	-	-	-	-	-
M/A-COM	-	-	-	-	-	-
Monsanto	7.5	1.4%	0.1	0.1%	7.6	1.2%
Motorola	-	-	-	-	-	-
NBK Corporation	0.1	0.0	-	-	0.1	0.0
Pensilco	-	-	-	-	-	-
Recticon	-	-	-	-	-	-
Silicon Services	-	-	-	-	-	-
Siltec	-	-	-	-	-	-
Spire Corporation	-	-	-	-	-	-
U.S. Semiconductor	-	-	-	-	-	-
Virginia Semiconductor	-	-	-	-	-	-
Total	$ 7.7	1.5%	$ 0.2	0.1%	$ 7.9	1.2%
Japan-Based Companies						
Japan Silicon	$ 88.4	17.0%	$ 33.3	25.5%	$121.6	18.7%
Komatsu Electronic Metals	83.7	16.2	23.8	18.2	107.5	16.6
Osaka Titanium Company	123.3	23.8	14.0	10.7	137.2	21.2
Shin-Etsu Handotai	174.0	33.6	52.7	40.4	226.6	34.9
Toshiba Ceramics	33.3	6.4	5.9	4.6	39.3	6.1
Total	$502.6	97.0%	$129.5	99.5%	$632.1	97.5%
Europe-Based Companies						
Dynamit Nobel Silicon	-	-	-	-	-	-
Topsil	$ 2.6	0.5%	-	-	$ 2.6	0.4%
Wacker	5.5	1.0	$ 0.5	0.4%	5.9	0.9
Total	$ 8.1	1.5%	$ 0.5	0.4%	$ 8.6	1.3%
Total Sales--Japan	$518.4	100.0%	$130.2	100.0%	$648.6	100.0%

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

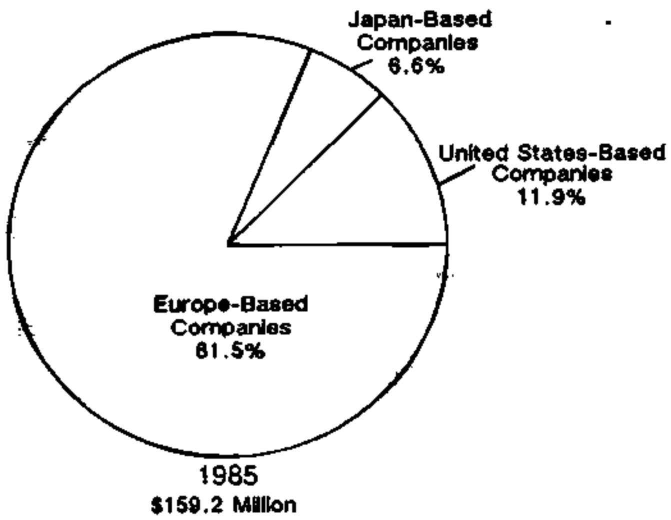
Europe

Figure 3 shows the market share of the regionally based silicon companies in the $159.2 million European wafer market in 1985. Dataquest estimates that Europe-based companies supplied more than 80 percent, or $130.0 million, of the silicon and epitaxial wafers sold in Europe in 1985. United States-based companies represented 11.9 percent and Japan-based companies, an additional 6.6 percent of the European silicon and epitaxial market. Europe-based silicon companies sold $126.8 million worth of wafers outside of Europe, or 49.4 percent of total Europe-based silicon company sales. Most of these sales were to the United States.

Table 16 presents figures for silicon and epitaxial wafer sales to semiconductor manufacturers in Europe in 1985.

Figure 3

REGIONALLY BASED SILICON COMPANY MARKET SHARE IN EUROPE, 1985



Source: Dataquest
February 1987

Table 16

EUROPEAN SILICON AND EPITAXIAL WAFER MARKET, 1985
(Millions of Dollars)

Company	Silicon Wafers	Percent Share	Epitaxial Wafers	Percent Share	Total Sales	Percent Share
U.S.-Based Companies						
Cincinnati Milacron	-	-	$ 1.7	7.6%	$ 1.7	1.1%
Crysteco	$ 0.3	0.2%	-	-	0.3	0.2
Epitaxy, Inc.	-	-	0.6	2.7	0.6	0.4
General Instruments Power Semicond. Div.	-	-	0.3	1.1	0.3	0.2
Gensil	0.5	0.4	-	-	0.5	0.3
Fairchild	-	-	-	-	-	-
M/A-COM	-	-	0.9	4.1	0.9	0.6
Monsanto	12.4	9.0	2.1	9.5	14.5	9.1
Motorola	-	-	-	-	-	-
NBK Corporation	-	-	-	-	-	-
Pensilco	-	-	-	-	-	-
Recticon	-	-	-	-	-	-
Silicon Services	-	-	-	-	-	-
Siltec	-	-	-	-	-	-
Spire Corporation	-	-	-	-	-	-
U.S. Semiconductor	-	-	0.1	0.5	0.1	0.1
Virginia Semiconductor	0.1	0.1	-	-	0.1	0
Total	$ 13.2	9.7%	$ 5.6	25.5%	$ 18.8	11.9%
Japan-Based Companies						
Japan Silicon	$ 2.7	2.0%	$ 1.1	5.0%	$ 3.8	2.4%
Komatsu Electronic Metals	-	-	-	-	-	-
Osaka Titanium Company	2.9	2.1	-	-	2.9	1.8
Shin-Etsu Handotai	2.5	1.8	1.3	5.9	3.8	2.4
Toshiba Ceramics	-	-	-	-	-	-
Total	$ 8.1	5.9%	$ 2.3	10.9%	$ 10.4	6.6%
Europe-Based Companies						
Dynamit Nobel Silicon	$ 21.5	15.6%	-	-	$ 21.5	13.5%
Topsil	3.5	2.6	-	-	3.5	2.2
Wacker	91.0	66.2	$14.0	63.6%	105.0	65.9
Total	$116.0	84.4%	$14.0	63.6%	$130.0	81.5%
Total Sales--Europe	$137.3	100.0%	$21.9	100.0%	$159.2	100.0%

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
February 1987

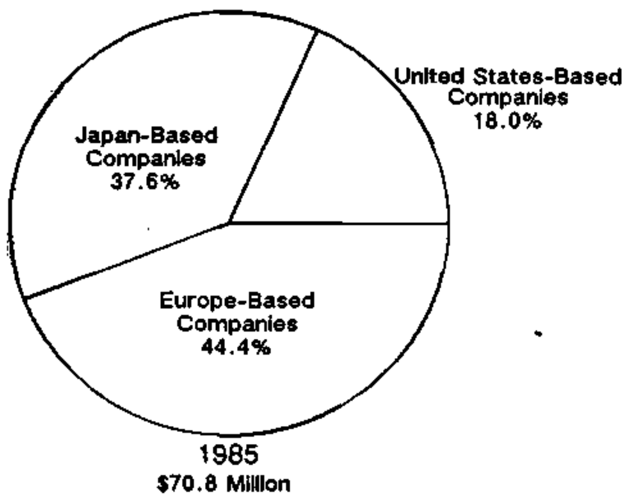
ROW

Figure 4 shows the market share of the regionally based silicon companies in the $70.8 million ROW wafer market in 1985. Dataquest estimates that Europe-based companies accounted for the majority of ROW sales, with 44.4 percent of regional share, or $31.5 million. Japan-based silicon companies accounted for a 37.6 percent share, whereas United States-based silicon companies represented only 18.0 percent of silicon and epitaxial wafers sold in ROW. The three major suppliers to ROW are Wacker (40.2 percent share), Shin-Etsu Handotai (25.4 percent share), and Monsanto (9.3 percent share). Both Monsanto and Shin-Etsu have established wafer production facilities in Kuala Lumpur, while Monsanto opened an additional wafer production facility in Korea in 1986. Wacker depends on its Wacker Chemicals Far East operations to supply sales and marketing support for customers in the Pacific Rim and Japan.

Table 17 presents figures for silicon and epitaxial wafer sales to semiconductor manufacturers in ROW in 1985.

Figure 4

REGIONALLY BASED SILICON COMPANY MARKET SHARE IN ROW, 1985



Source: Dataquest February 1987

Table 17

ROW SILICON AND EPITAXIAL WAFER MARKET, 1985
(Millions of Dollars)

Company	Silicon Wafers	Percent Share	Epitaxial Wafers	Percent Share	Total Sales	Percent Share
U.S.-Based Companies						
Cincinnati Milacron	-	-	$ 1.3	12.7%	$ 1.3	1.8%
Crysteco	-	-	-	-	-	-
Epitaxy, Inc.	-	-	2.7	26.5	2.7	3.8
General Instruments Power Semicond. Div.	-	-	-	-	-	-
Gensil	$ 0.3	0.5%	-	-	0.3	0.4
Fairchild	-	-	-	-	-	-
M/A-COM	-	-	0.3	3.0	0.3	0.4
Monsanto	6.2	10.2	0.4	3.9	6.6	9.3
Motorola	-	-	-	-	-	-
NBK Corporation	0.2	0.3	-	-	0.2	0.3
Pensilco	-	-	-	-	-	-
Recticon	-	-	-	-	-	-
Silicon Services	-	-	0.2	2.0	0.2	0.3
Siltec	1.0	1.6	-	-	1.0	1.4
Spire Corporation	-	-	-	-	-	-
U.S. Semiconductor	-	-	0.1	1.0	0.1	0.1
Virginia Semiconductor	0.1	0.2	-	-	0.1	0.1
Total	$ 7.7	12.8%	$ 5.0	49.0%	$12.7	18.0%
Japan-Based Companies						
Japan Silicon	$ 0.9	1.5%	$ 0.4	3.9%	$ 1.3	1.8%
Komatsu Electronic Metals	2.7	4.5	0.3	2.9	3.0	4.2
Osaka Titanium Company	4.4	7.2	-	-	4.4	6.2
Shin-Etsu Handotai	14.7	24.2	3.3	32.4	18.0	25.4
Toshiba Ceramics	-	-	-	-	-	-
Total	$22.7	37.4%	$ 3.9	39.2%	$26.6	37.6%
Europe-Based Companies						
Dynamit Nobel Silicon	$ 2.6	4.2%	-	-	$ 2.6	3.6%
Topsil	0.4	0.7	-	-	0.4	0.6
Wacker	27.3	44.9	$ 1.2	11.8%	28.5	40.2
Total	$30.3	49.8%	$ 1.2	11.8%	$31.5	44.4%
Total Sales--ROW	$60.7	100.0%	$10.1	100.0%	$70.8	100.0%

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

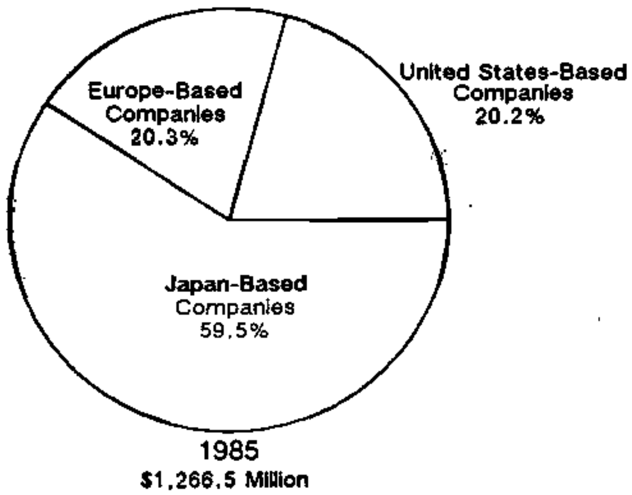
Worldwide Silicon and Epitaxial Sales

Figure 5 shows the 1985 market share of the regionally based silicon companies in the $1,266.5 million silicon and epitaxial wafer market. Japan-based silicon companies dominated, with $754.0 million in sales, or 59.5 percent of the market. Europe-based silicon companies ran slightly ahead of United States-based companies, capturing 20.3 percent ($256.8 million) of the market, just a tenth of a percent more than the 20.2 percent ($255.7 million) taken by United States-based companies. The sales of the top six merchant silicon companies accounted for $1,056 million, or 83.4 percent of the 1985 worldwide merchant silicon and epitaxial wafer market. These companies, in order of decreasing market share, are Shin-Etsu Handotai, Wacker, Osaka Titanium Company, Monsanto, Japan Silicon, and Komatsu Electronic Metals. Worldwide market share for each of these silicon manufacturers has been identified in Tables 1 and 18.

Table 18 presents figures for worldwide silicon and epitaxial wafer sales to semiconductor manufacturers in 1985.

Figure 5

REGIONALLY BASED SILICON COMPANY MARKET SHARE WORLDWIDE, 1985



Source: Dataquest
February 1987

Table 18

WORLDWIDE SILICON AND EPITAXIAL WAFER MARKET, 1985
(Millions of Dollars)

Company	Silicon Wafers	Percent Share	Epitaxial Wafers	Percent Share	Total Sales	Percent Share
U.S.-Based Companies						
Cincinnati Milacron	-	-	$ 42.0	17.1%	$ 42.0	3.3%
Crysteco	$ 9.0	0.9%	-	-	9.0	0.7
Epitaxy, Inc.	-	-	6.0	2.4	6.0	0.5
General Instruments Power Semicond. Div.	-	-	2.5	1.0	2.5	0.2
Gensil	2.5	0.2	-	-	2.5	0.2
Fairchild	0.2	0.0	-	-	0.2	0.0
M/A-COM	-	-	6.0	2.4	6.0	0.5
Monsanto	124.0	12.1	13.0	5.3	137.0	10.8
Motorola	1.8	0.2	0.3	0.1	2.1	0.2
NBK Corporation	7.0	0.7	-	-	7.0	0.6
Pensilco	3.3	0.3	-	-	3.3	0.3
Recticon	5.0	0.5	-	-	5.0	0.4
Silicon Services	-	-	1.0	0.4	1.0	0.1
Siltec	24.8	2.4	-	-	24.8	2.0
Spire Corporation	-	-	0.6	0.2	0.6	0.0
U.S. Semiconductor	-	-	5.2	2.1	5.2	0.4
Virginia Semiconductor	1.5	0.1	-	-	1.5	0.1
Total	$ 179.1	17.5%	$ 76.6	31.2%	$ 255.7	20.2%
Japan-Based Companies						
Japan Silicon	$ 93.0	9.1%	$ 35.0	14.3%	$ 128.0	10.1%
Komatsu Electronic Metals	91.0	8.9	25.0	10.2	116.0	9.2
Osaka Titanium Company	145.0	14.2	15.0	6.1	160.0	12.6
Shin-Etsu Handotai	245.0	24.0	65.0	26.5	310.0	24.5
Toshiba Ceramics	34.0	3.3	6.0	2.4	40.0	3.2
Total	$ 608.0	59.6%	$146.0	59.4%	$ 754.0	59.5%
Europe-Based Companies						
Dynamit Nobel Silicon	$ 43.0	4.2%	-	-	$ 43.0	3.4%
Topsil	8.8	0.9	-	-	8.8	0.7
Wacker	182.0	17.8	$ 23.0	9.4%	205.0	16.2
Total	$ 233.8	22.9%	$ 23.0	9.4%	$ 256.8	20.3%
Total Worldwide Sales	$1,020.9	100.0%	$245.6	100.0%	$1,266.5	100.0%

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

MARKET ANALYSIS--WAFER PRICING

Dataquest surveyed the merchant silicon companies to establish 1985 average selling prices (ASPs) for silicon and epitaxial wafers. The silicon wafer prices reflect the ASP for a polished CZ wafer. Table 19 presents these estimates (as measured in dollars) for the United States, Europe, and ROW combined, on a per wafer basis and per square inch. In addition, Table 19 specifically breaks out the price of 100mm through 150mm silicon wafers in Japan (in yen and dollars--exchange rate, ¥238/$1) because of the predominance of these sizes in Japan's wafer consumption mix and our knowledge of specific pricing differences between Japan and the United States. Epitaxial wafer prices vary considerably depending upon the level of custom specifications and the thickness of the epitaxial layer required.

Table 19

AVERAGE SELLING PRICES
OF SILICON AND EPITAXIAL WAFERS, 1985

Wafer Diameter	2 in.	3 in.	100mm	125mm	150mm	200mm
Wafer Area (Square Inches)	3.14	7.07	12.17	19.02	27.39	48.70
			Polished Silicon Wafer Prices			
U.S., Europe, ROW						
Per Wafer ($)	$ 3.40	$ 5.60	$10.30	$21.00	$ 37.80	$100-$200
Per Square Inch ($/SI)	$ 1.08	$ 0.79	$ 0.85	$ 1.10	$ 1.38	$2.05-4.10
Japan*						
Per Wafer (Yen)	-	-	¥2,250	¥4,600	¥ 9,000	-
Per Wafer ($)	-	-	$ 9.50	$19.30	$ 37.80	-
Per Square Inch ($/SI)	-	-	$ 0.78	$ 1.02	$ 1.38	-
			Epitaxial Wafer Prices			
Worldwide						
Per Wafer	$16.80	$21.70	$32.00	$54.70	$105.70	N/A
Per Square Inch ($/SI)	$ 5.35	$ 3.07	$ 2.63	$ 2.88	$ 3.86	-

*¥238 = $1
N/A = Not Applicable

Source: Dataquest
February 1987

The regional ASP per square inch of silicon and epitaxial wafers is dependent upon the wafer size mix in the different regions of the world. Table 20 is Dataquest's estimate of the wafer size distribution (by percent MSI) for the four regions of the world in 1985. (Dataquest's forecast for the U.S. wafer size distribution is presented in a later section.)

A regional ASP per square inch can be calculated by taking the sum of the products of per-square-inch price of a given size wafer (Table 19) multiplied by the appropriate percentage of the wafer size mix consumed in a given region (Table 20). For example, the ASP per square inch for polished CZ silicon wafers in the United States can be calculated as follows:

United States	=	(0% * $1.08/Square Inch)
Average Polished CZ	+	(7% * $0.79/Square Inch)
Wafer Price	+	(55% * $0.85/Square Inch)
	+	(30% * $1.10/Square Inch)
	+	(8% * $1.38/Square Inch)
	=	$0.96/Square Inch

Table 20

WAFER SIZE DISTRIBUTION BY REGION, 1985
(Percent of Million Square Inches)

	United States	Japan	Europe	ROW
2 in.	0	0	2%	2%
3 in.	7%	6%	23	19
100mm	55	42	58	52
125mm	30	40	15	21
150mm	8	12	2	6
200mm	0	0	0	0
Total	100%	100%	100%	100%

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

The regional ASPs per square inch for polished CZ silicon wafers and epitaxial wafers are presented in Table 21. Japan's ASP per square inch for polished wafers was generated using the Japanese silicon wafer prices, which were broken out separately in Table 19. (Average 2-inch and 3-inch silicon wafer prices in Japan are assumed to be the same as for the U.S., Europe, and ROW.) It is assumed that the wafer size distribution is the same for both silicon and epitaxial wafers in a given region.

Table 21

SILICON AND EPITAXIAL WAFERS
AVERAGE SELLING PRICE BY REGION, 1985
(Dollars per Square Inch)

	United States	Japan	Europe	ROW
Silicon Wafers (Polished CZ)	$0.96	$0.95	$0.89	$0.93
Silicon Wafers (Average)	$0.94	$0.98	$1.02	$0.96
Epitaxial Wafers	$2.84	$2.91	$2.85	$2.89

Source: Dataquest
February 1987

In addition, Table 21 presents a weighted ASP per square inch for all types of silicon wafers sold by merchant silicon companies (i.e., polished, test, Czochralski, float zone). Note that the silicon wafer ASP per square inch in the United States is lower than the ASP for polished CZ wafers, whereas the European silicon wafer ASP per square inch is higher than its CZ counterpart. We believe that the U.S. market is more competitive because of the large number of vendors fighting to gain share. While the usage of lower-priced nonprime wafers in the United States and Europe reduces the ASP, the average price for silicon wafers in Europe is higher than the price of CZ wafers because of the proportionately higher use of float zone material in that region. (Float zone is typically more costly than Czochralski material.) In Japan, semiconductor manufacturers typically use prime wafers as test wafers, so there is little price differential in that regard. The ASP for silicon wafers in Japan and ROW is slightly higher than for polished CZ wafers because of the use of float zone material in discrete fabrication.

In particular, it is difficult to establish an average selling price for float zone material since there is a wide range in prices. For some applications, such as IC fabrication, the price of float zone material may be less than or equal to the price of a polished Czochralski wafer, on the order of $1.00 per square inch. In other applications, such as the fabrication of power devices and other discretes, thicker wafers of float zone material, as thick as 1000 microns (two to three times thicker than a polished wafer), may be required. The cost of such wafers will be substantially higher, with the price equal to or greater than epitaxial silicon. Dataquest estimates that the average selling price for float zone wafers is on the order of $2.00 per square inch.

Effects of Yen Appreciation

In addition to domestic competition, in 1986 Japanese silicon companies also had to face the pressures of restricted markets overseas because of the yen's appreciation. Silicon wafer pricing has always varied from region to region. However, Japanese silicon companies found it difficult to compete in the U.S. and European markets in 1986 due to large differences in wafer pricing affected by exchange rate factors. For example, in 1984, the average U.S. price of a 100mm wafer was $10.50. At an exchange rate of ¥237/$1, a Japanese silicon company would receive ¥2,490 for a 100mm wafer. In 1986, the U.S. average selling price of a 100mm wafer came down to $10.00. However, at the 1986 exchange rate of ¥167/$1, a Japanese silicon company would now only receive ¥1,750 for a 100mm wafer sold in the United States.

Because of the high yen, Japanese silicon companies exporting silicon wafers to the United States have two options: 1) meet and maintain U.S. average selling prices for wafers and lose on margins in order to maintain U.S. market share and customer relationships, or 2) raise wafer prices in the United States to regain a given yen rate of return, and as a consequence, lose market share. Similar analysis of wafer pricing for 125mm and 150mm wafers confirms that Japanese silicon companies in 1986 were caught between the proverbial rock and a hard place, and had difficulty competing for silicon sales overseas.

Overseas Acquisitions - On the one hand, the high yen has made silicon exports from Japan more difficult. On the other hand, it has made the acquisition of U.S. firms more attractive. As mentioned earlier, in 1986, two Japanese silicon companies chose the latter method of competing in the U.S. market. Mitsubishi Metal acquired Siltec in the third quarter of 1986, and OTC announced its plans in December to acquire U.S. Semiconductor, an epitaxial silicon wafer manufacturer.

Other Japanese companies that have established or acquired silicon facilities in the United States include silicon manufacturer Shin-Etsu Handotai (which established SEH America, a wholly owned subsidiary in Vancouver, Washington) and steelmakers Kawasaki Steel and Nippon Kokan K.K. Kawasaki Steel acquired Santa Clara-based NBK Corporation in 1984, and Nippon Kokan K.K. bought Great Western's polysilicon facility in 1985. In December 1986, Nippon Kokan K.K. announced its purchase of land in Oregon for a new 1,000-metric-ton polysilicon plant.

MARKET ANALYSIS BY MILLION SQUARE INCHES

Both merchant and captive silicon producers manufacture silicon wafer substrate materials. The following section presents 1985 MSI estimates for the merchant silicon and epitaxial wafer market. Internal production of silicon by semiconductor manufacturers (captive silicon producers) is estimated.

Merchant Silicon Companies

The merchant silicon and epitaxial wafer market, as measured in MSI, can be calculated for each of the four regions of the world by dividing merchant silicon company sales in a given region (Tables 14 through 18) by the regional average selling price per square inch (Table 21). Table 22 contains the million square inch market of silicon and epitaxial wafers based on this analysis.

In the United States, several small epitaxial houses do not grow all of their own silicon substrate material, but rather purchase their wafers from other merchant silicon companies. For this reason, it is necessary to correct the square inches of silicon derived from sales of silicon wafers in the United States for the amount of silicon substrate sold to epitaxial silicon companies. Dataquest estimates that this corresponds to approximately 13 MSI in 1985. The U.S. silicon million square inch figure presented in Table 22 includes this corrective factor.

Silicon and Epitaxial Wafer Markets

Table 22 indicates that epitaxial wafers represent 29 out of 340 MSI sold in the United States in 1985, or approximately 8.5 percent. Japan's percentage is slightly lower, at about 7.8 percent. Europe's figure is approximately 5.3 percent. In Europe, the percentage is lower than for the United States and Japan, we believe, because epitaxial wafer demand for discretes is accounted for by semiconductor manufacturers that do their own epi, such as Philips, Siemens, and Thomson. Remember that the epitaxial million square inches presented in Table 22 do not include epitaxial deposition performed by semiconductor manufacturers, but only merchant silicon company sales of epitaxial wafers to the industry.

Table 22

MERCHANT SILICON AND EPITAXIAL MARKET BY REGION, 1985
(Million Square Inches)

Region	Silicon Wafers MSI	Silicon Wafers Percent	Epitaxial Wafers MSI	Epitaxial Wafers Percent	Total	Percent
United States	311	30.0%	29	34.1%	340	30.3%
Japan	529	51.0	45	53.0	574	51.1
Europe	135	13.0	8	9.4	143	12.7
ROW	63	6.0	3	3.5	66	5.9
Total	1,038	100.0%	85	100.0%	1,123	100.0%

Source: Dataquest
February 1987

Captive Silicon Production

In 1985, eight semiconductor manufacturers grew single crystal silicon to produce wafers for internal consumption. In the United States, these companies were AT&T, Delco, Fairchild, IBM, Motorola, and Texas Instruments. (As previously noted, Fairchild closed its silicon operations in June 1985; Delco stopped internal silicon production in the spring of 1986.) Hitachi in Japan, through its subsidiary, Hitachi Ohme Denshi (Yanai City, Yamaguchi), and Philips in Europe also perform captive silicon production. Table 23 contains Dataquest's estimates of the silicon produced, purchased, and consumed by these eight semiconductor manufacturers in 1985. No distinction is made between silicon and epitaxial wafers in the MSI estimates for the captive silicon producers.

Table 23

CAPTIVE SILICON PRODUCTION AND CONSUMPTION, 1985
(Million Square Inches)

Company	Location	Silicon Production MSI	Silicon Production Percent	Silicon Purchases MSI	Silicon Purchases Percent	Consumed
AT&T	United States	21	60%	14	40%	35
Delco	United States	4	57%	3	43%	7
Fairchild*	United States	3	17%	15	83%	18
Hitachi	Japan	20	30%	47	70%	67
IBM	United States	54	60%	36	40%	90
Motorola	United States	23	55%	19	45%	42
Philips	Europe	7	30%	16	70%	23
Texas Instruments	United States	45	75%	15	25%	60
Total		177	52%	165	48%	342

*Fairchild's silicon production based on Dataquest estimate of four months operation in 1985

Source: Dataquest
February 1987

Total Million Square Inch Market

Table 24 combines 1985 million square inch sales by the merchant silicon companies (Table 22) and captive silicon production (Table 23) in the four regions of the world. Captive silicon production has been allocated to the semiconductor manufacturer's home region. Internal production by the captive silicon producers, at 150 MSI, accounts for a sizable percentage of the U.S. million square inch market of 490 MSI. The captive silicon market in Japan and Europe is much smaller, and ROW has no captive silicon producers at this time. Japan has the largest share of the world million square inch market with 594 MSI, or 45.7 percent of the total square inch market in 1985.

Table 24

SILICON AND EPITAXIAL MILLION SQUARE INCH MARKET BY REGION, 1985

Region	Merchant	Captive	Total	Percent
United States	340	150	490	37.7%
Japan	574	20	594	45.7
Europe	143	7	150	11.5
ROW	66	0	66	5.1
Total	1,123	177	1,300	100.0%

Source: Dataquest
February 1987

HISTORICAL AND FORECAST DEVICE PRODUCTION BY REGION

The market for silicon and other fabrication materials is dependent upon the level of semiconductor device production in the different regions of the world. This section presents Dataquest's historical and forecast production revenue for captive and merchant semiconductor manufacturers by region of production. The production revenue presented in this section was first published in the SEMS November 1986 newsletter, "The Changing Landscape of Capital Spending."

Historical Production Revenue by Region

Table 25 gives historical merchant and captive worldwide semiconductor production from 1981 through 1986. In this table, United States refers to device production in the United States by either a U.S., Japanese, European, or ROW semiconductor manufacturer. A similar definition applies to producers of semiconductor devices in Japan, Europe, and ROW. (Please note that the regional designation, United States, includes Canadian semiconductor manufacturing activities.)

Table 25

TOTAL HISTORICAL SEMICONDUCTOR PRODUCTION BY REGION*, 1981-1986
(Millions of Dollars)

	1981	1982	1983	1984	1985	1986	CAGR 1981-1986
United States							
Merchant Prod.	$ 7,267	$ 7,260	$ 8,850	$13,428	$10,679	$12,223	11.0%
Growth		(0.1%)	21.9%	51.7%	(20.5%)	14.5%	
Captive Prod.	2,466	2,730	3,456	3,733	3,643	4,035	10.4%
Growth		10.7%	26.6%	8.0%	(2.4%)	10.8%	
United States	$ 9,733	$ 9,990	$12,306	$17,161	$14,322	$16,258	10.8%
Growth		2.6%	23.2%	39.5%	(16.5%)	13.5%	
Japan	5,252	5,584	7,722	12,007	10,655	14,292	22.2%
Growth		6.3%	38.3%	55.5%	(11.3%)	34.1%	
Europe	2,237	2,289	2,434	3,428	3,150	3,793	11.1%
Growth		2.3%	6.3%	40.8%	(8.1%)	20.4%	
ROW	45	98	170	240	339	368	52.2%
Growth		117.8%	73.5%	41.2%	41.3%	8.6%	
Worldwide							
Production	$17,267	$17,961	$22,632	$32,836	$28,466	$34,711	15.0%
Growth		4.0%	26.0%	45.1%	(13.3%)	21.9%	

*Region of device production, not country of company ownership

Source: Dataquest
February 1987
Reference: 1186NL

Production Revenue, Local Currency - Due to large fluctuations in exchange rates during the last few years, historical Japanese and European semiconductor production revenue is translated into local currencies in Table 26. This is done to more accurately reflect fluctuations in the semiconductor business cycle and thus provide a more appropriate gauge of silicon use. (Currency exchange rates for ROW countries are more closely tied to the U.S. dollar; thus no currency translation is presented for this region.) For comparison, production revenue for Japan and Europe is presented in both dollars and local currency.

Table 26

HISTORICAL SEMICONDUCTOR PRODUCTION REVENUE
IN LOCAL CURRENCY, JAPAN AND EUROPE
(Millions of Dollars, Billions of Yen, Billions of
European Local Currency Units)
1981-1986

	1981	1982	1983	1984	1985	1986	CAGR 1981-1986
Japan ($M)	5,252	5,584	7,722	12,007	10,655	14,292	22.2%
Growth		6.3%	38.3%	55.5%	(11.3%)	34.1%	
Exchange Rate (¥/$)	221.3	248.6	237.9	237.0	238.0	167.0	
Japan (¥B)	1,162	1,388	1,837	2,846	2,536	2,387	15.5%
Growth		19.4%	32.3%	54.9%	(10.9%)	(5.9%)	
Europe ($M)	2,237	2,289	2,434	3,428	3,150	3,793	11.1%
Growth		2.3%	6.3%	40.8%	(8.1%)	20.4%	
Exchange Rate (ELC/$)*	112.8	128.9	143.8	162.4	168.5	136.1	
Europe (ELC-B)	252.4	295.0	349.9	556.8	530.7	516.3	15.4%
Growth		16.9%	20.8%	55.9%	(13.5%)	(2.7%)	

*ELC = European Local Currency Units
Base Year, 1978 - 100 Local Currency Units

Source: IMF
Dataquest
February 1987

The conversion from dollar revenue to yen is a straightforward procedure. However, for Europe it is necessary to establish a yearly weighted average of all the individual European currencies. This average is weighted according to the semiconductor consumption of each country and therefore is more relevant as an average currency indicator for the European semiconductor industry. For convenience, this weighted average has been calculated from a base of 100 in the year 1978. The weighted average can be used to interpret the effect of the European currency fluctuations with respect to the U.S. dollar in a given year. It can also provide a better measure of aggregate local currency growth as opposed to U.S. dollar growth. Dataquest uses International Monetary Fund (IMF) average foreign exchange rates for historical data.

Note that while Japanese production revenue grew by 34.1 percent in dollars in 1986, in yen, it was down almost 6 percent. European production revenue was also dramatically affected by currency exchange rates in 1986. Its production revenue grew by 20.4 percent as measured in dollars but was down 2.7 percent as measured in local currency units.

Forecast Production Revenue By Region

Table 27 presents Dataquest's forecast of production revenue for merchant and captive semiconductor manufacturers by region of production.

Table 27

TOTAL FORECAST SEMICONDUCTOR PRODUCTION BY REGION*, 1986-1991
(Millions of Dollars)

	1986	1987	1988	1989	1990	1991	CAGR 1987-1991
United States							
Merchant Prod.	$12,223	$14,599	$18,923	$17,959	$20,638	$25,852	15.4%
Growth	14.5%	19.4%	29.6%	(5.1%)	14.9%	25.3%	
Captive Prod.	4,035	4,737	5,561	6,529	7,665	8,999	17.4%
Growth	10.8%	17.4%	17.4%	17.4%	17.4%	17.4%	
United States	$16,258	$19,336	$24,484	$24,488	$28,303	$34,851	15.9%
Growth	13.5%	18.9%	26.6%	0	15.6%	23.1%	
Japan	14,292	16,555	21,104	21,253	24,088	29,181	15.2%
Growth	34.1%	15.8%	27.5%	0.7%	13.3%	21.1%	
Europe	3,793	4,734	6,090	5,890	7,359	8,936	17.2%
Growth	20.4%	24.8%	28.6%	(3.3%)	24.9%	21.4%	
ROW	368	510	750	827	1,063	1,305	26.5%
Growth	8.6%	38.6%	47.1%	10.3%	28.5%	22.8%	
Worldwide							
Production	$34,711	$41,135	$52,428	$52,458	$60,813	$74,273	15.9%
Growth	21.9%	18.5%	27.5%	0.1%	15.9%	22.1%	

*Region of device production, not country of company ownership

Source: Dataquest
February 1987
Reference: 1186NL

Silicon and Epitaxial Wafer Markets

HISTORICAL AND FORECAST SILICON CONSUMPTION BY REGION

Dataquest assumes that, in a given year, the total square inches of silicon sold by the merchant silicon companies or produced by the captive silicon producers will be consumed by semiconductor manufacturers in that same year. This corresponds to an inventory flow at steady state conditions. With that assumption in mind, the historical and forecast silicon market is presented.

Historical Silicon Consumption by Region

Table 28 contains Dataquest's historical silicon consumption by region. In 1985, all regions except the ROW and the United States captive semiconductor manufacturers had reduced silicon consumption from 1984 values as a result of the industry downturn. U.S. merchant semiconductor manufacturers were worst hit by the industry recession and reduced their silicon consumption by almost 40 percent. Europe and Japan, while down in silicon consumption, did not drop as significantly as the United States, and ROW experienced modest growth in silicon consumption.

In 1986, semiconductor manufacturers producing in the U.S. increased silicon consumption on the order of 15 percent, whereas production revenue grew 13.5 percent in the same year. In contrast, Japanese silicon consumption in 1986 was down 3.5 percent in MSI when compared with 1985 levels as the combined effects of yen appreciation, increased trade friction, and reduced capital spending stalled Japan's semiconductor industry recovery. Although Japanese production increased 34.1 percent in dollars in 1986, production revenue in yen was down 5.9 percent, which tracked closely with the change in silicon consumption. European silicon consumption in 1986 remained at its 1985 level of 150 MSI. Although European semiconductor production revenue grew by 20.4 percent as measured in dollars, production in local currency was down by 2.7 percent, again closely tracking with the change in silicon consumption. ROW showed a healthy increase of silicon consumption in 1986, on the order of 20 percent from 1985 levels.

Table 28

TOTAL HISTORICAL SILICON CONSUMPTION BY REGION*, 1981-1986
(Million Square Inches)

	1981	1982	1983	1984	1985	1986	CAGR 1981-1986
United States Merchant Mfg.	356	361	453	570	344	429	3.8%
Growth		1.3%	25.6%	25.8%	(39.6%)	24.8%	
Captive Mfg.	114	119	113	137	146	135	3.4%
Growth		4.0%	(5.3%)	21.2%	6.6%	(7.9%)	
United States	470	480	566	707	490	564	3.7%
Growth		2.1%	17.9%	24.9%	(30.7%)	15.0%	
Japan	216	266	428	661	594	573	21.6%
Growth		23.1%	60.9%	54.4%	(10.1%)	(3.5%)	
Europe	101	103	112	160	150	150	8.2%
Growth		2.0%	8.7%	42.9%	(6.3%)	0%	
ROW	12	26	46	63	66	79	45.8%
Growth		116.7%	76.9%	37.0%	4.8%	19.7%	
Worldwide Silicon	799	875	1,152	1,591	1,300	1,366	11.3%
Growth		9.4%	31.7%	38.1%	(18.3%)	5.1%	

*Region of silicon consumption, not country of company ownership

Source: Dataquest
February 1987

Forecast Silicon Consumption by Region

Table 29 contains Dataquest's forecast of silicon consumption by captive and merchant semiconductor manufacturers by region of device production. In general, we believe that the growth in silicon consumption will follow growth in device production revenue in each of the four regions through 1991. We believe the long-term trend will be for silicon consumption (in MSI) to grow more slowly than production revenue (as measured in dollars). This translates to a slowly increasing revenue per square inch as a function of time. Factors that increase revenue per square inch include higher device ASPs and device yields. ASPs will increase as higher-valued products such as ASICs become a larger percentage of the product mix. Yields should improve as manufacturers focus on tighter particulate control and achieve shorter cycle times through manufacturing automation. However, as devices become more complex, die size typically increases. This will slow the upward trend of average revenue per square inch since yields drop with proportionately larger chips.

Table 29

TOTAL FORECAST SILICON CONSUMPTION BY REGION*, 1986-1991
(Million Square Inches)

	1986	1987	1988	1989	1990	1991	CAGR 1987-1991
United States Merchant Mfg.	429	514	681	586	708	910	15.4%
Growth	24.8%	19.8%	32.4%	(13.9%)	20.8%	28.4%	
Captive Mfg.	135	158	185	218	256	300	17.4%
Growth	(7.9%)	17.4%	17.4%	17.4%	17.4%	17.4%	
United States	564	672	867	804	964	1,210	15.8%
Growth	15.0%	19.3%	28.9%	(7.2%)	19.9%	25.5%	
Japan	573	651	814	804	893	1,060	13.0%
Growth	(3.5%)	13.6%	25.0%	(1.3%)	11.1%	18.8%	
Europe	150	182	229	218	266	317	14.9%
Growth	0	22.4%	26.1%	(5.2%)	22.5%	19.0%	
ROW	79	99	146	161	207	254	26.7%
Growth	19.7%	38.6%	47.1%	10.3%	28.5%	22.8%	
Worldwide Silicon	1,366	1,605	2,056	1,986	2,330	2,841	15.4%
Growth	5.1%	17.5%	28.1%	(3.4%)	17.3%	21.9%	

*Region of silicon consumption, not country of company ownership

Source: Dataquest
February 1987

Silicon and Epitaxial Wafer Markets

WAFER SIZE

The changing mix of wafer size is an indicator of the penetration of leading-edge equipment and new fab capacity. Further, as wafer diameter increases, poly usage increases at a more rapid rate, due to greater wafer thickness at the larger diameters. Estimated percent consumption of MSI of silicon by wafer size for 1982 through 1991 is presented in Table 30. This information reflects Dataquest's estimate of wafer size consumption for semiconductor production in North America.

Dataquest does not expect 125mm wafer consumption to reach the maximum levels of 100mm wafers in the United States. This is because the 125mm wafer is viewed as an interim step in the transition to 150mm wafers. The increase of 125mm wafer consumption to 30 percent of square inches in 1985 is believed to have been caused by difficulties that semiconductor manufacturers had in bringing on-line the fab equipment designed to handle 150mm wafers. This situation, coupled with the industry slowdown during 1985, increased 125mm wafer penetration, slowed the expected rise in 150mm wafer usage, and decreased 3-inch wafer usage.

The 100mm wafer will continue to account for the highest percent of consumption (as measured in MSI) for U.S. production until 1989. The 150mm wafer category is expected to increase its share throughout the decade and, by 1991, is expected to account for approximately 52 percent of silicon MSI. Although several U.S. semiconductor manufacturers are working with 200mm wafers in research and development, Dataquest does not expect this wafer size to enter the production environment until 1988.

For convenience, Table 30 has been translated into percent wafer starts, presented in Table 31. Wafer starts are calculated by taking the percent consumption for a given wafer size in a given year, multiplying by the U.S. silicon consumption in that year, and dividing by the number of square inches in that given wafer size.

Note that 200mm wafers are forecast to be 4.6 percent of the wafer size mix as measured in MSI in 1991. This translates to only 1.9 percent of the wafer starts in that year. This seeming paradox is due to the proportionately larger area represented by a 200mm wafer--it is almost 1.8 times larger than a 150mm wafer, 2.5 times larger than a 125mm wafer, and 4.0 times larger than a 100mm wafer. In 1991, 100mm wafers will represent approximately 23 percent of the MSI wafer size mix, as compared with 150mm wafers at 52 percent. However, when calculated in wafer starts, an almost equal number of 100mm and 150mm wafers will be going through U.S. semiconductor processing lines in 1991.

Table 30

UNITED STATES MILLION SQUARE INCH DISTRIBUTION BY WAFER SIZE
(Percent Million Square Inches)
1982-1991

Diameter	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
2 inch	3.0%	2.5%	2.0%	0.5%	0.4%	0.4%	0.3%	0.2%	0.2%	0.1%
3 inch	45.0%	33.0%	21.0%	6.8%	5.9%	5.1%	4.2%	3.4%	2.5%	1.7%
100mm	51.0%	57.0%	63.0%	55.3%	49.9%	44.4%	39.0%	33.5%	28.1%	22.7%
125mm	1.0%	6.0%	11.0%	29.9%	28.9%	27.7%	25.7%	23.4%	21.1%	18.9%
150mm	0.0%	1.5%	3.0%	7.5%	14.9%	22.4%	29.8%	37.2%	44.6%	52.1%
200mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	2.2%	3.4%	4.6%
Total MSI	480	566	707	490	564	672	867	804	964	1,210

Source: Dataquest
February 1987

Table 31

UNITED STATES WAFER START DISTRIBUTION BY WAFER SIZE
(Percent Million Wafer Starts)
1982-1991

Diameter	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
2 inch	8.3%	7.6%	6.7%	2.1%	1.9%	1.7%	1.5%	1.2%	0.9%	0.5%
3 inch	55.1%	44.4%	31.4%	12.8%	11.8%	10.7%	9.4%	8.1%	6.5%	4.6%
100mm	36.2%	44.5%	54.7%	60.5%	57.4%	54.0%	50.4%	46.4%	41.8%	36.4%
125mm	0.5%	3.0%	6.1%	20.9%	21.3%	21.6%	21.2%	20.7%	20.1%	19.4%
150mm	0.0%	0.5%	1.2%	3.6%	7.6%	12.1%	17.1%	22.9%	29.5%	37.2%
200mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.8%	1.3%	1.9%
Total (M)	55.5	59.6	67.0	36.8	40.3	45.4	55.1	47.8	53.3	61.9

Source: Dataquest
February 1987

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SEMICON TOKYO 1986:
WHAT GOES AROUND, COMES AROUND

INTRODUCTION

Each year Dataquest surveys the Semicon Equipment and Materials Expositions at San Mateo, California; Tokyo, Japan; and Zurich, Switzerland. These industry trade shows, sponsored by the Semiconductor Equipment and Materials Institute (SEMI), are yearly milestones for semiconductor equipment and materials vendors.

Last December, SEMS personnel travelled to Japan to visit Semicon Tokyo and to research the state of the equipment and materials industry. This newsletter serves as a report on that visit.

OVERVIEW

We visited a number of semiconductor manufacturing plants. Each plant looked like a ghost town compared to the activity we witnessed in 1984. Through interviews with plant personnel, we learned that each facility reported about 60 percent capacity utilization, which confirms our analysis (which comes from silicon usage) that the total capacity utilization for 1986 was 63 percent. Figure 1, capital spending as a percent of semiconductor revenue for U.S. and Japanese companies, shows quite clearly that Japanese companies "bought" the commodities market from the years 1983 to 1985. This strategy has come around to haunt these companies as the unrelenting business cycle imposes itself on the industry.

Like their counterparts in other world regions, Japanese plant personnel are far removed from the levels where trade agreements, foreign market values (FMVs), and trade sanctions are decided. Nevertheless, they are concerned about whether the United States will take further

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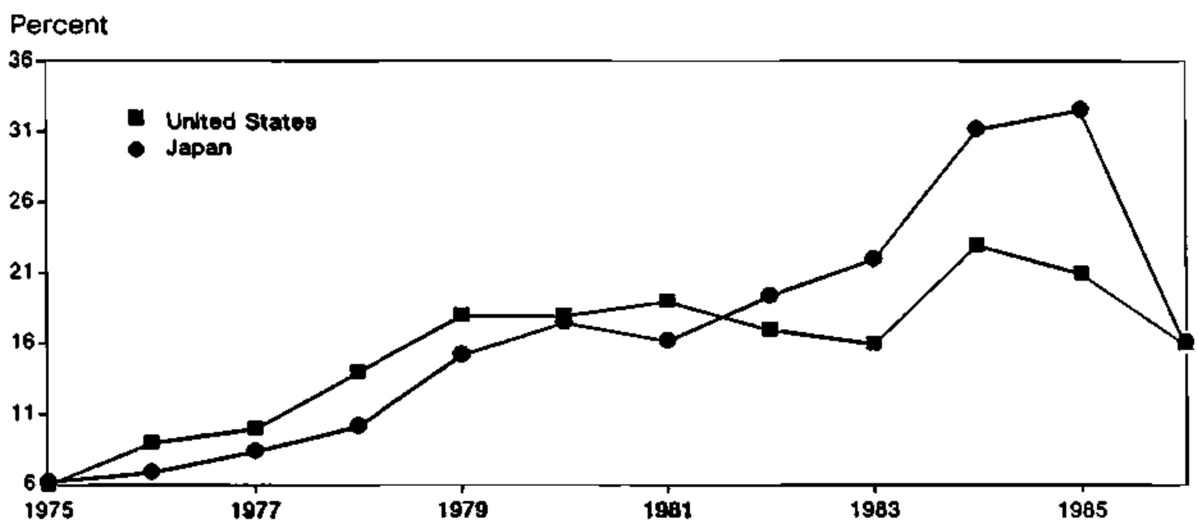
measures to restrict the import of Japanese ICs. The only bright spot in the general atmosphere of pessimism was the robust revenue that came from shipments of application specific ICs (ASICs). Those companies that are active in the ASIC market increased both capacity utilization and revenue.

The atmosphere of pessimism affected Semicon Tokyo, where attendance was 10 percent lower than in 1985. We noticed that there were very few new products but there were many product enhancements that were designed to be user friendly and to increase the users' productivity. The general consensus at the show, derived from dozens of interviews, was that capital equipment expenditures would not increase in 1987 but would wait until the first quarter of 1988. This is consistent with Dataquest's forecast that Japanese capital spending will decrease in 1987.

Figure 1

CAPITAL SPENDING AS A PERCENT OF REVENUE
U.S. VERSUS JAPAN



Source: Dataquest
January 1987

SEMICON TOKYO

Semicon Tokyo continued to outpace Semicon West as the most attended of SEMI's expositions for the second year. This year, a record 868 worldwide corporations participated, marking continual growth in the number of exhibitors for four consecutive years. The number of visitors to the show was about 50,000, which was 10 percent lower than SEMI expected. Table 1 illustrates the history of the exhibitors' profile at the show.

Table 1

SEMICON TOKYO EXHIBITORS BY REGION OF ORIGIN

Country of Origin	1982	1983	1984	1985	1986
Japan	232	327	413	468	507
United States	204	289	288	282	291
United Kingdom	11	15	19	19	22
West Germany	12	14	20	13	14
Other	16	30	28	25	34
Total	475	675	768	807	868

Source: SEMI

A quick analysis shows that the prodigious spending by Japanese semiconductor companies, as indicated in Figure 1, seemed to benefit Japanese suppliers the most as measured by number of exhibitors. Japanese suppliers represented 49 percent of the exhibitors in 1982 but grew to 58 percent of the total in 1986. U.S. companies represented 43 percent in 1982 but fell to only 34 percent of the total in 1986. Other regional suppliers, as a group, held their own during that period at approximately 8 percent of the total. This is but another indication that the semiconductor technological base is shifting to the Pacific rim.

A substantial portion of exhibits was dedicated to products related to magnetic disks, CDs, and LCDs, a reflection of the diversification effort against the backdrop of bearish demand in 1986 and the pessimistic market projection for 1987. Conspicuous by their absence were 200mm wafer processors. The market appears to be premature for movement into larger wafer sizes.

The most popular product categories at the show were testing and measurement (496 exhibits), wafer processing (279 exhibits), and chemicals, parts, and accessories (324 exhibits). The exhibits also included thin-membrane deposition devices and excimer lasers, as well as radiographic lithography instruments, harbingers of the next generation of LSI production technology.

WAFER FAB EQUIPMENT ANALYSIS

We found no company that was sanguine about its own sales or the market in general. Some market segments, such as ion implantation, have been devastated by the prolonged recession. In general, the new products that were introduced at Semicon West last May have not taken off; they are still waiting for the production buys that carry products from R&D sunk-costs into mature profitability. Some of these newer technologies, such as rapid thermal processing (RTP), vertical furnaces, wafer transport systems, new stepper lenses (i.e., I-line and high numerical aperture types), x-ray steppers, in-line wafer inspection systems, and new CVD systems, will have to wait at least three quarters before they see fab expansions. In Japan the waiting will be longer. This delay will put a severe strain on cash flow and will test the pocket depth of equity investors, setting back business plans and timing.

Excess Capacity

Several issues will affect the growth of equipment segments this year. It appears that semiconductor manufacturers are developing processes that will enable them to manufacture 4-Mbit DRAMs using existing optical technology with a modicum of modification. This will certainly increase return on capital in the near term, but will delay production purchases for new capacity until new products are introduced during the 4-Mbit-design-rule era.

However, there are equipment segments that do not have adequate capacity for the new generation of devices, notably deposition and particulate control. As the 1-Mbit and 4-Mbit DRAMs ramp up, these segments should do relatively well for the new products that have been recently released. As these newer equipment technologies make their way out of pilot production lines, we should see a very heated market by the end of 1987. Lagging behind CVD and particulate control in priority will be RTP and inspection.

Lithography Philosophy

We are seeing a polarization of lithography philosophy between Japan and the rest of the world. The two leading stepper manufacturers in Japan, Nikon and Canon, have shown a reluctance to develop a production, I-line lens. Canon has even publicly stated that it will not develop such a lens, but will concentrate on improving the resolution of the G-line lens and bettering the registration of the wafer alignment system. While most of the stepper manufacturers have R&D versions of I-line capability, these Japanese companies seem convinced that high numerical aperture (NA) lenses, even with their concomitant smaller depth of focus, will be the production technique for 4-Mbit DRAMs. Such a strategy implies that semiconductor manufacturers will choose planarization as a processing technique for these devices. Dataquest's research determines that the Japanese semiconductor companies are far more inclined to use this technique than their competitors in the rest of the world.

In the United States, the remaining stepper manufacturers, GCA, Perkin-Elmer, American Semiconductor Equipment Technologies (ASET), and Ultratech (a unit of General Signal), are mixed in their philosophies. GCA and ASET are moving into products based on illuminating with shorter wavelengths. GCA has introduced its I-line lens and will introduce an excimer laser source in 1987; a source that will vastly improve the illumination at this wavelength. ASET has an I-line and is concentrating on niche markets such as gallium arsenide production. Perkin-Elmer has introduced an H-line lens (390nm wavelength). Ultratech, with its 1X, catadioptic lens, will concentrate on improving the performance at its present broadband spectrum (390nm to 465nm).

In Europe, ASM Lithography (a Netherlands-based joint venture between ASM International and Philips, with sales and service in Phoenix, Arizona), has introduced an I-line capability using Zeiss lenses. ASM Lithography has sold this product into silicon markets for advanced products such as megabit memories.

In theory, I-line lenses should outperform longer-wavelength lenses, but the high quality glass that provides low absorption at this wavelength has been in short supply. The high-numerical-aperture G-line lens is a viable alternative (1) if semiconductor manufacturers are willing to compromise their processes to compensate for a smaller depth of focus, and (2) if these process compromises do not reduce the effectiveness of stepper alignment techniques. It is interesting to note that compromises, such as planarization techniques, may be required because of other considerations, which would tend to prolong the life of G-line lenses anyway.

NEW COMPETITION

One of the ways in which Japanese equipment companies have gained entry into the market place has been to spin-off from semiconductor manufacturers. Anelva, originally affiliated with NEC and Varian, and Tokuda, originally affiliated with Toshiba, are examples. When the smaller company reached adequate capacity to supply the market, the parent gave permission for it to become a merchant. This is a natural outcome of the tendency for Japanese manufacturers to engage in considerable equipment development. Two semiconductor manufacturers were conspicuous at Semicon Tokyo this year: Hitachi and Toshiba. (Incidentally, Texas Instruments and Philips also have considerable equipment development.)

Hitachi

Hitachi is one of the leading semiconductor manufacturers in the world. In its fiscal year ending March 31, 1986, Hitachi reported $29.5 billion (¥170 to the dollar), essentially unchanged from fiscal 1985. Dataquest estimates that Hitachi was second in worldwide semiconductor sales at $2.3 billion in calendar 1986, behind NEC and ahead of Toshiba. Hitachi has 164,000 employees and $30.4 billion of assets. The company reports its sales in five main categories:

- Power systems and equipment
- Consumer products
- Information and communication systems, and electronic devices
- Industrial machinery and plants
- Wire and cable, metals, chemicals, and other products

This huge company has developed more types of semiconductor equipment than any one single company, captive or merchant. The Hitachi booth at Semicon Tokyo was very popular and the company had most of its equipment exhibited. Table 2 lists Hitachi's fabrication equipment.

As can be seen by this list of 42 models, Hitachi has had considerable experience in developing equipment. The parent company's semiconductor facilities make excellent beta sites. (Note: A beta site is a manufacturing facility that will test an early version of a product to identify potential problems with the use of the product in production.)

Hitachi's equipment is manufactured in two factories, the Kasado Works and the Naka Works. The Kasado Works manufactures chemical equipment, material-handling equipment, and rolling stock. It is part of the Industrial Processes Group. The Naka Works manufactures scientific and industrial instruments. It is part of the Electronic Devices group, Instrument Division.

Hitachi estimates that its equipment production was 9 percent of the total Japanese market for fab, assembly, and test equipment. By Dataquest's market estimates for the total equipment purchases in Japan in 1986, that would equate to approximately $58 million of equipment sales for Hitachi. The distribution of this equipment is through Hitachi, Ltd. and Nissei Sangyo, a wholly owned subsidiary. Nissei Sangyo also manufacturers some of Hitachi's equipment in two factories.

Hitachi is active in the marketing of several types of fab equipment and will become more active in others. The fab equipment to watch from Hitachi in the near future is the reduction stepper, the high current ion implanter, the sputtering system, the electron beam system, and the microwave dry etcher. For instance, we expect Hitachi to introduce a Zeiss, I-line lens in 1987 capable of 0.15 micron registration (3 sigma) in 1987. We also expect that the company will actively market its microwave etcher in the United States in 1987 or in early 1988. With the right marketing and support, any of the above systems could become leading products in their respective markets.

Table 2

HITACHI'S SEMICONDUCTOR FABRICATION

Model	Type	Comments
Production Equipment		
HL-700	E-beam lithography	
LD-5010A	Reduction stepper	
FEB S-6000	CD measurement	Automatic wafer loading
FEB S-900	Super CD measurement	
PD-1000	Reticle/mask inspection	
M-206A	Microwave dry etcher	Single wafer, RIE
PS-306A	Sputtering	
TVP-60	Turbo vacuum pump	Oil free
WD-6100-P	Plasma CVD	Single wafer
IP-825A	High current implanter	
HLD-100M	Mask substrate inspection	
WF-610	Photoresist coater	Automatic
LAMU-600	CD measurement	
UG-12360-P	Gas analyzer	
PM-1400	Photoresist stripper	Wet
SEB-W100	Wafer polisher	
HILIS-200	Wafer inspection	Patterned wafers
LS-5000	Laser surface testing	
CD-10/CD-11	Wafer drying	
S-806	SEM inspection	
H-9000	Electron microscope	
IMA-3	Ion microanalyzer	

(Continued)

Table 2 (Continued)

HITACHI'S SEMICONDUCTOR FABRICATION

Model	Type	Comments
Assembly Equipment		
WB-230-TS	Wire bonder	Automated
AU-1200A	IC assembly	Multiple pin
AT-2000A	IC assembly	
AT5000	Ultrasonic detection	
EC-126MH2	Temp./humidity bath	
ES-64LTA	Heat shock test	
FH-103	FPP handler	
EA-175MT	Dynamic edging	
EA-8821HC	PLCC type 8 handler	High/low temperature
EA-61611H-FA	DIP type 16 handler	High temperature
Facilities Equipment		
KCL	Clean line	KCL type
TS-1400	Dust monitor	
DCV-1600BY	Clean draft chamber	
SC-30TT	Clean room unit	Temperature controlled
PCJ-750GII	Air shower	
PCV	Clean bench	PCV type
Clean Liner	Wafer transfer system	
Clean Carrier	Automatic guided vehicle	For clean room
DSP-15A5	Air compressor	Oil free, air cooled
CSV-5Z4	Vacuum pump	Oil free, screw type

Source: Hitachi

Toshiba Machine Co., Ltd.

Toshiba Machine is a wholly owned subsidiary of Toshiba Corporation. The corporation had sales of $14.1 billion in its fiscal year ending March 31, 1985. Dataquest estimates that the Electronic Components and Industrial Electronic Business Division had $4.7 billion in revenue in that fiscal year. Dataquest estimates that Toshiba's semiconductor revenue for calendar 1986 was $2.3 billion, which puts it third in the world, behind Hitachi and ahead of Motorola.

Toshiba Machine also has a captured user and an excellent beta site in its sister division, the electronics components division. This division has rapidly advanced the company's worldwide semiconductor market share, jumping from fifth in 1985 to third in 1986. Toshiba is the largest user of equipment from Toshiba Machine, typically using 70 percent of its production. Table 3 is a listing of the equipment that is available from Toshiba Machine.

Toshiba had exhibited a new product at Semicon Tokyo: a radiantly heated, cylinder-type reactor. Toshiba's installed base of epitaxial reactors is approximately 60 reactors, 70 percent of which are internal installations. We believe that most of the equipment it produces is used in the sister company, Toshiba Semiconductor. However, we suspect that Toshiba's manufacturing capacity may be high enough to be considered potential competitors in each of the segments the company addresses. Semiconductor-related equipment is manufactured at Toshiba's Numazu Plant along with machine tools, plastics-processing machines, precision molds, and beverage-dispensing equipment.

Table 3

TOSHIBA MACHINE'S SEMICONDUCTOR PRODUCTION EQUIPMENT

Model	Type	Comments
MCG-150S	Silicon growing reactor	100mm to 150mm capacity
DSPM-1000B	Wafer polishing system	100mm to 150mm capability
EGV-28F	Epitaxial reactor	Vertical configuration with several models, 100mm to 125mm capability
EPM-130/40P	E-beam exposure system	Masks and reticles only
APC-130R	Reticle inspection system	Compares reticles to design data
APF	Wafer track system	Scrubber, dehydrator, coater, developer, 125mm to 150mm wafers
CVA-5/6	Atmospheric CVD system	Continuous belt feed, 100mm to 150mm wafers
MTS-250	IC molding press	
EBT	E-beam tester	In-circuit inspection of electrical signals

Source: Toshiba Machine Co.

Automation

Wafer transport systems have always been a major emphasis in the automation programs of Japanese semiconductor manufacturers. In our visits to Japanese semiconductor plants, we have noted the presence of sophisticated cell-to-cell wafer transport systems, which have included both automatic guided vehicles (AGVs) as well as elevated wafer tracks running between processing bays. These cell-to-cell wafer transport systems have typically been designed in-house at a semiconductor manufacturer's plant, and either built by a sister division within the company, or the construction has been contracted to an outside engineering firm. At Semicon Tokyo this year, both Shimizu Construction Co. and Toshiba Corporation announced what Dataquest believes are the first commercially available products for wafer transport systems from Japanese companies.

Shimizu Construction has combined efforts with Shinko Electric to jointly develop CLEANWARP, an automatic wafer transport system. The CLEANWARP product includes a stocker system, an interprocess transfer system to transfer wafer cassettes between processing bays, an intraprocess transfer system that includes robotic load/unload at designated processing equipment, and a system controller to link with the shop floor's host computer. The full system can support 13 processing bays and has been designed for a class 10 (0.1 micron particle size) clean room environment.

Toshiba's product is a magnetically levitated carrier system that includes overhead traffic guideways and elevator stations for load/unload processing of wafer cassettes. The system is manufactured by Toshiba's Heavy Apparatus Division (which also builds AGVs), and is being marketed by Toshiba's Factory Automation and Industrial Electronic Components Group. The system has been designed for a class 10/100 clean room environment, and is currently being tested at Toshiba semiconductor manufacturing locations.

Both products will be available in the spring of 1987. Preliminary prices of these systems will be on the order of ¥1,000,000 per meter of transport system. At the 1986 exchange rate of 167 yen per dollar, this would correspond to approximately $6,000 per meter, or $750,000 for a 125-meter distance.

Dataquest believes that these are the first wafer transport systems to be offered by Japanese manufacturers. Several competitive products are already available from U.S. manufacturers including flexible AGVs from FMS and Veeco, and fixed wafer transport systems from Nacom, Programmation, and Shuttleworth. Both Toshiba and Shimizu are leveraging existing technology and automation know-how to penetrate an as-yet-untapped product segment within the automation products market in Japan.

SEMICONDUCTOR PROCESSING MATERIALS

Like a cascade of falling dominoes, Japanese electronic materials companies along with process equipment companies and semiconductor manufacturers, have felt the impact of the continuing semiconductor industry recession. Japanese materials companies have been affected by decreased demand for their products, downward pricing pressures from semiconductor manufacturers, and intense domestic competition for market share. In addition, the appreciation of the yen in 1986 has further reduced market opportunities and penetration strategies in markets overseas. This final portion of our newsletter focuses on the three major processing materials used in wafer fabrication--silicon, photoresist, and gases--and describes the current market conditions for these materials in Japan.

Silicon

In 1985, Japanese semiconductor manufacturers consumed 594 million square inches (MSI) of silicon, down 10 percent from 1984's consumption of 661 MSI. Dataquest believes that demand for silicon and epitaxial wafers remained essentially flat in 1986, and that only modest growth on the order of 10 percent will occur in 1987.

The silicon market in Japan is strongly dominated by the domestic merchant silicon manufacturers that had a combined market share of 97.5 percent of the $648.6 million silicon and epitaxial wafer market in 1985. The major Japanese merchant silicon companies are Shin-Etsu Handotai, Osaka Titanium Corporation, Nippon Silicon (a subsidiary of Mitsubishi Metal, Nippon Silicon is also known as Japan Silicon or JASIL), Komatsu Electronic Metals, and Toshiba Ceramics. Captive silicon production in Japan is limited to only one major semiconductor manufacturer, Hitachi, which meets 25 percent to 30 percent of its needs with internal silicon production.

There were two new entrants in the Japanese silicon market in 1986, Nittetsu Denshi (a subsidiary of Nippon Steel) and Showa Denko. Showa Denko brings 10 years of experience in compound semiconductor material manufacturing and an existing distribution network, factors that Showa Denko hopes will provide it with a competitive advantage. Nittetsu Denshi (also referred to as Nittetsu Shoji or NSC Electron) was established as a wholly owned subsidiary of Nippon Steel in June 1985. In addition to financial backing, the steelmaker can provide its new venture with a strong background in support technologies for silicon manufacturing such as crystal growth control and precision measurement. To speed its entry into the silicon market, Nippon Steel has agreed to provide Hitachi Ltd. a stable supply of silicon wafers from its new subsidiary in exchange for technological assistance. Both Showa Denko and Nittetsu Denshi started sampling 125mm polished wafers in the third quarter of 1986, and industry sources expect both companies to be significant competition in the 1987/1988 time frame.

If domestic competition were not enough, Japanese silicon companies also faced the pressures of restricted markets overseas because of the yen appreciation in 1986. Silicon wafer pricing has always varied from region to region. However, Japanese silicon companies found it difficult to compete in the U.S. and European markets in 1986 due to large differences in wafer pricing affected by exchange rate factors. For example, in 1984, the average price of a 100mm wafer in the United States was $10.50. At an exchange rate of ¥237 per US$1, a Japanese silicon company would receive ¥2,490 for a 100mm wafer. In 1986, the average selling price of a 100mm wafer in the United States came down to $10.00. However, at the 1986 exchange rate of ¥167 per US$1, a Japanese silicon company would now only receive ¥1,750 for a 100mm wafer in the United States.

Because of the high yen, Japanese silicon companies exporting silicon wafers to the United States have two options: 1) meet and maintain U.S. average selling prices for wafers and lose on margins in order to maintain U.S. market share and customer relationships, or 2) raise wafer prices in the United States to regain a given yen rate of return, and as a consequence, lose market share. Similar analysis of wafer pricing for 125mm and 150mm wafers confirms that Japanese silicon companies in 1986 were caught between the proverbial rock and a hard place, and had difficulty in competing for silicon sales overseas.

While the high yen has made silicon exports from Japan prohibitive, it has also made the acquisition of U.S. firms more attractive. In 1986, two more Japanese silicon companies have chosen to compete in the U.S. market by acquiring U.S.-based silicon manufacturing capability. Mitsubishi Metal acquired Siltec in the third quarter of 1986, and Osaka Titanium announced its plans in December to acquire U.S. Semiconductor, an epitaxial silicon wafer manufacturer.

Other Japanese companies that have established or acquired silicon facilities in the United States include silicon manufacturer Shin-Etsu Handotai (established SEH America, a wholly owned subsidiary in Vancouver, Washington) and steelmakers Kawasaki Steel and Nippon Kokan K.K. Kawasaki Steel acquired Santa Clara-based NBK Corporation in 1984, while Nippon Kokan K.K. bought Great Western's polysilicon facility in 1985. In December, Nippon Kokan K.K. announced its purchase of land in Oregon for a new 1,000 metric-ton polysilicon plant.

Photoresist

The consumption of photoresist in a given region of the world is strongly tied to the consumption of silicon wafers, so, as goes silicon, so goes photoresist in Japan. In 1986, photoresist manufacturers supplying the Japanese semiconductor industry experienced growth on the order of a few percent in photoresist (by volume) over the approximately 1,075,000 liters (284,000 gallons) of optical resist consumed in 1985. The photoresist market size in yen increased in 1986 due to the trend toward increased usage of positive resist (47 percent positive in 1986 versus 42 percent in 1985). Positive optical resist traditionally commands a price approximately four to five times that of negative resist so as a market shifts toward increased positive resist consumption, even with little or no growth in volume, the market value increases.

However, in Japan in 1986, the increased usage of positive resist was offset by the decrease in the average selling price of positive resist; down on the order of 10 percent in yen in 1986 over 1985's price of ¥17,500 per liter. Downward pricing pressure for both positive and negative resists in Japan reflects aggressive pricing policies of the smaller resist companies attempting to wrest away a few percentage points of market share from the market leader, Tokyo Ohka Kogyo (TOK). Dataquest estimates that in 1985, TOK had approximately 65 percent to 70 percent of the optical resist market in Japan. Other major suppliers to the optical resist market in Japan include Dainippon Ink and Chemicals, Fuji-Hunt, Hoechst Japan, Japan Synthetic Rubber, Merck Japan, Shipley Far East, and Sumitomo Chemical. In its efforts to expand its presence in overseas markets, TOK recently opened a new sales office and warehouse center in Livingston, Scotland for packaging and storage of TOK resist materials for distribution to the European market.

Semiconductor Process Gases

The semiconductor process gas manufacturers in Japan have felt many of the same competitive pressures as the silicon and photoresist companies. Nitrogen, however, represents a large percentage of the market value of the bulk gases, and since the nitrogen market exhibits remarkable stability during industry recessions, bulk gas suppliers have not been affected to quite the same extent as the specialty gas companies. (The other bulk gases--argon, hydrogen, and oxygen--as well as the specialty gases, typically track with silicon and photoresist consumption.)

The semiconductor gas companies have focused on international alliances in order to survive in a global competitive market. At the Semicon Tokyo show, the booths of the Japanese semiconductor gas companies prominantly displayed the logos, literature, and equipment of their international partners. Table 4 illustrates those relationships between Japanese gas companies and their foreign partners that are based on investment position, joint ventures, or ownership.

In addition to the formal investment positions identified in Table 4, several Japanese specialty gas companies at Semicon Tokyo identified their major supplier relationships through promotional displays; examples include Seitetsu Kagaku (obtains silane from the Linde division of Union Carbide) and Tokyo Kaseihin Co., Ltd. (supplies excimer and other laser source gases from Messer Griesheim).

Table 4

SEMICONDUCTOR GAS COMPANIES AT SEMICON TOKYO

Foreign Partner		Japanese Gas Company	Nature of Relationship
Air Products	------>	Daido Sanso	Air Products has investment position in Daido Sanso
Linde	<------>	Iwatani	Linde and Iwatani have joint venture, Iwatani Industrial Gases
Matheson	<------	Nippon Sanso	Nippon Sanso has ownership position in Matheson through joint venture with Amerigas
B.O.C.	------->	Osaka Sanso	B.O.C. has investment position in Osaka Sanso
L'Air Liquide	------->	Teisan	Teisan is wholly owned by L'Air Liquide

Source: Dataquest
January 1987

These international partnerships are particularly important in the area of specialty gases, since no one specialty gas company has full manufacturing capability for all of the specialty gases. Thus, it is necessary to obtain some types of specialty gases from other gas companies. For example, Japan currently has no primary manufacturing capability for arsine gas, though industry sources indicate that Furukawa Electric may consider building such a facility in the near term. Dataquest believes that the only primary manufacturer of phosphine in Japan is Nissan Kogyo K.K., a subsidiary of Nippon Sanso, and its sales of phosphine are limited to its parent company. Therefore, the specialty gas companies in Japan are dependent on international partners to maintain the supply and flow of these vital dopant gases into Japan to support semiconductor device fabrication.

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The Education Market for PCs in Europe

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Who's Who in CAD/CAM 1986

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Conference Schedule

1987

Semiconductor Users/Semiconductor Application Markets	February 4-6	Saddlebrook Resort Tampa, Florida
Copying and Duplicating	February 23-25	San Diego Hilton Resort San Diego, California
Imaging Supplies	February 25-26	San Diego Hilton Resort San Diego, California
Electronic Printer	March 23-25	Silverado Country Club Napa, California
Imaging Supplies	March 25-26	Silverado Country Club Napa, California
Computer Storage	April 6-8	Red Lion Inn San Jose, California
Japanese Semiconductor	April 13-14	The Miyako Kyoto, Japan
Color Conference	April 24	Red Lion Inn San Jose, California
European Telecommunications	April 27-29	The Beach Plaza Hotel Monte Carlo, Monaco
CAD/CAM	May 14-15	Hyatt Regency Monterey Monterey, California
Graphics/Display Terminals	May 20-22	San Diego Hilton Resort San Diego, California
European Semiconductor	June 4-5	Palace Hotel Madrid, Spain
European Copying and Duplicating	June 25-26	The Ritz Hotel Lisbon, Portugal
Telecommunications	June 29-July 1	Silverado Country Club Napa, California
Financial Services	August 17-18	Silverado Country Club Napa, California
Western European Printer	September 9-11	Palace Hotel Madrid, Spain
Manufacturing Automation	September 14-15	San Diego Hilton Resort San Diego, California
Business/Office Systems and Software	September 21-22	Westford Regency Hotel Littleton, Massachusetts
Asian Peripherals and Office Equipment	October 5-8	Tokyo American Club Tokyo, Japan
Technical Computers	October 5-7	Hyatt Regency Monterey Monterey, California
Semiconductor	October 19-21	The Pointe Resort Phoenix, Arizona
Office Equipment Dealers	November 5-6	Hyatt Regency Monterey Monterey, California
Military IC	November 12	Hotel Meridien Newport Beach, California
Electronic Publishing	November 16-17	Stouffer Hotel Bedford, Massachusetts
Asian Information Systems	November 30-December 4	Tokyo, Japan
CAD/CAM Electronic Design Automation	December 10-11	Santa Clara Marriott Santa Clara, California

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Research Newsletter

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1987-8

III-V MATERIALS--WHO'S ON FIRST?

Since our August 1986 newsletter on GaAs materials, the compound semiconductor materials situation has evolved into a new game. In most high-technology business areas, innovation never ceases, leading to gyrations in the competitive lineup. The III-V materials industry is no exception.

Recent developments that we consider worth watching include:

- GaAs on Si substrates
- Progress in NDF wafer manufacture
- New entrants and start-ups
- Increases in the price of gallium in Japan
- Innovations in InP manufacture

DATAQUEST ANALYSIS

Although Sumitomo Electric in Japan is the acknowledged leader in GaAs wafers with an estimated world market share of 50 percent, the competition is heating up with major expansions under way. For this newsletter, Dataquest identified 39 companies in the Free World marketplace that are involved in compound semiconductor materials manufacturing operations. These include 18 in the United States, 2 in Canada, 11 in Japan, 3 in West Germany, 2 in the United Kingdom, 2 in France, and 1 in Sweden. As we predicted earlier, materials companies are becoming increasingly aggressive in their attempts to establish a significant presence in this market.

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A key factor in the growth of the compound semiconductor industry is the ability to move into LSI and VLSI levels of integration. This movement is presently limited by the quality of substrate material. Although NTT announced development of a 16K SRAM in 1984, none of the device suppliers has been able to mass-produce the chip for the commercial market, at any price. Dataquest believes that recent laboratory work by Westinghouse and others on GaAs crystal growth has resolved the technical problems associated with VLSI from the standpoint of materials. Which company or companies will be first to benefit from this in the merchant market is not yet clear.

A promising alternative to GaAs substrates is the possible move to GaAs on silicon substrates, with pioneering work under way at start-up Kopin Corporation and other companies. Vertically integrated companies believed to be working in the field of GaAs on Si include AT&T Bell Laboratories, Ford, Fujitsu, GTE, HP, NEC, NTT, Oki, Texas Instruments, and Xerox. TI demonstrated a 1K SRAM implemented on a GaAs on Si substrate, in 1986. IBM's position in this area is not known, although it is believed to be heavily engaged in GaAs device and chip development, and has publicized its work on GaAs ballistic transistors. GaAs on Si, when perfected, will also significantly reduce wafer and, therefore, chip costs, bringing GaAs cost/performance at the system level much closer to that of Si ECL.

Table 1 summarizes the activities of merchant suppliers of GaAs and other compound semiconductor materials companies. It is arranged alphabetically and identifies the companies' corporate nationalities, major compound semiconductor products, methods of manufacture, wafer sizes, expansion plans, and other information that Dataquest believes is of value to its clients.

In addition to Kopin Corporation, the table shows other compound semiconductor materials start-up companies including Picogiga (France) and Preussag AG (West Germany). Dataquest expects 1987 to bring more new players to this field, as if it weren't crowded already.

Peggy Wood
Gene Miles

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Table 1

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Airtron	U.S.	GaAs undoped and Si-doped wafers	Growth method: LPLEC Firm is a division of Litton Industries 2", 2.5", and 3" wafers available
Bertram Labs	U.S.	GaAs wafers	Growth method: HB 2" GaAs wafers available
Boliden Finemet AB	Sweden	GaAs wafers	Growth method: HPLEC 2" and 3" GaAs wafers available
Cominco Electronic Materials	Canada	GaAs GaSb, InSb, InAs, CdTe, HgTe, and CdHgTe wafers	Growth methods: HPLEC, HB Completed expansion of LEC GaAs wafer plant in Trail, BC, Canada in 1985. Capacity 250K sq. in./year; 2", 3", and 4" wafers available
Commercial Crystal	U.S.	GaAs, GaP, InP wafers	Growth methods: LEC, HB 2" wafers available
Cryscon Technologies	U.S.	GaAs wafers	Growth method: LEC Subsidiary of Alcan Aluminum of Canada. Started shipping GaAs Q4/85. Cryscon supplies 2" and 3" GaAs wafers produced by LEC and electrodynamic gradient freeze (EFG) technique. Annual capacity approx. 2 million sq. in./year. Cryscon was for sale as of 10/22/86
Crystacomm Inc.	U.S.	InP crystals and wafers	Growth method: LEC 2.5" wafers available
Crystal Specialties	U.S.	GaAs wafers, MOULD epi reactors	CSI became subsidiary of Kollmorgen Co. in summer 1984. Wafer facility moved to Colorado Springs, CO, from Ephraim, UT, in Q3/86; reactor facility in Portland, OR
Dowa Mining	Japan	GaAs, InP wafers, poly InP, high purity In	Growth method: HB Research lab located in Akita
EMCORE	U.S.	GaAs epitaxial wafers (MOCVD epi reactors)	Start-up in New Jersey Founded in late 1984 2" and 3" wafers
Epitaxy	U.S.	Epi wafers, photodetectors	Start-up in Puncton, NJ, founded in 1984. Adding InGaAs layer onto InP wafers for photonics and other applications
Epitronics	U.S.	GaAs expitaxial wafers	MOCVD and LPE epi methods Subsidiary of Alcan Aluminum of Canada

(Continued)

Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Furukawa Electric	Japan	GaAs, InP wafers, GaAs epi wafers	Growth method: LEC Wafers produced at Tokyo lab
GAIN Corporation	U.S.	GaAs epi wafers	Production expected in 1987
Galarix Corporation	U.S.	GaAs wafers, poly and single-crystal GaAs ingots	Growth method: HB Started in 1983 as research organization Marketing of GaAs materials primarily focused toward R&D facilities
Gallium Arsenide Substrates	U.S.	GaAs wafers, poly and single-crystal GaAs ingots	Using gradient freeze process with less than 1,000 dislocation defects/square cm Capitalized with $1 million in private funding
Hitachi Cable	Japan	GaAs, InP epi wafers, single-crystal GaAs ingots	Growth method: LEC Production of III-V materials at Takasago plant in Ibaraki. Investing ¥2 billion to expand two plants including epi plant at Kidaka
Hitachi Metals	Japan	Single-crystal GaAs ingots	Growth method: LEC Developing single-crystal undoped GaAs
ICI Wafer Technology	U.K.	GaAs, InP wafers, poly and single-crystal GaAs and InP ingots	Growth method: LEC ICI bought Cambridge Instruments' III-V operations in 1/85. 2" and 3" GaAs and 2" InP wafers available
Iwaki Handotai	Japan	GaAs wafers	Growth method: LEC 50-50 joint venture of Furukawa Mining/Shin-Etsu Handotai (SEH), founded 1982. Plant in Fukushima prefecture began 2" and 3" wafer production in June 1983. SEH began shipping 2" GaAs wafers to subsidiary, SEH America, from Iwaki Handotai June 1985. 3" wafers available in R&D quantities
Kopin Corporation	U.S.	GaAs-on-Si wafers	Start-up in Taunton, MA 3" and 4" wafers. Developing MOCVD epi process
M/A-COM Semiconductor Products	U.S.	GaAs and GaAs epi wafers	Growth method: LEC Merchant sales as well as captive consumption of GaAs wafers. Microwave Assoc. Ltd. is M/A-COM distributor in the United Kingdom
MCP Limited	U.K.	GaAs wafers	Located in Wembley, Middlesex, England

(Continued)

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Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Metal-Specialties Inc.	U.S.	GaAs, GaP, GaSb InAs, InP, InSb wafers	Growth methods: LEC, HB
Meteaux Speciaux	France	InP ingots wafers	Growth method: LEC Plant located in Moutiers, France Production expected mid-1987
Mitsubishi Metal Corporation	Japan	GaAs wafers	Growth methods: LEC, HB Wafer plant located in Omiya, Saitama prefecture. Nissho Iwai Corp. is the U.K. distributor
Mitsubishi Monsanto Kasei (MMK)	Japan	GaAs, GaP wafers	Growth methods: LEC, HB Production system for 3" NDF GaAs wafers developed at Tsukuba plant. MMK spending ¥3 billion for expansion; plans to double sales by 1989. Planned capacity is 500 wafers/month. MMK using NTT's vertical magnetic CZ method to produce 3" wafers with 10 defects/ square cm. max. MEMC to sell MMK wafers in U.S. market
Morgan Semiconductor (division of Ethyl Corp.)	U.S.	GaAs wafers; GaAs epitaxial wafers	Growth methods: LEC, HB Started sampling LP LEC 3" GaAs wafers in 1984; med. pressure LEC 3" GaAs in September 1986. Shipment of 2" and 3" GaAs epi wafers began 4Q/1986
Nippon Mining	Japan	InP wafers, poly and single-crystal InP, single-crystal GaAs and CdTe ingots	Growth method: LEC First Japanese company to grow NDF 3" InP crystal material. Nimio (Cupertino, CA) is a Nippon Mining subsidiary; purpose is to promote sales of GaAs, InP, CdTe, other III-V and II-VI materials in the U.S. market
OMVPE Technologies	Canada	GaAs epitaxial wafers	Start-up located in St. Laurent, Quebec, Canada
Picogiga	France	GaAs epi wafers	Start-up with $4 million in private funding, located in Les Ulis (Orsay). Began operation in August 1986. 2" GaAs MBE wafers
Preussag AG	West Germany	GaAs wafers	New division of Preussag, located in Gossiar, West Germany. Spending $30 million+ to develop wafer capability. Preussag is a major mining interest and supplier of Ga material.

(Continued)

Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Raytheon	U.S.	GaAs epitaxial wafers	Growth methods: LEC, HB
Showa Denko	Japan	GaAs, GaP, InP wafers	Growth method: LEC First company in Japan to produce InP wafers by MLEC. Sampled reduced-defect GaAs wafers in summer 1985
Siemens Company, Inc. Opto Div. (Litronix)	U.S.	GaAs wafers	Growth method: HB Facility located in Cupertino, CA 1.6" to 3" wafers available
Spectrum Technology	U.S.	GaAs wafers	Growth method: HP and LP LEC Spectrum founded in 1982, acquired in Q2/1985 by NERCO Advanced Materials, Inc. (Portland, OR), a large mining interest
Spire Corporation	U.S.	GaAs epitaxial wafers and equipment	Located in Bedford, MA. MOCVD growth of III-V and II-VI compounds, including GaAs, AlGaAs, GaAsP, InP, ZnS, ZnSe on 2" and 3" substrates
Sumitomo Electric	Japan	GaAs, GaP, InP, InSb, InAs, GaSb wafers	Growth method: LEC, HB Largest III-V substrate supplier in the world; 50 percent share of GaAs market. Has capacity for 3,000 3" GaAs wafers/month. GaAs material produced in Itami City (north of Osaka), Hyogo prefecture
Sumitomo Metal Mining	Japan	GaAs, GaP and CdTe wafers	Growth method: LEC
United Epitaxial Technologies	U.S.	GaAs and AlGaAs epitaxial wafers	Start-up in Oregon; received approx. $5 million in first-round venture funding. Founded mid-1984. Working with Crystal Specialties to develop MOCVD equipment. 2" and 3" epi wafers
Wacker	West Germany	GaAs, GaP InP wafers	Growth methods: LEC, HB Shipping 2" and 3" epi wafers

Note: LPLEC = Low Pressure Liquid-Encapsulated Czochralski, HB = Horizontal Bridgeman, HPLEC = High Pressure Liquid-Encapsulated Czochralski, LEC = Liquid Encapsulated Czochralski, MOCUD = Metal Organic Chemical Vapor Desposition, LPE = Liquid Phase Epitaxy, MBE = Molecular Beam Epitaxy, MLEC = Magnetic Liquid-Encapsulated Czochralski

Source: Dataquest
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A CLIMATE OF CONSOLIDATION: UNION CARBIDE ACQUIRES KODAK RESIST OPERATIONS

On Tuesday, May 5, Eastman Kodak announced the sale of its photoresist operations to Union Carbide Corporation. Dataquest views this acquisition as an important strategic move on the part of Union Carbide to strengthen its position as a major electronic materials supplier to the semiconductor industry. The sale of Kodak's resist operations to Union Carbide is one of the many examples of the mergers, acquisitions, and consolidation that currently characterize the business climate within the industry. This research bulletin details the acquisition, provides a brief overview of the semiconductor photoresist industry, discusses the sale of Kodak's resist operations in light of its impact on other resist companies, and concludes with a look at Union Carbide's position in the electronic materials market.

THE SALE OF KODAK'S RESIST OPERATIONS

With the acquisition of Kodak's photoresist operations, Union Carbide obtains the manufacture and sales of Kodak photoresist products, including both macro- and microresists and the ancillary products. Application markets for Kodak's macroresists include printed circuit boards, gravure cylinders, and chemical milling. Microresists are used in the semiconductor industry to transfer circuit patterns to wafers and photomasks. Current Kodak microresists include positive and negative optical resists, negative e-beam and negative X-ray resists. In addition to existing resist technology, Union Carbide has acquired Kodak's current research projects in advanced photoresist materials. This research includes product development in new deep-UV, e-beam, and X-ray resist materials.

The Kodak resist products will be customized, packaged, and distributed by KTI Chemicals, Inc., a wholly owned subsidiary of Union Carbide. This should not be viewed as a new avenue of business for KTI Chemicals--the company has been a major supplier of Kodak photoresist products for many years. KTI, however, does not have primary resist manufacturing capability within its organization. Although Union Carbide has been involved in some R&D aspects of photoresist development, Dataquest believes that the acquisition of Kodak's technology will substantially augment Union Carbide's existing programs. Photoresist manufacturing will occur at Union Carbide's plant in South Charleston, West Virginia, where its Chemicals and Plastics Group has its primary manufacturing facility.

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SEMICONDUCTOR PHOTORESIST INDUSTRY OVERVIEW

Approximately thirty companies supply photoresist to the worldwide semiconductor industry for device fabrication and maskmaking applications. Resist product categories include positive and negative optical resists, deep-UV, e-beam, and X-ray resists. The majority of these photoresist companies have primary manufacturing capability; however, some vendors supply only reformulated resist products. Photoresist reformulators purchase bulk resist materials from other resist companies, formulate and custom blend the photoresist products according to individual customer specifications, and provide focused technical support and service to their customers. This type of service-oriented approach to materials distribution in the photoresist market was pioneered by KTI Chemicals in the mid-1970s. KTI currently provides reformulated resists based on products from AZ Photoresist, Eastman Kodak, Shipley Corporation, and Toray Industries of Japan.

ACQUISITION IMPACT ON OTHER SUPPLIERS

Eastman Kodak does not sell its microresists directly to semiconductor manufacturers, but instead has depended on reformulator companies to do so. In the United States, these companies are J.T. Baker, KTI Chemicals, and ROK Industries (Chemtech Microelectronic Chemicals Industries). Micro Image Technology supplies Kodak resists to the European semiconductor community while Nagase Chemicals, Eastman Kodak's exclusive distributor in Japan, supplies Kodak microresists in that country. Dataquest believes that, of these five companies, KTI is the largest supplier of Kodak microresists.

What Now?

Union Carbide and KTI Chemicals have planned in the short term to continue to honor existing supplier/distributor relationships with the other microresist reformulator companies. Long-term continuation of such relationships will be under evaluation during the next few months. Dataquest, however, expects that the Kodak microresist supplier relationship with other reformulator companies will be severed since KTI Chemicals is a direct competitor with these companies in the photoresist market place.

CONCLUSION

Union Carbide was a logical suitor for Kodak's resist operations. Through its subsidiary, KTI Chemicals, Union Carbide already has an established photoresist distribution network as well as years of experience with the Kodak resist line. The acquisition of Kodak's resist operations provides Union Carbide with a strong base of primary manufacturing technology for photoresist, a factor that Dataquest believes is essential for establishing a significant market-share position in this electronic materials segment. The strengthening of Union Carbide's photoresist operations enhances the company's position overall as a major worldwide supplier of electronic materials to the semiconductor industry. In addition to photoresist, Union Carbide has extensive operations in polysilicon as well as in bulk and specialty semiconductor gases. Dataquest views the acquisition of Eastman Kodak's resist operations by Union Carbide as another example of the continuing process of consolidation within a maturing semiconductor industry.

Peggy Marie Wood

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SILICON AND EPITAXIAL WAFER MARKETS: AN INDUSTRY OVERVIEW

Dataquest recently completed an analysis of the worldwide silicon and epitaxial markets. This newsletter provides an overview of silicon and epitaxial wafer companies, the silicon and epitaxial wafer market size by region, the effects of yen appreciation on wafer pricing, and concludes with Dataquest's forecast of silicon consumption by region and U.S. wafer size distribution.

MARKET SUMMARY

In 1985, silicon and epitaxial wafer sales to the worldwide semiconductor industry by merchant silicon companies were $1,266.5 million. Silicon wafers accounted for $1,020.9 million (80.6 percent) of this figure, and epitaxial wafer sales accounted for $245.6 million (19.4 percent). These sales represented 1,038 million square inches of silicon wafers and 85 million square inches of epitaxial wafers. The average selling price of silicon wafers ranged from $0.90 to $1.00 per square inch as compared with $2.80 to $2.90 per square inch for epitaxial wafers. Several semiconductor manufacturers have captive production of silicon material, which accounted for an additional 177 million square inches of silicon that year. When merchant wafer sales are added to captive silicon production, total silicon consumption amounted to 1,300 million square inches in 1985.

Table 1 summarizes worldwide silicon and epitaxial wafer sales (and market share) for the top six merchant silicon companies in 1985. The market is strongly dominated by four Japan-based silicon companies, Monsanto of the United States, and Wacker of West Germany.

SILICON PRODUCERS

Dataquest defines companies that produce silicon and epitaxial wafers as either merchant silicon companies or captive silicon producers. Merchant silicon companies are suppliers such as Monsanto Electronic Materials Company

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in the United States, Shin-Etsu Handotai (also known as SEH) in Japan, and Wacker in Western Europe. These three merchant silicon companies, along with about 20 more companies worldwide, produce most of the silicon consumed by the semiconductor industry today.

Silicon is also produced to a lesser extent by both merchant and captive semiconductor manufacturers. Dataquest refers to these semiconductor manufacturers collectively as captive silicon producers because they grow single-crystal silicon to produce wafers for their own internal consumption. Captive producers with significant internal silicon production include AT&T, IBM, Motorola, and Texas Instruments in the United States, Philips in Europe, and Hitachi in Japan. Dataquest estimates that the U.S. captive silicon producers meet from 50 to 75 percent of their silicon requirements with captive silicon operations, whereas this amount is approximately 30 percent for Hitachi and Philips.

WORLDWIDE MERCHANT SILICON MARKET

Table 2 contains a list of merchant silicon manufacturers that were active in the world market in 1985. This list, organized by region in which the company headquarters are based, summarizes whether a company offers silicon and/or epitaxial wafers. Fifteen of the 23 companies are located in the United States, 3 in Europe, and 5 in Japan. (The acquisition by Japanese manufacturers of U.S. silicon companies NBK, Siltec, and U.S. Semiconductor will be discussed in a later section.) Fourteen manufacturers supply epitaxial wafers, 16 supply silicon wafers, and 7 provide both types of wafers. (Dynamit Nobel began manufacturing epitaxial wafers in late 1986, so is not included in the count of epitaxial wafer suppliers for 1985.) Table 2 also includes five new merchant silicon companies that entered the market in 1986/1987; two are located in Japan, two in Europe, and one in Korea.

Table 2 shows the percentage of silicon substrate material (based on square inches) each company produces internally and the percentage purchased from other silicon vendors. This is an important distinction since several United States-based epitaxial wafer manufacturers purchase some or all of their silicon substrate from other companies. For example, in 1985, Cincinnati-Milacron, an epitaxial silicon wafer company, internally produced 60 percent of its silicon substrate and purchased 40 percent from other merchant silicon companies. This practice must be noted when evaluating total wafer consumption because of the potential problem of double-counting million square inches of silicon based on company sales alone.

Table 3 presents the combined sales of silicon and epitaxial wafers by regionally based merchant companies to given regions of the world. For example, in these tables, Shin-Etsu Handotai's worldwide sales, which include the sales of Shin-Etsu's U.S. subsidiary, SEH America, are included under the heading "Japan-Based Companies." Similarly, the worldwide sales of Europe-based Wacker Chemitronic include the sales of its U.S. affiliate, Wacker Siltronic.

EFFECTS OF YEN APPRECIATION

In 1986, Japanese silicon companies had to face the pressures of restricted markets overseas because of the yen's appreciation. Silicon wafer pricing has always varied from region to region. However, Japanese silicon companies found it difficult to compete in the U.S. and European markets in 1986 due to large differences in wafer pricing affected by exchange rate factors. For example, in 1984, the average U.S. price of a 100mm wafer was $10.50. At an exchange rate of ¥237/$1, a Japanese silicon company would receive ¥2,490 for a 100mm wafer. In 1986, the U.S. average selling price of a 100mm wafer came down to $10.00. However, at the 1986 exchange rate of ¥167/$1, a Japanese silicon company would now only receive ¥1,750 for a 100mm wafer sold in the United States.

Because of the high yen, Japanese silicon companies exporting silicon wafers to the United States have two options: 1) meet and maintain U.S. average selling prices for wafers and lose on margins in order to maintain U.S. market share and customer relationships, or 2) raise wafer prices in the United States to regain a given yen rate of return, and as a consequence, lose market share. Similar analysis of wafer pricing for 125mm and 150mm wafers confirms that Japanese silicon companies in 1986 were caught between the proverbial rock and a hard place, and had difficulty competing for silicon sales overseas.

Overseas Acquisitions

On the one hand, the high yen has made silicon exports from Japan more difficult. On the other hand, it has made the acquisition of U.S. firms more attractive. As mentioned earlier, in 1986, two Japanese silicon companies chose the latter method of competing in the U.S. market. Mitsubishi Metal acquired Siltec in the third quarter of 1986, and Osaka Titanium Company announced its plans in December to acquire U.S. Semiconductor, an epitaxial silicon wafer manufacturer.

Other Japanese companies that have established or acquired silicon facilities in the United States include silicon manufacturer Shin-Etsu Handotai (which established SEH America, a wholly owned subsidiary in Vancouver, Washington) and steelmakers Kawasaki Steel and Nippon Kokan K.K. Kawasaki Steel acquired Santa Clara-based NBK Corporation in 1984, and Nippon Kokan K.K. bought Great Western's polysilicon facility in 1985. In December 1986, Nippon Kokan K.K. announced its purchase of land in Oregon for a new 1,000-metric-ton polysilicon plant.

TOTAL MILLION-SQUARE-INCH MARKET

Table 4 combines 1985 million-square-inch sales by the merchant silicon companies and captive silicon production in the four regions of the world. Captive silicon production has been allocated to the semiconductor manufacturer's home region. Internal production by the captive silicon producers, at 150 MSI, accounts for a sizable percentage of the U.S. million square inch market of 490 MSI. The captive silicon market in Japan and Europe is much

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smaller, and ROW has no captive silicon producers at this time. Japan has the largest share of the world million square inch market with 594 MSI, or 45.7 percent of the total square inch market in 1985.

FORECAST SILICON CONSUMPTION BY REGION

Table 5 contains Dataquest's forecast of silicon consumption by captive and merchant semiconductor manufacturers by region of device production. In general, we believe that the growth in silicon consumption will follow growth in device production revenue in each of the four regions through 1991. We believe that the long-term trend will be for silicon consumption (in MSI) to grow more slowly than production revenue (as measured in dollars). This translates to a slowly increasing revenue per square inch as a function of time. Factors that increase revenue per square inch include higher device ASPs and device yields. ASPs will increase as higher-valued products such as ASICs become a larger percentage of the product mix. Yields should improve as manufacturers focus on tighter particulate control and achieve shorter cycle times through manufacturing automation. However, as devices become more complex, die size typically increases. This will slow the upward trend of average revenue per square inch since yields drop with proportionately larger chips.

WAFER SIZE

The changing mix of wafer size is an indicator of the penetration of leading-edge equipment and new fab capacity. Further, as wafer diameter increases, poly usage increases at a more rapid rate, due to greater wafer thickness at the larger diameters. Estimated percent consumption of MSI of silicon by wafer size for 1982 through 1991 is presented in Table 6. This information reflects Dataquest's estimate of wafer size consumption for semiconductor production in North America.

Dataquest does not expect 125mm wafer consumption to reach the maximum levels of 100mm wafers in the United States. This is because the 125mm wafer is viewed as an interim step in the transition to 150mm wafers. The increase of 125mm wafer consumption to 30 percent of square inches in 1985 is believed to have been caused by difficulties that semiconductor manufacturers had in bringing on-line the fab equipment designed to handle 150mm wafers. This situation, coupled with the industry slowdown during 1985, increased 125mm wafer penetration, slowed the expected rise in 150mm wafer usage, and decreased 3-inch wafer usage.

The 100mm wafer will continue to account for the highest percent of consumption (as measured in MSI) for U.S. production until 1989. The 150mm wafer category is expected to increase its share throughout the decade and, by 1991, is expected to account for approximately 52 percent of silicon MSI. Although several U.S. semiconductor manufacturers are working with 200mm wafers in research and development, Dataquest does not expect this wafer size to enter the general production environment until 1988.

Peggy Marie Wood

Table 1

WORLDWIDE MERCHANT SILICON COMPANY MARKET SHARE, 1985
(Millions of Dollars)

Company	Silicon and Epitaxial Wafer Sales	Percent Share
Shin-Etsu Handotai	$ 310.0	24.5%
Wacker	205.0	16.2
Osaka Titanium Company	160.0	12.6
Monsanto	137.0	10.8
Japan Silicon	128.0	10.1
Komatsu Electronic Metals	116.0	9.2
Others	210.5	16.6
Total	$1,266.5	100.0%

Source: Dataquest
May 1987

Table 2

WORLDWIDE MERCHANT SILICON COMPANIES

	Substrate Grown	Substrate Purchased	Silicon Wafers	Epitaxial Wafers
U.S. Companies				
Cincinnati Milacron	60%	40%		X
Crysteco, Inc.	100%	0	X	
Epitaxy, Inc.	0	100%		X
General Instruments Power Semiconductor Div.	0	100%		X
Gensil	100%	0	X	
M/A-Com	50%	50%		X
Monsanto Electronic Materials Company	100%	0	X	X
NBK Corporation	100%	0	X	
Pensilco	100%	0	X	
Recticon	100%	0	X	
Silicon Services	0	100%		X
Siltec	100%	0	X	
Spire Corporation	0	100%		X
U.S. Semiconductor	0	100%		X
Virginia Semiconductor	100%	0	X	

(Continued)

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Table 2 (Continued)

WORLDWIDE MERCHANT SILICON COMPANIES

Companies	Substrate Grown	Substrate Purchased	Silicon Wafers	Epitaxial Wafers
Japanese Companies				
Japan Silicon	100%	0	X	X
Komatsu Electronic Metals	100%	0	X	X
Osaka Titanium Company	100%	0	X	X
Shin-Etsu Handotai	100%	0	X	X
Toshiba Ceramics	100%	0	X	X
European Companies				
Dynamit Nobel Silicon	100%	0	X	(X-1986)
Topsil Semiconductor Materials A/S	100%	0	X	
Wacker	100%	0	X	X
New Entrants--1986				
Lucky Advanced Materials (Korea)	100%	0	X	
Nittetsu Denshi (Japan)	100%	0	X	
Okmetic (Finland)	100%		(X-1987)	
Rhone-Siltec (France)	100%	0	X	
Showa Denko (Japan)	100%	0	X	

Table 3

WORLDWIDE MERCHANT SILICON AND EPITAXIAL WAFER MARKET, 1985
(Millions of Dollars)

Region of Sales	United States-Based Company Sales	Japan-Based Company Sales	Europe-Based Company Sales	Total
United States	$216.3	$ 84.9	$ 86.7	$ 387.9
Japan	7.9	632.1	8.6	648.6
Europe	18.8	10.4	130.0	159.2
Rest of World	12.7	26.6	31.5	70.8
Total	$255.7	$754.0	$256.8	$1,266.5
Percent	20.2%	59.5%	20.3%	100.0%

Source: Dataquest
May 1987

Table 4

SILICON AND EPITAXIAL MILLION-SQUARE-INCH MARKET BY REGION, 1985

Region	Merchant	Captive	Total	Percent
United States	340	150	490	37.7%
Japan	574	20	594	45.7
Europe	143	7	150	11.5
ROW	66	0	66	5.1
Total	1,123	177	1,300	100.0%

Source: Dataquest
May 1987

Table 5

TOTAL FORECAST SILICON CONSUMPTION BY REGION*, 1986-1991
(Million Square Inches)

	1986	1987	1988	1989	1990	1991	CAGR 1987-1991
United States							
Merchant Mfg.	429	514	681	586	708	910	15.4%
Growth	24.8%	19.8%	32.4%	(13.9%)	20.8%	28.4%	
Captive Mfg.	135	158	185	218	256	300	17.4%
Growth	(7.9%)	17.4%	17.4%	17.4%	17.4%	17.4%	
United States	564	672	867	804	964	1,210	15.8%
Growth	15.0%	19.3%	28.9%	(7.2%)	19.9%	25.5%	
Japan	573	651	814	804	893	1,060	13.0%
Growth	(3.5%)	13.6%	25.0%	(1.3%)	11.1%	18.8%	
Europe	150	182	229	218	266	317	14.9%
Growth	0	22.4%	26.1%	(5.2%)	22.5%	19.0%	
ROW	79	99	146	161	207	254	26.7%
Growth	19.7%	38.6%	47.1%	10.3%	28.5%	22.8%	
Worldwide							
Silicon	1,366	1,605	2,056	1,986	2,330	2,841	15.4%
Growth	5.1%	17.5%	28.1%	(3.4%)	17.3%	21.9%	

*Region of silicon consumption, not country of company ownership

Source: Dataquest
May 1987

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Table 6

UNITED STATES MILLION-SQUARE-INCH DISTRIBUTION BY WAFER SIZE
(Percent Million Square Inches)
1982-1991

Diameter	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
2 inch	3.0%	2.5%	2.0%	0.5%	0.4%	0.4%	0.3%	0.2%	0.2%	0.1%
3 inch	45.0%	33.0%	21.0%	6.8%	5.9%	5.1%	4.2%	3.4%	2.5%	1.7%
100mm	51.0%	57.0%	63.0%	55.3%	49.9%	44.4%	39.0%	33.5%	28.1%	22.7%
125mm	1.0%	6.0%	11.0%	29.9%	28.9%	27.7%	25.7%	23.4%	21.1%	18.9%
150mm	0.0%	1.5%	3.0%	7.5%	14.9%	22.4%	29.8%	37.2%	44.6%	52.1%
200mm	0	0	0	0	0	0	1.0%	2.2%	3.4%	4.6%
Total MSI	480	566	707	490	564	672	867	804	964	1,210

Source: Dataquest
May 1987

Research Newsletter

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SEMICON/West 1987 EQUIPMENT SURVEY

The SEMICON/West Equipment and Materials Exposition is held annually in San Mateo, California. This industry trade show is sponsored by the Semiconductor Equipment and Materials Institute and is a yearly milestone for the semiconductor equipment and materials vendors. Each year, Dataquest surveys the wafer fabrication equipment vendors and reports on significant new products and enhancements introduced at the show. The results of the survey are published in this annual newsletter.

INTRODUCTION

While many exhibitors seemed to think that attendance was low, there were actually more than 45,000 attendees at this year's show, compared with 50,000 last year. One reason that attendance seemed low is that the show was spread over four days instead of three days as in the past. There were 1,035 companies at the show, compared with 1,061 in 1986.

The last two years have been tough for the equipment and materials vendors as they have seen orders and shipments slide to very low levels compared with the boom year of 1984. Everyone is anxiously awaiting an upturn, which has definitely occurred in the semiconductor industry, but because of the world's excess semiconductor manufacturing capacity, has not yet manifested itself in the equipment and materials industry.

However, Dataquest believes that the long slide down in the equipment and materials industry has been halted and that the industry has, indeed, turned the corner. Many vendors at the show told Dataquest that orders have increased recently, and interestingly, they uniformly reported that their orders have picked up within the same time span--six to eight weeks prior to the show. A leading indicator for the equipment industry is assembly equipment. Since this equipment segment is largely driven by capacity, it is

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the first to feel the downturn when there is excess capacity and is a good barometer when the semiconductor industry begins to need additional capacity. Therefore, it is welcome news that some assembly equipment vendors are reporting that orders are finally on the increase after a two-year dearth.

SEMICON/West is a key event for vendors to introduce new products, and it is a time to view the collective results of the industry's R&D activities during the past year. As we reported in the 1986 newsletter, the level of new product introductions was very high. This year, new product introductions were at a much lower level. Because of the worldwide recession in the industry, many of the 1986 new products have not had an opportunity to really get off the ground. It appeared to Dataquest that sales of the new products have been disappointingly slow. Thus, without sales revenue to fund the R&D cycle, new products and product enhancements for the industry will fall off, which is what we witnessed at this year's SEMICON/West.

Not all equipment segments were off in new product introductions, however, as the chemical vapor deposition (CVD) and wafer inspection segments continued their higher level of activity. Last year, we reported that SEMICON/West 1986 was the "coming-out party" for CVD equipment. This year, the pace continued as several significant new products were introduced. Last year we did not report on wafer inspection, but do so this year because of the higher level of interest and significant new products in this area.

Because of space considerations, we can give only a brief overview of the products. For further information please contact the manufacturers directly. Please refer to last year's newsletter. Together, the two newsletters provide a good picture of the direction of the equipment industry.

LITHOGRAPHY

The key developments in steppers were mainly in the area of submicron lenses, as the stepper manufacturers pushed further and further into the submicron realm. As lens resolution continues to increase, however, concomitant improvements in overlay accuracy need to be made to take full advantage of the resolution gains. Accordingly, we also saw improvements in alignment systems and barometric and magnification control systems. The technical approach towards submicron lenses vary: the Japanese are continuing their strategy of high numerical aperture, g-line lenses, while U.S. and European manufacturers are taking the i-line approach.

The advent of the excimer laser optical stepper may have dealt another delay to X-ray. Nevertheless, a new X-ray stepper manufacturer appeared in the market while another X-ray stepper manufacturer was fighting for survival. It is still not clear when the X-ray market will become a reality, although development of synchrotron sources continues to increase on a worldwide level.

In maskmaking lithography, new high-speed laser optical pattern generators were introduced by two companies. One company, ATEQ, has a novel approach of putting the laser pattern generator in the wafer fab area, next to the steppers for quick prototype device turnaround.

Steppers

Most of the key developments were in lenses. Last year at this time there were nine stepper vendors; six of the vendors used either Zeiss or Wild Heerbrugg lenses, and the other three built their own lenses. Since then, Eaton has left the stepper market, Perkin-Elmer has decided to build its lenses in-house, and GCA is relying more and more on its own Tropel lenses. Now only three companies rely solely on Zeiss for its lenses. In last year's newsletter, we remarked that with so many vendors relying on Zeiss for lenses, supply could be a problem. It now appears that this is no longer a concern. Incidentally, it was always a puzzlement why Perkin-Elmer did not build its own lenses earlier, since it has had world-class optical fabrication facilities for some time.

Other developments in lenses include the introduction of variable numerical aperture lenses by two companies (Canon and Ultratech). Also introduced was a special lens designed by GCA for production use in excimer laser steppers.

Last year, American Semiconductor Equipment Technologies introduced the world's first large-substrate stepper or flat panel display stepper. Since then, both Canon and Nikon have introduced large-substrate steppers and another U.S. company will soon enter the market. This is an embryonic market, and Dataquest believes only a few systems have been delivered.

ASM Lithography

ASM exhibited the PAS 2500/10, which was first exhibited in the United States at last year's SEMICON/West. This system uses the Zeiss 10-78-46 lens, which is a 5X, 0.38 NA, g-line lens with 0.9-micron resolution over a field size of 20mm. ASM claims the highest throughput in the industry for the 2500/10, which is 62 125mm or 50 150mm wafers per hour with global alignment. Overlay accuracy is specified to be 0.15 micron (3 sigma). The system was basically the same as exhibited last year, except that the automatic reticle changer is SMIF compatible and handles 6 instead of 7 reticles. Perhaps the most significant new feature introduced for the PAS 2500 is the 2-year warranty on parts and labor.

Other recent developments include the replacement of the PAS 2500/20 system with the PAS 2500/40. These systems differ only in the choice of lens used: the 2500/20 uses the Zeiss 10-78-52 i-line lens, while the 2500/40 uses the Zeiss 10-78-58 i-line lens. The 10-78-58 is a 5X, 0.40 NA lens with a resolution of 0.7 micron over a field size of 20mm. Throughput for the 2500/40 is the same as that for the 2500/10.

Since no calibration is required for the PAS 2500, ASM claims that equipment utilization, or system production availability, can be as high as 80 percent.

The price of the 2500/10 is $1.035 million, the 2500/40 is $1.2 million.

American Semiconductor Equipment Technologies (ASET)

ASET has just successfully completed its first full year of operation after the February 1986 buyout of the assets and technology of TRE Semiconductor.

ASET exhibited the 900 SLR Series stepper, which it announced but did not exhibit at last year's SEMICON/West. The five steppers in the 900 Series, three g-line and two i-line steppers, all use Zeiss lenses and are summarized in Table 1.

Table 1

LENSES USED BY ASET

Model	Zeiss Lens	Wavelength	Reduction Ratio	NA	Field Diameter (mm)	Resolution (micron)
945	10-78-45	g-line	10X	0.38	14.5	0.91
946	10-78-46	g-line	5X	0.38	20.0	0.91
947	10-78-47	g-line	5X	0.28	29.0	1.25
948	10-78-48	i-line	10X	0.42	13.0	0.70
952	10-78-52	i-line	5X	0.32	23.0	0.91

Source: ASET

The 900 Series has an overlay accuracy of 0.2 micron (3 sigma). The 900 Series offers a choice of a 4-reticle carousel with a 5-second reticle change time, or a 10-reticle cassette with a change time of 15 to 20 seconds. Other new features of the 900 Series include automatic compensation for barometric pressure changes, magnification control via keyboard, a more user-friendly computer system with expanded capability, and the use of a nonactinic wavelength alignment system, which enables capturing of difficult targets.

The price of the 900 Series g-line systems is about $900,000; i-line systems are in the range of $1.2 million to $1.3 million.

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ASET also purchased the assets and technology of TRE's maskmaking operations and is continuing to manufacture a line of optical pattern generators and image repeaters for use in the maskmaking industry. At SEMICON/West, ASET introduced the 600 Series image repeater, a repeater with superior positional resolution especially designed for manufacturing 1X masks. Currently, highly accurate 1X must be completely written on an E-beam pattern generator, as present optical image repeaters do not have the required positional accuracy. Writing a 1X mask on an E-beam could take three to four hours, and hence, be very costly. The 600 Series image repeater will once again allow 1X masks to be made by the less costlier optical step-and-repeat method.

There are three models in the 600 Series. Depending upon the choice of Zeiss lens, resolutions down to 0.91 micron can be obtained.

<u>Canon</u>

Canon exhibited the FPA-1550MII stepper with the new selectable numerical aperture lens. By means of a switch, the numerical aperture can be changed from 0.35 to 0.43. This lens has a field diameter of 21.2mm and programmable masking blades under computer control, which can be varied at each site if desired. Resolution of the lens is 0.8 micron (at 0.43 NA) or 1 micron (at 0.35 NA) with a total depth of focus of 2 microns with the 0.43 NA.

The price of the FPA-1550MII with selectable lens is $1.15 million, and this system is currently being shipped.

Canon also introduced, but did not exhibit, the MPA-1500 Mirror Projection Mask Aligner to the U.S. market. This system, which is specifically designed for flat panel displays, has a 280mm x 332mm exposure area that is exposed with four step-and-repeat exposures. Either four different masks can be used in the step-and-repeat operation, or a single mask can be stepped four times in the exposure field. Throughput is 35 to 46 substrates per hour, using four different masks, or 41 to 57 per hour, using a single mask.

The MPA-1500 was introduced in Japan in 1986 and exhibited at SEMICON/Europe in March 1987. The system uses the same optical system as that used by the MPA-500/600 series of projection aligners, which Canon has been marketing since 1981.

Until recently, only lithography products manufactured by Canon's semiconductor equipment operations have been marketed by Canon in the United States. At SEMICON/West, however, Canon exhibited a wider range of its semiconductor equipment, including the AIM-630 Automatic Identify Marker, the ARS-630 Automatic Reader and Sorter, the ESC-530 Epitaxial Spike Crusher, the MAS-800 Microwave Asher, and the CDS-650 Coater/Developer. Thus, it is apparent that Canon, like Nikon, wants to market more of its products in the United States.

GCA

GCA exhibited its new wide-field i-line version of the Model 8500 DSW Wafer Stepper fitted with the new Tropel 2235i lens. This 5X i-line lens has a numerical aperture of 0.35, resolution of 0.7 to 0.8 micron, a 22mm diameter field, and a depth of focus of 2 microns. Previously, GCA offered the Model 8000 DSW with the Tropel 1635 5X i-line lens, which will still be available. The 1635 lens has the same NA and resolution as the 2235i, but the 1635 has a smaller field size of 16mm diameter.

The 8500 includes the new dark field alignment system, a through-the-lens local alignment technique that provides 0.2 micron (3 sigma) overlay accuracy on a single machine, or 0.3 micron (3 sigma) for matched steppers, machine-to-machine. Also new to the 8500 is an auto focus system that provides focus and tilt at each exposure site. Throughput for the 8500 is 48 125mm wafers per hour and 38 150mm wafers per hour.

The price of the 8500 DSW with the 2235i lens is $1.2 million.

GCA also showed the Tropel lens designed for use with 248nm excimer lasers. This is a 5X, 0.35 NA lens, with a resolution of 0.5 micron and a field size of 20mm diameter. The GCA stepper designed for use with excimer lasers was developed under a VHSIC contract, and the first GCA excimer laser stepper is expected to be shipped to a VHSIC contractor in June 1987.

Nikon

Nikon exhibited the NSR-1505G4 stepper which can be equipped with several g-line lenses. The submicron g-line lenses offered for this system are listed in Table 2.

Table 2

LENSES USED BY NIKON

NSR Model	Reduction Ratio	Resolution (micron)	NA	Exposure Area (mm)
1505G4D	5X	0.75	0.45	15 X 15
1505G4C	5X	0.8	0.42	15 X 15
1505G4B	5X	0.9	0.35	15 X 15
0510G4	10X	0.6	0.60	5 X 5

Source: Nikon

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The 0.45 NA lens (Model 5A3S) was announced by Nikon in January 1987. This lens has a distortion, including magnification error, of less than 0.13 micron. Total depth of focus is 1.5 microns for 0.75-micron geometries.

The 1505G4 series steppers offer two alignment options: dark field, site-by-site alignment and enhanced global alignment (EGA) to obtain an alignment accuracy of 0.18 micron (3 sigma) in either mode of operation. Machine-to-machine interchangeability is 0.18 micron (95 percent). Throughput for the 1505G4 steppers with EGA is 58 125mm wafers per hour and 48 150mm wafers per hour. The 1505G4 series also includes automatic magnification adjustment and site-by-site focus control.

Nikon has also recently introduced, both in Japan and the United States, the NSR-L7501G stepper for flat panel displays (not exhibited at SEMICON/West). This is a 1:1 system that uses conventional reticles. The 300mm x 300mm exposure area is covered in a step-and-repeat fashion with eight 75mm x 75mm exposures. The price of the NSR-L7501G is $1.3 million.

Perkin-Elmer

Perkin-Elmer exhibited the new Micrastep, an enhanced version of the SRA-9000 Series stepper that uses lenses fabricated by Perkin-Elmer in lieu of the Zeiss and Wild Heerbrugg lenses used in the SRA-9000 steppers. Two lens options are available for the Micrastep: one is a 0.35 NA lens that provides 1.0-micron resolution and the other is a 0.8-micron lens. Both lenses have 24mm diameter fields that can expose 17mm x 17mm fields.

New features on the Micrastep, besides the new lenses, include air gauge, site-by-site focusing and leveling, dark field/bright field alignment, and digital signal processing for alignment on tough levels. Site-by-site alignment accuracy is 0.15 micron (98 percent), and machine-to-machine overlay is 0.25 (98 percent). Throughput is 60 125mm wafers per hour.

Micrastep 1 (1-micron resolution) is priced at $995,000; Micrastep 2 (0.8-micron resolution) is priced at $1.15 million. Perkin-Elmer began shipping Micrasteps in November 1986.

Ultratech

Ultratech exhibited two new products: the UltraStep 990, a wide-field, high-throughput stepper designed to replace projection aligners and the UltraStep 1100-4035 variable aperture stepper.

The Model 990 uses a lens with a 0.21 NA and a production resolution of 1.4 microns over a very large field size of 30mm x 15mm (4.5cm^2) maximum rectangle or 18mm x 18mm maximum square. Throughput is 65 125mm or 50 150mm wafers per hour. The price of the 990 is $440,000. The first system has been shipped to Linear Technology.

The UltraStep 1100-4035 is the Model 1100 stepper fitted with the new 4035 variable numerical aperture lens. The 4035 lens uses an adjustable iris to vary the numerical aperture from 0.20 to 0.40. At 0.32 NA the resolution of the lens is 0.95 micron; at 0.35 NA it is 0.85 micron; and at 0.40 NA it is 0.70 micron. Field size at 0.32 NA is 30mm x 15mm ($4.5cm^2$), or 18mm x 18mm. At 0.40 NA, the field size is 30mm x 12mm ($3.6cm^2$), or 15mm x 15mm.

Depth of focus of the 4035 at 0.40 NA is 1.5 microns total. Throughput at 0.40 NA and 0.70-micron resolution is 40 125mm or 30 150mm wafers per hour.

In 1987 the 1100-4035 will be offered only as a limited product. One reason for this is the lens material availability. Also, Ultratech will discuss each customer's specifications so that the stepper is individually configured to meet customer requirements. In the future, Ultratech expects to see more and more custom steppers. An interesting side note is that the 4035 lens weighs 180 pounds.

Ultratech is also pushing its retrofit strategy by which it can upgrade its first stepper, the Model 900 (initially delivered in 1981), to the latest Model 1100-4035. A historical note of interest is that the 900 had a field size of $1.52cm^2$ as compared to $4.5cm^2$ on today's systems.

The price of the 1100-4035 is more than $1 million. A Model 1100 with the 4035 lens has not yet been delivered.

X-ray Lithography

With the advent of Hampshire Instrument's new X-ray stepper, three companies are now offering X-ray steppers to the commercial market. Each company has taken a different technical approach. Hampshire uses a pulsed laser source, Micronix uses a fixed palladium source, and Karl Suss's stepper is intended for a synchrotron source. The resolution of the Hampshire and Micronix steppers is 0.5 micron, which is the same resolution that the optical people say they can attain with excimer laser steppers. Thus, it is still not clear what lithography technology will be used in the realm of 0.5 micron and below, and the outlook for nonsynchrotron source, X-ray lithography remains vague.

Worldwide development of synchrotron sources is increasing. Besides the extensive work being done by the West Germans, the Japanese, and IBM at Brookhaven, there is activity in Italy, France, and at other locations in the United States. In fact, the first commercial synchrotron-compatible X-ray stepper, outside of IBM and the Fraunhofer Institute, will most likely be installed at the University of Wisconsin's large synchrotron ring. Before X-ray synchrotron becomes a production reality, however, compact rings must be developed, and such activity is being undertaken in Europe and Japan. Besides Cosy-Microtec in Germany and Oxford Instruments in England, there are two organizations in Japan. Cosy-Microtec's system, using superconducting magnets, is expected to be on the market about 18 months from now.

Hampshire Instruments

Hampshire, a start-up company formed in late 1983, exhibited its first product, the XRL 5000 X-ray stepper. The XRL 5000 uses a pulsed, highpeak power, solid state slab laser that illuminates a target to generate a source of X-rays with a diameter of 100 microns and a range of 0.8 to 2.2nm. Target life is one 8-hour shift (20,000 exposures). Source-to-mask distance is 7 to 12cm and mask-to-wafer distance is nominally 20 microns. A single pulse from the source exposes a field of 20mm x 20mm on the wafer with a depth of field of 30 microns.

The XRL 5000 has a resolution limit of 0.3 micron and a working resolution of 0.5 micron. Throughput is 15 to 40 wafers per hour. Dark field alignment is used to provide an alignment precision of 0.15 micron (2 sigma).

Hampshire uses 76mm diameter masks that can be fabricated with conventional thin film technologies. Mounted on top of a 76mm diameter support ring is a silicon wafer with the center etched out. On the wafer is an epitaxial layer of silicon then a layer of tungsten on the epi silicon, and finally a layer of photoresist. After patterning the photoresist, the tungsten is etched and the photoresist stripped. Hampshire has its own X-ray mask shop, and intends to supply its customers with masks.

The XRL 5000 is priced at $1.75 million, and the first systems will be delivered late in 1987. Dataquest believes that the first machines will be delivered to Digital Equipment Corporation, with whom Hampshire has had a joint development agreement since 1985.

Karl Suss

Last year, Suss introduced its XRS-200 X-ray stepper, but exhibited only a model. This year, an actual system was on display. The XRS-200 is a joint development effort between Karl Suss America, which developed the entire electronic subsystem, and Karl Suss West Germany, which developed the rest of the machine. The XRS-200 alignment system, which has an alignment accuracy of 0.1 micron (2 sigma), was developed by Siemens.

The XRS-200, specifically designed for use with X-ray synchrotron sources, holds the mask and wafer in a vertical position and scans them through the X-ray beam. Mask-to-wafer distance is typically 40 microns. Field size can range from 26mm x 26mm to 45mm x 45mm, although initially field size will be limited by maskmaking technology. Both alignment and exposure times for each field are typically one second. Stepping time from field to field is one second. The XRS-200 is capable of 0.2-micron resolution and a throughput of 20 150mm wafers per hour with a synchrotron source.

Suss is also developing a plasma source for use with the XRS-200, but because exposure time per field will be in minutes rather than seconds obtainable with a synchrotron source, it will only be suitable for R&D use.

The first XRS-200 will ship to the Fraunhofer Institute in Berlin to replace one of the two Karl Suss prototype X-ray aligners that have been operating for the last three years. Suss will begin shipments in the first half of 1988 to the commercial market to those organizations that have access to synchrotron sources. The price of the XRS-200 is $1 million. Suss says it has orders in hand for the commercial market.

Optical Maskmaking Lithography

In the past, optical pattern generation has given way to the much higher-speed e-beam pattern generators. While laser beam optical pattern generators have been on the market, they were still quite slow compared with e-beam machines. This year, however, two high-speed optical systems appeared on the market. ATEQ's high-speed system, in particular, is intended to compete against e-beam machines.

ATEQ

ATEQ introduced its CORE-2000, a high-speed optical pattern generator intended to compete directly against the industry-standard e-beam pattern generator. The CORE-2000 is a raster scan system that writes the reticle with eight parallel laser beams and is especially designed to write 5X and 10X reticles. As each beam can potentially write at a rate of 50 MHz, the CORE-2000 can achieve a system rate of 400 MHz.

The CORE-2000 accepts standard industry format tapes and exposes standard optical photoresists. ATEQ has exceeded its composite overlay specification design goals and now claims the tightest specification in the industry at 0.15 micron (3 sigma). ATEQ has also increased addressing to 0.1 micron.

Besides the market for the CORE-2000 as a maskmaking tool for the maskmaking industry, ATEQ is targeting the semiconductor manufacturer for the quick-turn prototyping market. In this application, a CORE-2000 would be installed in the wafer fab area next to a stepper. The reticle for the prototype IC would be generated on the CORE-2000, processed immediately in the lithography area, and then inserted directly into the stepper for exposure. Reticle inspection and repair may or may not be used, depending upon the strategy.

The CORE-2000 is priced at $1.8 million. ATEQ shipped its first machine in early 1987 to Canon Sales, Tokyo, its representative in Japan. ATEQ has had a second system accepted by Canon Sales, and in addition, has received two more orders from Cannon. ATEQ has also received an order from Master Images, the first order from a U.S. maskmaker.

Micronic Lasersystem

This Swedish company introduced the LASERSKAN II, a second-generation, laser pattern generator for the production of masks and reticles. Micronic Lasersystem introduced its first laser pattern generator in 1978, but only sold a few systems. The current system is 10 times faster than the earlier system. The LASERSKAN II, a single-beam system, can focus the laser beam into a spot 0.5 micron in diameter and uses raster scan to expose the optical photoresist. Throughput for a 70mm x 70mm 5X substrate is 30 minutes for a 1-micron raster.

Besides maskmaking use, it can be used in direct-write applications, such as quick-turn prototyping, gate arrays, and small-volume production.

The price of the system is $800,000 to $1 million. No systems have yet been delivered.

AUTOMATIC PHOTORESIST PROCESSING EQUIPMENT

Eleven new track systems premiered at SEMICON/West, as well as enhancements of existing systems. Improvements and enhancements of existing systems tended to focus on increased manufacturing flexibility, improved process control, improved wafer handling, and increased throughput.

Dainippon Screen

Dainippon Screen did not show any equipment at SEMICON/West, but did have a booth to announce its products. We think this is significant because Dainippon is a major semiconductor equipment manufacturer in Japan, and this is the first time it had exhibited at SEMICON/West. In addition to track equipment, Dainippon Screen also manufactures maskmaking process equipment, wet and dry etch equipment, and lead bonders.

Eaton

Eaton introduced a new spin-on-glass (SOG) system, the 6030XL. This system has an SOG process module and dispense system that features both a teflon tub bowl wash and a nozzle wash. It also has three different pump options for its dispense station: a pressurized pump, a Millipore pump, or a Tri Tech pump. It also has a programmed pre-dispense purge and a Sierra systems programmable exhaust to maintain a constant exhaust pressure in the system. Each of the two hotplates on the 6030XL can be set to three different temperatures.

GCA

Shown for the first time at SEMICON/West was the Wafertrac III V, made specifically for fragile gallium arsenide wafers. The Wafertrac III V is designed to handle wafer sizes from 2 inches to 125mm. It has no air bearings, as wafers are transferred on an O-ring transport system. The system has a moving arm resist dispense system with a nozzle purge, plus a spinner program step capability for flexibility. The III V also has spin speed control of +/- 0.5 percent and a spinner edge-bead removal feature.

GCA also showed its Microtrac for the first time at SEMICON/West. The Microtrac is a one-track module for develop/bake, coat/bake, or vapor/prime. First shipments for the Microtrac were made in fourth quarter 1986.

GCA has added vacuum vapor prime to its 1006 track equipment, which it believes will provide better uniformity than the older batch prime process. The new vacuum vapor prime can be retrofitted to older 1006s.

Machine Technology Inc. (MTI)

MTI introduced a new handler for its MultiFab system. The new handler has full backside support for the wafer and does not use a vacuum to support the wafer. The MultiFab also has a double bake station featuring new software for increased processing flexibility or throughput.

MTI also announced, but did not show, a new spin-on-glass system.

Solitec

Solitec offered several new track systems for the first time at SEMICON/West. These new systems were the Optimist Positive Developer Nozzle, the Auto Coat, the In-Line Thickness Monitor, and the Flood Exposure Track.

Solitec designed the Optimist to meet a number of goals, including to reduce developer usage by 50 percent, to prevent any developer drips from falling on the wafer, to provide a process that is insensitive to ambient air movement, to provide a nozzle with wide position latitude, and to provide a process with excellent CD control (0.3 micron with 1 sigma variation across a 150mm wafer with 2-micron line geometries.) A unique feature of the Optimist nozzle is that nitrogen is pumped through the nozzle with the developer. The nitrogen is then able to act as a protective shroud over the wafer.

Solitec also introduced the Auto Coat, which Solitec claims reduces photoresist usage by 50 percent (2cm^3 per 150mm wafer). The Auto Coat also monitors suckback and bubbles in the resist line and then alerts the operator to conditions that might cause defective coatings. Solitec claims coating uniformities of 60 angstroms (3 sigma) across a 150mm wafer.

The In-line Thickness Monitor (ILTM) features real-time in-line thickness measurement. It can measure resist thickness in 2 seconds per point (up to 17 points) and at either the hotplate or inspection station. The ILTM has a process analysis software package that monitors single or multiple tracks. The method of measurement is based on a spectrometer and incorporates fiber optics.

The Flood Exposure Track has a DUV flood exposure simultaneous with the hotplate bake. The system is designed for high throughput and for a small clean room footprint.

Semix

Semix introduced the Spin-on-Glass Coat/Bake System manufactured in Japan by Tazmo. The new system, the TR 6002, is a fourth generation SOG coating system. It offers a new noncontact alignment option (patent pending) for soft handling of gallium arsenide wafers. The TR 6002 has the only patented dispense system for spin-on-glass and has a wafer transfer system that is both beltless and without air bearings. It features a small footprint and a user interface that has remote capabilities. The home position for the dispense nozzle arm is on the side of the dispense cup so it is impossible for drips to fall on the wafer. The TR 6002 also has a new cup design to control the air flow of programmable exhaust. Semix reports that it has shipped some units.

Silicon Valley Group (SVG)

SVG introduced the 8632 CTD-MD, positive develop/hot plate system. The 8632 features a radial dispense system to achieve a uniform develop and to eliminate hot spots. The 8632 CTD-MD can dispense developer by spray, puddle, or spuddle methods (spuddle is a combination of spray and puddle).

SVG also introduced the 8642 SOG MHP. The 8642 is a spin-on-glass system with a radial dispense and bowl wash. It features an alcohol bath system at the dispense tip to prevent crystallization. The 8642 also features a multiple hotplate with a linear transfer arm that has a three-position vacuum wand pick up. This arm does not pass over another process module. The 8642 operates in either series or parallel mode. The 8642 has a programmable Sierra flow controller to maintain constant exhaust. SVG reports that it has already shipped some units.

Semiconductor Systems, Inc. (SSI)

SSI introduced the System One-B, a new automatic spin coating and baking system designed for increased reliability, improved process control, and higher throughput. Available modules include automated spin coaters for application of photoresists, polyimides and dopants; modules for spin-on-glass; spray developers; bake modules; and cooling units. An open electronics architecture, designed around an RS-485 bit-bus network, allows microprocessor control of each module.

DRY STRIP AND ETCH

Dry Strip

Consistent with the general showing at this year's exposition, there was a deficit of new products. The trend in this equipment segment was demonstrated last year with the introduction of nine single-wafer strippers. This new product is envisioned to solve many problems that arise from processing resist in very harsh environments such as during reactive ion etching and high-current implantation.

Under the high energy conditions of these processes, the resist becomes akin to Bakelite and is extremely difficult to remove. These resists are traditionally removed by wet stripping, which introduces the problems associated with process-induced particulates and hazardous chemicals. If dry stripping in barrels were used, the time that the substrate film is exposed to the oxygen plasma causes oxidation, which in turn compromises subsequent processing steps. Even after dry stripping, the wafer must be dipped in acid to remove the residual resist scum and the unwanted oxide film.

Semiconductor manufacturers would choose to suffer the process complications in barrels if they could solve the problem of C-V shift and threshold voltage shifts in the devices. These electrical problems are believed to be caused by residual sodium from the photoresist being driven into the film during stripping. With the introduction of single-wafer strippers, in which the plasma is generated remotely from the wafer, these problems of removing tenacious resists are drastically reduced.

The data that Dataquest have seen demonstrate that C-V and threshold voltage shifts and film oxidation are much lower in single-wafer strippers than in barrel systems. The intense plasma stream efficiently removes the baked-on resist, completing processing in typically less than two minutes. This brief processing time reduces the oxidation of the substrate. In addition, end-point can be more accurately assessed on a single wafer than over a batch of wafers; hence, oxidation from overetching is reduced. Finally, the added advantages include cassette-to-cassette operation and reduced wet chemical usage and waste.

In 1986, the market for dry strip was $32 million. We estimate that the market for wet strip adds $13 million, bringing the total market to $45 million. Companies that are introducing products into this segment perceive that the whole strip process installed base, including both barrels and wet benches, will convert to single-wafer dry stripping. This could indeed be a high-growth market niche. However, this market niche is currently somewhat crowded. This year, two companies introduced new single-wafer systems: General Signal/Drytek and Yield Engineering Systems.

Table 3 lists the various companies that market single-wafer strippers.

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Table 3

SINGLE-WAFER STRIPPERS

Company	Price	Comments
Alcan Tech, Inc.	$100,000	Includes pump
Drytek	$100,000	Without pump
Branson/IPC	$130,000	Without pump, two chambers
Emergent Technologies	$110,000	Includes pump
Gasonics	$ 78,000	Without pump
Machine Technology	$110,000	Includes pump
Matrix	$ 87,500	Includes pump
Plasma Systems (Semix)	$125,000	Includes pump
Plasma-Therm	N/A	Discontinued product
Tegal	$110,000	Includes pump, contact plasma
Yield Engineering Sys.	$ 40,000	With pump

N/A = Not Applicable

Source: Dataquest
June 1987

General Signal/Drytek

Drytek introduced a downstream plasma stripper that utilizes the same frame as that used in the company's other dry etch products. The stripper accommodates two gases. The plasma is created remotely in a chamber above the wafer chamber and is pumped from below the wafer. There is not line-of-sight from the remote chamber to the wafer. The system has cassette-to-cassette operation. The price of the system is approximately $100,000 without the pump.

Yield Engineering Systems

This company manufactures various resist processing equipment. It introduced a manually loaded, single-wafer stripper with no bells and whistles that sells for approximately $40,000, including the pump.

Dry Etch

As in most other equipment categories, this segment saw product development efforts materialize into system introductions at last year's SEMICON/West. This year, companies that are selling into this segment are still waiting for some return on their investment.

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Most vendors took the opportunity to distance themselves from the competition by featuring cleanliness, particularly, particulate control. While this is an extremely important feature, the emphasis will shift to equipment versatility.

The process shift is in the etching of refractory metals and single crystal silicon. It is apparent now that the next evolution of technology, that of the 4-Mbit DRAM, will use both refractory metal interconnects and trenches. Unlike the previous evolutionary step, the 1-Mbit DRAM, in which semiconductor manufacturers did not move the R&D devices into production, there appears to be little choice at line geometries below 1 micron. There are numerous scenarios for the process flow and architecture of these new devices, and the competitive drama is again centered on the "batch/ single-wafer" issue.

The versatility necessary for solving these new processing problems may be achieved by leveraging productivity over a large batch, or by adding multiple processing chambers. The former approach is dominated by Applied Materials, with its hexode configuration. The company has gained 10 percent market share, growing from 25 percent in 1985 to 35 percent in 1986. The latter approach has been taken by several companies vying for position in the single-wafer segment: Lam Research Corporation (LRC) and Tegal are the leaders in this segment; LRC fell from 11.4 percent in 1985 to 11 percent in 1986, while Tegal grew from 8.4 percent in 1985 to 10.6 percent in 1986.

Since last year's SEMICON/West, Dataquest has seen several new products that target these new markets. These are featured below.

Lam Research Corporation

The company introduced the much-heralded Rainbow Etcher at this year's SEMICON/West. The system is remarkably similar to the earlier product in that it has a similar chamber configuration, can adjust electrode spacing, and uses a 13.5 MHz power supply. The attractiveness of the system is more in the added value than in the visible features.

One obvious change from the previous design is that the power supply can supply both the upper and lower electrodes. With its grounded chamber walls, this systems falls into the triode category, a feature which greatly enhances its versatility. The hidden feature, which could greatly improve its competitiveness, is the cleanliness of the system. The specification is less than 0.3 particle per cm^2 for particles 0.3 micron or larger.

The company will offer a family of products to target all processes and chemistries being used on advanced devices. The price of the system will be approximately $550,000.

Varian/Zylin

Zylin has leapfrogged its new Zylin 100 system to introduce the Model 6100. This system incorporates downstream, microwave processing to remove and/or passivate photoresist after aluminum etching. Zylin has added the ability to power either the upper or lower electrode, so the system can be used in plasma or RIE configuration. The system can be configured with two, three, or four in-line chambers, each isolated from the other. This flexibility can enhance throughput in single-layer applications or provide multilayer processing for composite structures.

The 6100 series uses helium, beneath-the-wafer cooling to control the processing temperature. Dataquest learned that Varian holds the patent on this technique and will "go after" other equipment vendors that have adopted it. The system price is $550,000.

Tegal

Tegal has beefed up its Model 1500. The system can power both the upper or lower electrodes and can use either 2.45 GHz or 13.6 MHz on the upper electrode. By using two frequencies, the energy/ion density ratio of the plasma can be adjusted to enhance process versatility. Three models in the family can target several processes, including advanced processes for next-generation devices. The system cost is $350,000 to $390,000

Electron Cyclotron Resonance

Although systems utilizing electron cyclotron resonance (ECR) were not exhibited at SEMICON/West this year, they warrant some mention as advanced new products. This technology was invented by Nippon Telephone and Telegraph (NTT) in 1978 as a deposition technique.

The technique utilizes the excitation and ionization of the working gas by a microwave source in a high magnetic field at the cyclotron resonance of the outer shell electrons. This produces an extremely high density plasma, one or two orders of magnitude more dense than conventional plasmas, which can be utilized at low energy levels to etch or deposit. The strong magnetic field induces a small electric field of about 20V at the extraction exit. This low energy, directional stream of high-density ions can then impinge on the wafer surface below the excitation chamber. Etch or deposition by-products are pumped out at very low pressures from below the wafer.

Several companies have experimented with this technology, including Anelva, Sumitomo Metal, Plasma Technology, and Hitachi. Sumitomo, Plasma Technology, and Hitachi have formal product introductions in this area.

Sumitomo Heavy Metal

This Japanese company introduced a multichamber version of ECR processing at SEMICON/Japan last December. The system uses two chambers and operates at less than 1 millitorr chamber pressure. The price of the system is approximately ¥90 million ($600,000 at current exchange rates).

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Plasma Technology

This U.K. company is a spin-off from E.T. Electrotech and is located in Bristol, England. The company has introduced an R&D version, manual load system for deposition or etching and intends to introduce a cassette-to-cassette version by the end of 1987. For the R&D version, it recorded processing pressures of 10^{-5} torr, etch rates 100 times greater than conventional plasma, and nonuniformities of less than 3 percent across a 200mm wafer. The company is targeting silicon dioxide, silicon trench, aluminum alloy, and GaAs processes.

Hitachi

This Japanese company has vertically integrated systems, semiconductors, and equipment under one parent. The equipment division was actually 13th in the world in 1986 sales of front-end fabrication equipment. It publicly introduced a version of an ECR system that does not use NTT technology, but does use a microwave power supply to excite the plasma.

The plasma and wafer are confined within a quartz bell jar surrounded with magnetic coils. While a magnetron waveguide is used to excite the plasma, the wafer sits on a powered cathode which can be biased by 13.5 MHz RF power. Without RF bias, the voltage at the substrate is about 20V. Bias raises the plasma potential between 100 and 200V. The company claims that the damage is from one-tenth to one-thirtieth that caused by reactive ion etching (RIE). The price for this system is approximately ¥140 million ($930,000 at current exchange rates). The company expects to begin exporting the system in 1988.

CHEMICAL VAPOR DEPOSITION

Last year we remarked that SEMICON/West 1986 was the "coming-out party" for CVD equipment, as new companies appeared in this segment, and many new models of equipment were introduced by both new and established companies. The intense activity in CVD equipment has continued into 1987, as still more new equipment and improved processes were introduced. It is likely that there is more activity in the CVD area than in any other area of wafer fab equipment, as CVD technology advances to meet the needs of leading-edge ICs.

This portion of the newsletter reports only on the dedicated CVD reactor market (nontube market--please refer to the section on diffusion for horizontal/vertical tube CVD) that for the most part has emerged only in the last two to three years. For instance, of the 12 companies listed below, all have introduced significant new products within the last three years. Even at this year's SEMICON/West, where new product introductions were generally more subdued across the industry, there were five significant new CVD equipment introductions.

Four of the companies (Genus, Spectrum CVD, Ulvac, and Varian) provide reactors for the deposition of tungsten films, an area where only a year ago Genus had the market to itself. The other companies are mainly concentrating on depositing dielectrics, and here competition is intense as film quality becomes the battleground. Particular emphasis is being addressed to high-quality intermetal dielectrics, resulting from the industry move to double-metal ICs. Particulates is another battleground, and many vendors are beginning to provide cleanliness specifications for their equipment.

Currently, CVD is one of the more exciting areas in wafer fab equipment. We expect it to continue to be so, as CVD technology continues to evolve and as the players compete for a market that is forecast to be $350 million by 1990.

Applied Materials

Applied Materials exhibited its new Precision 5000 CVD system for the low-temperature deposition of dielectrics. Processes include intermetal dielectrics, passivation, and conformal depositions in such applications as, sidewall spacers, trench liner, or trench isolation.

The system deposits pyrolytic (thermal) oxide at a rate of 3000 angstroms per minute for a 100 percent conformal film using TEOS as the source. Applied has developed a proprietary process that deposits TEOS oxides below 400°C; thus, TEOS films can be used as intermetal dielectrics. The Precision 5000 also provides for plasma enhanced deposition (PECVD) at rates of 8000 angstroms per minute. For passivation, nitride, oxide, oxynitride, or combination films can be deposited. Liquid sources only are used for all deposition processes.

The system uses a multichamber approach in which multiple processes can occur in a single chamber. A multiple in-situ process, for example, would be a PECVD oxide deposition, followed by a pyrolytic oxide deposition, and then an etch-back step. The resulting film would be a planarized, void-free oxide film. The final process is the plasma clean cycle that occurs after every wafer is processed during the wafer transfer cycle. Two chambers are standard, with four chambers optional.

Price of the Precision 5000 with two chambers is $750,000; with four chambers the price is $1.2 million. Applied Materials says it has commitments for 20 systems from 10 customers. The first systems were shipped in May 1987.

Electrotech

Electrotech introduced a higher throughput version of the ND6200 PECVD system, called the ND6201. In the ND6200, batches of wafers are transferred and processed in batches in the parallel plate process chamber. The ND6201 uses the same process chamber except that individual wafers are continuously transferred into and out of the chamber. The result is that throughput for the ND6201 has been increased to 50 100mm wafers per hour for a 1-micron film of oxide. The ND6201 is for an oxide process only. For the ND6200, Electrotech has introduced plasma BPSG and oxynitride processes.

Price of the ND6200 is $450,000; the ND6201 is priced at $480,000. Also available is the ND8200, a 200mm version of the ND6200 introduced last year; it is priced at $500,000.

Focus Semiconductor

Focus, a venture capital backed firm established in May 1984, exhibited the F1000 LTO Deposition System. This system, the firm's initial product, was displayed for the first time at SEMICON/West 1986 and is described more fully in last year's newsletter.

The battle for the CVD market will be fought not only on film quality, but also cleanliness. Focus presented the typical cleanliness results of the F1000. For particle sizes greater than 0.4 micron, average particles on a 100mm wafer were measured to be 0.04 particles per cm^2 before processing in the F1000, and 0.08 particles per cm^2 were counted after processing. These results were obtained after 25 microns of film had been deposited in the F1000 after 11 hours of operation.

Focus is currently shipping the F1000.

Genus

Genus introduced the Model 8710 system for the deposition of tungsten silicides. The 8710, a cold-wall reactor, is a further development of Genus's cold-wall technology, as used in its 8300/8400 series reactors. The 8700 is a 200mm, production system with dual load-locks that uses a batch type reactor processing six wafers per batch. Throughput is 20 to 40 wafers per hour.

The 8710 can use either silane chemistry, or the newly developed dichlorosilane chemistry, for the deposition of tungsten silicide. The dichlorosilane process uses higher deposition temperatures (525°C versus 360°C for the silane process) to provide films with more surface mobility, thus enhancing step coverage. This is particularly beneficial in EPROM devices, where higher steps are encountered.

The 8710 is priced at $750,000. The first production unit was shipped in December 1986, but a 200mm prototype 8710 was shipped 18 months ago.

Currently, the 8710 is for tungsten silicide films; under development is a selective tungsten-on-aluminum process targeted for double metal ICs.

Machine Technology, Inc. (MTI)

MTI introduced, at last year's SEMICON/West, the AfterGlo CVD system, a downstream 2.45 GHz plasma system for the deposition of undoped oxide. This year, however, MTI did not exhibit the product, and Dataquest believes that only a very few of the systems have been delivered since June 1986. The price of the AfterGlo CVD system is $250,000.

Novellus

Novellus, a venture capital-backed company formed in 1984, exhibited its first product, the Concept One CVD system. (Last year only a model was exhibited.)

The reaction chamber in the Concept One consists of a circular rotating platen with positions for multiple wafers. Each wafer rotates under seven plasma deposition stations, such that the final film is built up from seven sequential depositions. As the wafer completes its deposition sequence, it is transferred back into the cassette in the load-lock, and a new wafer is transferred onto the platen. Thus, the Concept One is a continuous process system.

The load-lock contains three cassettes, and during the time it takes to exchange cassettes in the load-lock, a self-clean cycle can be initiated in the process chamber so as not to affect the throughput of the system. The Concept One has a cycle time of 80 minutes for 75 wafers for an 8000-angstrom film.

The Concept One provides +/-1 percent uniformity (1 sigma), both within a wafer and wafer-to-wafer, on undoped oxide, PSG, and BPSG films. Low temperature (400°C) TEOS oxide, nitride, and planarized oxide processes are under development. All processes on the Concept One are plasma processes. Novellus claims excellent hillock suppression for the system as film deposition begins within 10 seconds after the wafer is brought to deposition temperature.

Price of the Concept One is $550,000. Dataquest believes that the first system was just shipped immediately prior to SEMICON/West.

Plasma-Therm

Last year we reported on Plasma-Therm's new plasma vertical reactor for the deposition of oxides and nitrides. The vertical reactor had a capacity of 25 wafers; this has been increased to 50 wafers per load. Also new is the addition of an oxynitride process. The system is priced at $500,000, and Dataquest does not believe that any systems have yet been sold in the United States.

SVG/Anicon

In February 1987, Silicon Valley Group purchased Anicon for $8.5 million in stock and simultaneously renamed the Anicon operation SVG/Anicon.

Last year Anicon exhibited its new Pro-II CVD system, which was basically the same machine shown this year by SVG/Anicon. However, SVG/Anicon has made some improvements in its quartzware policy; the price has been reduced by 50 percent, and SVG/Anicon will now give the quartzware drawings to the customers to choose their own fabricators.

The Pro-II is still not automated as the automation strategy promoted by Anicon before to its acquisition was not cost effective. Dataquest believes that development activity at Anicon before its acquisition had been moving very slowly. Now that they are under the aegis of SVG, we should see development activity increase, particularly in the area of automation.

The price of the Pro-II is $350,000.

Spectrum CVD

Last year Spectrum CVD, a Motorola New Enterprise Group company, introduced its Model 202 manual system and Model 211 cassette-to-cassette system for the deposition of tungsten silicide, selective tungsten, and blanket tungsten films. The Model 202 ($250,000) is intended for R&D use, while the 211 ($419,000), which uses the same reaction chamber as the 202, is for production use. The 211 has a three wafer load-lock and utilizes continuous processing of wafers in the single-wafer reaction chamber. Throughput is approximately 20 wafers per hour.

First deliveries were made for the 202 in December 1986; several systems have been shipped since then. Deliveries for the 211 were scheduled to begin in December 1986, but first shipments will not actually begin until the end of 1987.

Ulvac

Ulvac introduced, for the first time in the United States, its new ERA-1000 CVD system for the deposition of tungsten silicide, selective tungsten, and blanket tungsten. The ERA-1000 has two reaction chambers, which can be used in parallel to process two wafers simultaneously. Also possible is a sequential mode of operation for multistep processes. For example, for the deposition of two layers, one layer is deposited in one chamber and then moved to the other chamber for a second deposition. Another multistep process would be a plasma pretreatment prior to deposition.

Although selective tungsten deposition rate is a function of deposition conditions, typical rates of 500 to 1500 angstroms per minute are obtained. For an 8000-angstrom selective tungsten film, throughput is 5 to 15 wafers per hour using both chambers. Throughput for an 3,000-angstrom tungsten silicide film is 20 to 30 wafers per hour, also using both chambers.

The ERA-1000 has 200mm wafer capability and is priced at $750,000.

Varian

Last year Varian introduced its Model 5101 load-locked, single-wafer system for the deposition of tungsten silicide, selective tungsten, and blanket tungsten. Varian has delivered several of these systems for R&D use, mostly for tungsten silicide applications. Because of its low throughput, Varian is developing a two-chamber system for use in production. Price of the 5101 is $350,000.

Varian also announced last year that it was developing the Model 5150 hot-wall CVD reactor intended for low-temperature oxides, nitrides, and polysilicon. However, this program has subsequently been put on hold.

Watkins-Johnson

Watkins-Johnson (WJ) exhibited its new WJ-998 CVD system for the deposition of oxides, PSG, and BPSG. The WJ-998, which is a compact version of the much larger WJ-985 continuous belt system, occupies little clean room space, because the entire system, with the exception of the input/output stations, can be installed in the chase area.

The WJ-998, which is an atmospheric CVD (APCVD) reactor, appears to have overcome the limitations of APCVD that were problems in the past. For oxides and PSG, film uniformity on 150mm wafers is +/-4 percent within a wafer, and +/-2 percent wafer to wafer. For BPSG the within wafer uniformity is +/-5 percent. Guaranteed particulate contamination is less than 0.1 particle per cm^2 for particles greater than 0.3 micron. Throughput for a 6000-angstrom oxide film is 96 150mm wafers per hour. Watkins-Johnson is also stressing quality of intermetal dielectric: planarized coverage with no voids and anti-hillock control.

For increased productivity, the WJ-999, a high throughput version of the WJ-998, is available. The WJ-999 has a continuous belt that is wider than the belt on the WJ-998; thus, wafers can be placed side by side on the belt. Throughput for a 6000-angstrom oxide film is 192 150mm wafers per hour, double that of the WJ-998.

The WJ-998 is priced at $550,000; the WJ-999 is $650,000. Several systems have already been shipped to VHSIC contractors.

PHYSICAL VAPOR DEPOSITION

The PVD equipment market includes sputtering and evaporation technologies. In sputtering, the most notable new developments involved planarization of aluminum. At last year's SEMICON/West show only Varian had announced a planarization capability for sputtering. Varian began shipments of the technology near the end of 1986. At this year's show several new contenders entered the planarization arena: Electrotech, Gryphon Products, Machine Technology Inc. (MTI), and Materials Research Corp. (MRC).

Planarized Aluminum is being developed to overcome the topographical problems arising from the demands of micron and submicron line geometries and vias. The most common topographical problems are related to poor step coverage, which can cause electromigration problems and voids in the contacts and vias. With typical sputtering techniques, step coverage ranges between 30 to 50 percent. All manufacturers offering these new planarization technologies are claiming step coverage better than 80 percent. Planarization of aluminum appears to be the PVD answer to filling 1 x 1-micron vias in the near future. Planarization technology will most likely be faced with severe competition for advanced via filling applications by the emerging selective tungsten-on-aluminum CVD processes.

In the evaporation segment of the PVD market, most new evaporators designed for semiconductor applications were being targeted toward the gallium arsenide (GaAs) industry. Of all the semiconductor-related evaporation sales made, approximately 90 percent are being used for GaAs lift-off processing. It has become apparent to evaporation equipment manufacturers that the GaAs industry will drive the semiconductor-related segment of their market in the future.

While the nonsemiconductor-related PVD equipment introductions will not be covered in this section, it should be noted that most PVD equipment suppliers are diversified into other thin film markets. These equipment markets include compact disks, memory hard disks, optics/sunglasses, razor blades, windows/mirrors, flat panel screens, jet turbines, hybrid circuits and solar cells. At SEMICON/West there were many new pieces of equipment designed for compact disks and memory hard disk sputtering. The vendors at the show indicated that these markets have enjoyed robust growth.

The PVD product introductions in the following section cover only new products that have been introduced since SEMICON/West 1986 and existing equipment with significant product enhancements. All of the equipment mentioned in this section are also production-oriented equipment.

Alcatel

Alcatel, previously only a European vendor, has now decided to market its products in North America. Sales, service, plus a demo lab are now available in San Jose, California. Two products are now available in North America, the LINA 350 and the PUMA 500.

The LINA 350 is a horizontal, in-line sputtering system. The system has a throughput of 50 to 60 wafers per hour, and can coat substrates up to 400mm x 550mm. The deposition module is capable of single deposition or multilayer modes. Three types of deposition can be performed with this machine: reactive sputtering, RF bias sputtering, and co-sputtering. The deposition chamber can be set up to run one to four rectangular DC/RF magnetrons. The system is being used in Europe for the production of ICs, hybrid circuits, disks, flat panel screens, sensors, and solar cells. The price of the system runs between $500,000 and $750,000, depending on the system configuration.

The PUMA 500 is a magnetron, horizontal batch load, sputtering system. Operation modes include sequential sputtering and co-sputtering. Wafer batch capacity is 17 3-inch wafers, 9 100mm wafers, or 7 125mm wafers. Throughput is 35 wafers per hour; the price ranges from $275,000 to $400,000. This system is being used in Europe to produce ICs, optics, and compact disks.

Balzers

Model BAK 640 SC is a new evaporation system designed primarily for GaAs lift-off processing. The system is equipped with a split chamber, which allows the source to remain isolated and under constant vacuum during the loading, evacuation, substrate heating, or RF etching and venting phases. This chamber configuration is said to greatly improve the results when doing highly contamination-sensitive metalization processes such as lift-off technology. Two-inch or 3-inch wafers can be processed in this machine. In addition to the lift-off processes, other applications include interconnect, multilayer systems, silicides, wafer backside metalization, dielectric layers, power devices and contact layers for bonding.

Circuits Processing Apparatus (CPA)

CPA featured the C/C 100, a cassette-to-cassette sputtering system designed for single loading and unloading of wafers up to 150mm in diameter. Operation is completely menu driven. Throughput of 120 wafers per hour for 1-micron deposition using four targets is possible. It processes wafer sizes up to 150mm, with an optional 200mm wafer package available. The wafers are held at a near-vertical position on the outside of a carousel that continuously rotates as it loads and unloads. Film uniformity is within +/- 3.5 percent, and either RF or DC bias can be used. Price of the system is between $600,000 and $700,000.

CVC Products

Some improvements were made to the Model 2800, including an improved robotic arm that has increased throughput. The system is now equipped with a menu-driven system. Also available is a new third-chamber option, retro-fittable to installed 2800 systems. The third-chamber option will increase throughput from 60 to 100 wafers per hour for 100mm wafers for a 1-micron film of Al/Si. The third chamber modifies the system into a true continuous process. The price for the two-chamber system is $500,000; that for the three-chamber system is $600,000.

Electrotech

The successor to the Model MS6200 sputtering system was introduced this year as the Model MS6210. Throughput for the new system is 96 wafers per hour for a deposition of 1.2 microns of Al/Si. The system can handle wafers from 3 inches to 150mm. The MS6200 is now offered with a RF bias option that provides a lower temperature reflow than the competition. With this option planarization and filling of contact holes 1 micron deep by 1.2 microns wide with 1 micron of Al/1%Si can be obtained. The eight-chamber, multitarget design allows cosputtering of barrier layer materials. The MS6200 basic system cost is $620,000. Electrotech also offers the model MS8200 sputtering system which can process wafers from 125mm to 200mm.

Gryphon Products

Gryphon Products announced its new product called the Horizon. This system is fully automated and provides true planarization of aluminum and aluminum alloys. The Horizon uses a proprietary low-temperature process that can planarize features of 1.5 microns and less, while not exceeding 360°C. Dual chamber, parallel batch processing is offered with single-wafer tracking. Gryphon Products sees temperature control as a critical factor for maintaining the quality, accuracy, and repeatability of a sub two-micron process. With the Horizon, the user can control the temperature of the growing film within +/-20°C.

The Horizon will handle wafers from 3 inches to 150mm and will provide step coverage uniformity of +/-5 percent over an entire 150mm wafer. System throughput ranges from 90 100mm to 50 150mm wafers per hour. The chamber is configured with three targets that sputter down. The chamber processes 12 100mm, 10 125mm, or 8 150mm wafers. The Horizon is priced at $1.25 million.

Machine Technology, Inc. (MTI)

The SypherLine sputtering system can now planarize aluminum films over severe geometrical structures. MTI is guaranteeing +/-4 percent uniformity over 200mm wafers (3 sigma). Throughput is 40 wafers per hour for deposition of 1-micron aluminum films. MTI's planarization process is based on a combination of geometrical, thermal, and ion bombardment effects. Deposition rates exceeding 1 micron per minute are being achieved without high-temperature heating of the wafer and without DC/RF bias. The wafer size range for the SypherLine is 100mm to 200mm.

Materials Research Corp. (MRC)

MRC now offers planarization of aluminum as an option for the ECLIPSE sputtering system. This optional process is capable of via filling for submicron geometries. MRC claims thickness uniformity of +/-5 percent using RF bias, tight control over wafer temperature, and a low base volume. Throughput for Al/1%Si at a temperature of 530°C is 25 wafers per hour for a 1-micron deposition.

Temescal

Temescal has been integrated into Edwards High Vacuum International. Temescal introduced a Ultra High Vacuum (UHV), linear, four-pocket, E-gun source. This E-gun source has been developed for molecular beam epitaxy (MBE) vendors to the GaAs industry. The source is conflat flange mounted and is available now.

Ulvac

The ISOVAP-400 load-lock evaporator is designed to handle wafers from 2 inches to 200mm. The system can handle wafers using single dome or planetary motion systems. For lift-off processing which requires the single dome, the chamber can process 99 3-inch GaAs wafers per batch. A menu-driven touch-screen system is available. The price is $300,000.

The MCH-9800 sputtering system is an improved version of the MCH-9000 that Ulvac introduced last year. The 9800 is equipped with eight in-line chambers, compared with six last year. The two additional chambers allow for isolated heatup and cooldown modes. The chamber process sequence is load/pump down, heatup, four sputter chambers, cool down, and unload. The 9800 has a throughput of 50 wafers per hour, up from 35 last year. The throughput was increased by pumping down one wafer at time in a very small chamber, as opposed to pumping down an entire cassette. The MCH-9800 can process 125mm and 150mm wafers and is priced at $1.2 million.

Varian

The XM-90 sputtering system has replaced the XM-8. The XM-90 has all the features of the XM-8, plus expanded flexibility, process recipe control, and backside substrate heating. The addition of a microcontroller allows precise set and control of load-lock pressure, deposition time, deposition power, and substrate heater temperatures. The system allows separate control of the four in-line process stations, plus the capability of depositing three separate times in a single process station. The features allow the user to interlayer sputtered films reactively and nonreactively. Varian also introduced a backside, gas conduction substrate heater option for the XM-90. This option is also available as a retrofit for the XM-8. The XM-90 will operate with DC or RF bias. The price of the XM-90 is $350,000.

Varian now has 8 to 10 3290 sputtering systems installed that use Varian's Viafill planarization process. These systems are now planarizing aluminum over 1 x 1-micron steps. The Viafill process can be tweaked at Varian's demo labs for each customer's requirements before the system is shipped. Varian is working with NTT on a reduced-heat planarization process. Sputtering applications for titanium nitride are also being developed by Varian.

EPITAXY

Silicon Epitaxy

The market for epitaxial reactors has been very weak during this recessionary period. It has been one of the hardest-hit of all front-end equipment segments because of the poor demand for bipolar devices. Total industry sales fell 55 percent from $101 million in 1984 to $46 million in 1986. To exacerbate the situation, the expected usage of epitaxy in CMOS processes simply has not materialized. Extreme over-capacity continues to exist.

Several companies have devoted valuable resources to product development in an attempt to be early winners in the CMOS epi market. Such an investment was necessary because the previous generation of epitaxial reactors were not cost effective for the fabrication of commodity devices such as DRAMs. Companies with appreciable investments in silicon epitaxy for CMOS processing include Applied Materials, Gemini, Anicon, and Epsilon Technology, Inc. (a limited partnership with ASM America as the principal investor).

Only two of these companies have brought a system to market: Applied Materials and Gemini. Anicon's system, announced at SEMICON/West last year, has been tied-up by the acquisition of Anicon by Silicon Valley Group. (The product was developed within an R&D partnership from which investors must recoup their investment before the product is marketed.) Epsilon has told Dataquest that its product will be introduced in third quarter 1987. We believe that it will be a single-wafer system using multichambers, or rapid thermal processing.

Of Applied and Gemini, Applied's system has had nearly a year head start. Because of the market softness, this delay has not cost Gemini any market share. Both systems are poised to take advantage of the incipient industry up-turn. The market for epitaxial wafers is increasing, and silicon wafer vendors are nearly at full production capacity. However, these companies are purchasing reactors of the old vintage, which requires them to sell the product wafers at prices too high to be used for commodity devices. However, the epitaxial wafers produced on these systems can command a premium because they are being used for high-end devices, such as microcontrollers in the U.S. and for charge-coupled devices in Japan. Dataquest believes that the 1Mb CMOS DRAMs and the concomitant CMOS devices that follow, will use epitaxy layers. These epitaxial layers must be processed on the new generation of reactors.

Gemini

Gemini did, however, introduce its third-generation vertical reactor, the Gemini III. The Gemini series has been very successful in wrestling market share away from Applied Materials for very thick films and for less critical films. This is because the system uses two bell jars and tends to be more cost effective for those processes. The series uses a heated graphite susceptor, as opposed to the radiant heating technique of Applied Materials. The heated-susceptor technique tends to be more susceptible to slip faults in the crystal structure, which positions Applied as the vendor of choice for advanced films.

Applied Materials has been able to maintain its dominant position, capturing nearly 70 percent of the market in 1986. However, Gemini hopes to gain share in the bipolar market with its new product. The Gemini III has included a metal can around the bell jar to reflect the heat back into the chamber. This will tend to flatten the temperature profile and reduce slip. Its uniformity guarantee is now +/-1.5 percent (1.6 sigma). It has added robotic handling to reduce the need to rely on an operator. This should increase the productivity of the system. It has also added the ability to process at pressures as low as 80 torr.

The system price is $1.1 million, fully loaded. The Applied Model 7810, priced at approximately $800,000, was essentially the same price as the previous Gemini version, the Gemini II. Applied overcame the throughput disadvantage with excellent marketing, applications support, field service, and process quality. This new price structure essentially reduces the productivity advantage that Gemini previously enjoyed.

Molecular Beam Epitaxy

ISA Riber introduced a chemical beam epitaxy system, and Varian showed its Modular GEN II MBE System for the first time. Chief features of these systems were increased throughput, better yields, decreased downtime, and enhanced manufacturing flexibility.

ISA Riber

ISA Riber announced, although it did not exhibit, a chemical beam epitaxy (CBE) system, the CBE 32. Chemical beam epitaxy is a technique that combines features from both molecular beam epitaxy (MBE) and metalorganic CVD (MOCVD). Traditional MBE uses a solid source, while CBE uses a gas source such as that used in MOCVD. The advantage of a gas source in CBE is increased cleanliness and a more abrupt interface between the epitaxial layer and the substrate. ISA Riber has already delivered a CBE 32 to Bell Labs in New Jersey and has orders for the system in Europe, Japan, as well as the United States. The price of the CBE 32 starts at $750,000.

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ISA Riber also introduced a new solid arsenide cracker source for its MBE 32 system. This new solid source enhances the sticking coefficient of arsenide, which reduces downtime because the source need not be reloaded as often as previously.

Varian Associates, Inc.

Varian showed its Modular GEN II MBE System for the first time as a complete unit. The new system is modular and thus allows users greater flexibility in selecting an MBE for particular process requirements. The new system has a new entry/exit chamber that allows outgassing of up to 16 wafers at once for improved throughput. The modular configurations use a unique trolley cassette wafer handling system that travels from one chamber to another in a vacuum; it is not necessary to house the entire system in a clean room environment, only the entry door. The new system handles up to 3-inch wafers, has a new silicon wafer heater in the buffer chamber, and has larger effusion cells to provide longer periods between cell changes.

Varian believes that perhaps the most significant feature of the new system is the nonindium bonded wafer holder. This new holder holds the wafer with minimum strain and also yields temperature uniformity of better than 5°C over the exposed wafer area.

Metalorganic CVD

New systems, new generations, and enhancements were the order of the day in metalorganic CVD. Crystal Specialties introduced a new system, Emcore showed its new growth chamber, and Cambridge Instruments offered a new enhancement. The focus of enhancements and improvements was to bring MOCVD out of the R&D environment and into a production environment, and to increase yields.

Cambridge Instruments, Inc.

Although Cambridge did not show its MOCVD system, it has added load-lock capability on its MO102 system. This load-lock will allow the system to be pumped down without as much purging as before. Cambridge now has a cadmium mercury telluride (CMT) cell for its MOCVD system. This CMT cell is now undergoing beta site testing.

Crystal Specialties, Inc.

Crystal Specialties introduced the Model 411 MOCVD system. The 411 is a production system which features a new radial injection head to minimize gas residence time. The 411 also has four chambers within the growth chamber (one within the other) to minimize chamber volume, and thus, achieve thinner layers and more abrupt junctions. Additionally, the 411 features a magnetically coupled wafer carrier rotation system that eliminates O-rings to minimize leaks and seal maintenance. The 411 also features a new load/unload station with a pure nitrogen glove box.

Emcore

Emcore displayed the GS3300M MOCVD system. This system features the semiautomated load-lock for processing up to 12 3-inch gallium arsenide wafers per load. A load-lock can significantly cut production time. New wafers can be loaded and pre-heated for insertion while the growth chamber is in use. Finished wafers can be unloaded into the load-lock, thus the system need not be shut down between runs. The load-lock also cuts down on production time since it eliminates the need to manually insert wafers after each run. Loading wafers without exposing the reactor chamber to atmospheric impurities reduces particulate.

Emcore also introduced the Emcore Toxic Gas Absorber to remove hazardous emissions from semiconductor process effluent.

DIFFUSION

This section of the SEMICON/West newsletter contains new product and feature information for horizontal and vertical tube diffusion furnaces, and the associated LPCVD processes. It also discusses horizontal tube plasma enhanced CVD equipment (PECVD).

Almost all introductions in the vertical and horizontal tube markets were focused on robotic wafer handling capability and software automation. As fabs produce larger wafers the diffusion area is being driven to robotic loading due to the sheer weight of quartz boats, which hold up to 200 wafers. Almost every vendor in the diffusion market now sells 200mm robotic wafer-handling capability.

In the horizontal tube PECVD market, only ASM had a new introduction. ASM introduced a system with a very small footprint targeted towards the ASIC and R&D market.

ASM America

The System 250, a horizontal tube furnace, is a low-pressure chemical vapor deposition (LPCVD) system that processes 150mm wafers and is now available in the United States. System 250 is offered with a fully automated cassette-to-cassette material management system. Quartz tubes of up to 235mm inner diameter can be used to accommodate advanced LPCVD processes. Standard process guarantees are offered for silicon nitride, HTO, TEOS, LTO, and in-situ doped polysilicon. ASM has developed dedicated quartzware, quartz injectors, in-tube temperature measurement, and special gas systems for these processes. Also available with System 250 is ASM's Stand-Alone Tube Controller (SATC II), based on the Motorola 68000 microprocessor. Each tube is controlled by its own SATC II. Up to 250 user-defined steps can be accommodated. The System 250 is priced at $400,000 to $700,000, depending upon options.

The SF-50 is a PECVD system. It is designed with a very small footprint ($15ft^2$) and is intended for ASIC, moderate-volume production and R&D applications. The SF-50 can process wafers from 3 inches to 200mm. Throughput is 30 wafers per hour for a 1-micron nitride film. The price of the SF-50 is $200,000.

<u>BTU Engineering</u>

The Series 2000 Automated Material Handling System is a wafer handling robot for horizontal tube diffusion furnaces. This system is capable of automatic tool changing for processing 100mm to 200mm wafers. The module is fully enclosed in a free-standing structure that maintains a class 10 environment. First deliveries of the system will begin during the third quarter of this year. The price of the Series 2000 is $450,000.

A compact cassette-to-cassette loading module was also being demonstrated. The module consists of a two-axis elevator combined with a mass transfer system and an integrated controller. The system provides wafer handling and tube loading for the BTU models BDF-4 and BDF-41 vertical tube systems. The loading module is designed to occupy aisle space formerly needed by the operator. Operator tasks are reduced to supplying and removing product in plastic carriers, removing and supplying empty carriers between transfers, and initiating process cycles at the tube controller. The loading module can change the spread of wafers in the boat and uses slot sensors for precise wafer placement. Load capacity is 200 wafers for sizes of 75mm to 150mm. The price of the system is $145,000.

BTU also has phase one of its APEX software product line available. The software is based on the Apollo workstation and permits the user to manage diffusion tubes or to integrate wafer processing systems with related equipment in a flexible manufacturing cell architecture. The system is compatible with Bruce Systems' automated material handling modules. APEX offers an optional SECS host communications link and is consistent with CIM/MAP cell architectures.

<u>Dainippon Screen</u>

Brochures for the vertical furnace were available at the show for the first time. Although the brochure is sketchy, it appears that Dianippon may begin to market the system in the U.S. The system is designed to automatically load the wafers into the quartz cassette, and then load the cassette into the furnace. The system is designed to operate in the 200°C to 600°C range and has an effective heating length of 300mm.

<u>Gasonics</u>

Gasonics is the only U.S. supplier of high pressure diffusion furnaces. The system is now capable of processing 200mm wafers and is equipped with two tubes per unit. The basic system price is $800,000. The system equipped with the Wafer Robotic Automation Package (WRAP) has a price of $1.5 million.

Process Technology Limited (PTL)

As an improvement to its LPCVD system, PTL has developed a reduced temperature, all liquid source process for the deposition of BPSG films. Undoped oxide, PSG, and BPSG can all be produced with this process. Successful depositions of BPSG have been performed at temperatures below 575°C with deposition rates competitive with conventional hydride processes. The price per tube is $100,000.

PTL now has a wafer carrier handling system available for demonstration. The system is based on a scaled-down model of a robot used in the motion picture industry. The system is strong enough to handle full 200mm wafer quartz boats. The entire system breaks down into sections five feet long or less. The system allows installation in any floor plan, requires no wall moving and will fit through standard fab doors. The system can be equipped with three-axis or five-axis robots and is Class 10 compatible.

Semitherm

Semitherm displayed its vertical tube reactor for diffusion and/or LPCVD processing. The system can process up to 100 150mm wafers at a time. Key benefits of the system include the low-temperature processes and the total control of the process atmosphere during heatup and cool down. Wafers can be processed both vertically and horizontally. The price for the diffusion process is $100,000; the LPCVD process costs $140,000.

Silicon Valley Group (SVG)

The SVG vertical tube reactor (VTR) is now equipped with 200mm wafer automation capability. SVG now guarantees less than 0.01 particle per cm^2 larger than 0.4 micron. SVG is also guaranteeing 10,000 operations without failure. The price of the diffusion VTR is $170,000; the LPCVD VTR is $190,000.

Tempress

The Tempress VR-2000 VTR is now available for shipment. Bottom-up loading is intended to minimize contamination and heat loss. The loading chamber is class 10. The system operates continuously at temperatures between 1250°C and 1350°C. The price for the diffusion process is $150,000; the LPCVD process costs $200,000.

Tempress also exhibited its direct digital controller, which is designed to control temperature and process parameters during diffusion and LPCVD operations. The system features a simplified touch-screen flat panel control for easy data input and user-friendly operation. The system can be linked to a host computer manager and is SECS I/II compatible.

Thermco

The model HLF 5110 Laminar Flow Load Station is designed to be used in conjunction with the 5000 series Thermco four-stack diffusion/LPCVD furnace. The load station is compatible with various cantilever loading systems. This station offers full robotic cassette-to-cassette handling. The system handles wafer transfer from plastic to quartz and back-up boats. Test wafers and solid source wafers can also be automatically loaded. The price of the system is $450,000.

A symmetrically exhausted scavenger exhaust system designed to carry away heat and process gases is available with the load station. The scavenger includes a method of adjusting the air flow velocity without changing the symmetrical, exhausting pattern around the tube. The symmetrical design reduces trapping of particles in the scavenger and also reduces particle-laden, turbulent swirl across the wafer surfaces during insertion and extraction of the load. The price for the load station is $55,000

RAPID THERMAL PROCESSING

In rapid thermal processing the emphasis seemed to be in "application-specific" equipment in an attempt to broaden the applications for this type of equipment. AG Associates introduced a low-temperature machine for contact alloying. Peak introduced a system for thin film deposition. Eaton, which finally repackaged its unit into a more reasonable size, added mass flow controllers and vacuum capability to the new system.

The market for rapid thermal processors is expected to have high growth rates. There was little growth in 1986 sales, however, mainly because of the semiconductor recession, and because we have yet to see the movement of rapid thermal processors into the production environment.

AG Associates

Last year AG introduced its first "application-specific" system, the Heatpulse 2146 Oxidation System, to meet thin film requirements in oxidation, nitridation, or annealing applications. This year AG introduced another application-specific system, the Heatpulse 2126 Contact Alloying System, specifically designed for low-temperature contact alloying of aluminum and other materials in silicon and gallium arsenide applications.

The Heatpulse 2126 has a temperature range of 400°C to 700°C with a maximum temperature ramp-up rate of 100°C per second. The 2126 uses a proprietary, low-temperature pyrometer which measures the temperature of the wafer through quartz. Compared with a typical diffusion furnace anneal, a Heatpulse 2126 alloy cycle of 5 to 10 seconds at 400°C to 500°C will reduce spiking by as much as 90 percent, and eliminate hillock formation.

The system can handle up to two noncorrosive gases. Unlike the other AG rapid thermal processors that use upper and lower banks (each of 11 lamps) the 2126 uses a single bank of eight lamps. The price of the 2126 is $144,000.

Eaton

Eaton introduced the ROA-500 rapid thermal processor, which is essentially a repackaged version of the ROA-400. The ROA-400 had a very large footprint of 63 ft^2, while the new ROA-500's footprint is 33 ft^2. The newer system uses the same 100kW lamp with the same temperature specifications, but has provision for handling up to six corrosive gases.

The price of the ROA-500 is $240,000. First deliveries are scheduled to begin at the end of 1987.

Peak Systems

Peak, a start-up company formed in 1983, exhibited its first product, the ALP 6000, at last year's SEMICON/West. This year Peak exhibited its new Model 6500, which uses the same 35kW lamp as the 6000, but is specifically designed for deposition of thin films. Typically, the thin films deposited in the 6500 would be less than 800 angstroms. It has eight mass flow controllers (the 6000 uses rotameters) and has vacuum processing capability.

Dataquest believes that more than a dozen 6000s have been delivered since last May and that one 6500 has been shipped. The 6500 is priced at $250,000.

Thermco

Last year Thermco made the U.S. introduction of the LA-14AD rapid thermal processor manufactured by TEL/Thermco in Japan. Thermco did not have the system at this year's SEMICON/West, Dataquest believes that the reason for this is that the LA-14AD may still be undergoing debugging.

ION IMPLANTATION

SEMICON/West saw the debut of an new player in the ion implantation market--ASM America--and the introduction of a new system from National Electrostatics. In addition to new players or systems, most of the established players in the market showed systems with improvements in contamination control, automation, yield enhancements, smaller footprints, or wafer handling.

Applied Materials

Applied showed the process wheel of its 6000 for the first time at SEMICON/West. The wheel can hold 25 wafers per batch. The company believes the process wheel has several advantages over the process disk, since it eliminates cross contamination and aluminum contamination. The 6000 is designed to operate at less than 80°C, and Applied claims that it processes wafers in the 45°C to 50°C range because the beam is spread over a large batch size.

In addition to the 25 wafer batch process wheel, the 6000 features automatic wafer handling, automatic setup and conditioning, closed loop beam-line and incipient warning and failure diagnostics. The price of the 6000 is $2.2 million. Shipments began in 1986.

ASM America

ASM America introduced the ASM-220 medium current serial process ion implanter. This is a fully automated system that is optimized for small geometries and wafer sizes up to 200mm. The 220 was designed as a serial wafer processing system in order to minimize the number of wafers at risk at any one time. This system uses a unique parallel-beam scanning technique which ASM claims minimizes nonuniformity from shadowing and channeling due to implant angle variations.

The 220 also features a proprietary in situ dose monitoring and correction system that records the dose accumulated on each pass and corrects errors during the implant. By using fiber optics whenever possible, ASM claims that it has eliminated a major source for high voltage transients throughout the system.

The 220 also features easy-to-use touch screen graphics with color display. The machine initiates automatic setup and optimization of all beam parameters, including ion sources.

The price of the 220 is $700,000.

Eaton Corporation

The NV6200, a medium-current implanter, featured a new adjustable implant angle that can be varied from 0 to 10 degrees.

The NV20, high-current implanter featured a new improved wafer handling system that features little or no wafer breakage. The new system is a pick-and-place system with wafer position feedback. The NV20 is made in Japan by Sumitomo/Eaton, a joint venture. The NV20 was first introduced in Japan in early 1987 and was introduced into the United States at SEMICON/West. The NV20 also features a single chamber that is tilted at 45 degrees for a smaller footprint on the cleanroom floor. The chamber also features a faster pump speed for better handling of photoresist outgassing. Eaton claims that the NV20 can handle 100,000 wafers without breakage.

Eaton also showed the NV200 Simox oxygen implanter for silicon on insulator technology. This system was designed to be used for 16- and 64-Mbit DRAM production.

Eaton also introduced the SKM Medium Current Ion Source. This source can provide a boron beam current in excess of 1mA and delivers a fourfold increase in doubly charged beam currents. Eaton believes that the SKM sources offer the highest beam currents available in the medium current marketplace. The SKM can be used for the NV6200, NV4200, and NV3200 ion implantation systems.

National Electrostatics Corporation (NEC)

National Electrostatics announced a new 2 MeV production implant system, the Model MV-H20. The H20 is designed for the production processing of silicon wafers and can deliver ion beam energies that range from below 300 keV to above 2000 keV for singly charged ions. This system will implant phosphorus ions to the same depth in silicon as 800 keV boron ions. National Electrostatics has quoted prices for this system but has not yet delivered a system.

National Electrostatics also introduced a batch wafer handler for its MeV production ion implantation system. This mechanically scanning, batch wafer handler increases the throughput of the NEC high-energy ion implanter to 300 wafers per hour. It is equipped with a unique beam monitor control which eliminates inaccuracies due to beam neutralization. The wafer handler is retrofitable on existing NEC high energy implanters.

Nissin Electric Company, Ltd.

Nissin had no implanters at SEMICON/West. It did, however, announce its new STAR (Selectable, Tilt, Adjustable, Rotational) end station. The STAR features a self-spinning platten with a 0 to 60 degree tilt and deep well trenching with uniformity of 0.5 percent. Nissin is now taking orders for the STAR.

Varian Associates, Inc.

While Varian did not introduce any new systems, it did show some interesting new enhancements and improvements to its existing systems. The 160XP medium current implanter has a new automated loader which can handle 100mm to 150mm wafers. This new loader features automatic orientation of the wafer.

Varian has reduced the number of parts by two-thirds on the 160XP's disk drive for both increased reliability and easier maintenance. Additional new features on the 160XP include: an improved seal in the faraday cup valve, improved beam spot size control, and an improved electron flood gun. The 160XP can be run either manually or automatically.

The 300XP high-current system has new software to check auto-cyclying. The 300XP specifications now include breakage: one broken wafer in 20,000, with a 70 percent confidence level. It has been designed to contribute no more than 0.1 particle per cm^2 for particles greater than 0.5 micron.

WAFER INSPECTION

In today's semiconductor industry, line geometries are shrinking, while device complexity, processing steps, and mask levels continue to increase. In response to requests for smaller, smarter, and faster measurements, new generations of wafer inspection tools are being developed to meet the requirements of advanced device processing technology. Wafer inspection currently is making a transition from operator-intensive inspection and measurement systems to fully automated tools as the semiconductor industry looks to automate its manufacturing processes. Accordingly, the price of wafer inspection tools has also increased, and in some cases has reached the price of a wafer stepper at approximately $1 million.

This portion of the newsletter examines new equipment introductions and enhancements in the area of wafer inspection, with particular emphasis on automatic critical dimension (CD)/linewidth and defect inspection systems. Some selected information on new equipment announcements and enhancements in other areas of process control, such as film thickness measurement, mask metrology, resisitivity mapping, and surface defect inspection is also presented.

Critical Dimension And Defect Inspection Equipment

Cambridge Instruments

Cambridge Instruments introduced its Microcheck 1 and Polycheck critical dimension measurement systems. The Microcheck 1 is a completely manual tool with applications in optical linewidth and overlay registration measurements. The price is approximately $60,000. Several systems have been installed at semiconductor manufacturers' facilities in the United States in the last year. The Polycheck is a fully automated CD measurement system and provides measurement capability down to 0.5 micron in addition to macro measurements of larger dimensions. The price of this system is $115,000. There are no deliveries of the Polycheck system at this time.

The Polycheck VLSI was also exhibited at the show, although the formal introduction of this system will be at SEMICON/East in September. The Polycheck VLSI is a fully automated CD measurement system with pattern recognition and auto-align capability. This tool has a four-cassette material handling system with 200mm wafer capability. The system displayed at the SEMICON/West show was a second-generation prototype tool. The price of the Polycheck VLSI is approximately $170,000. The Polycheck VLSI has been designed specifically for wafer inspection applications in the semiconductor industry in contrast to the Microcheck 1 and Polycheck systems, which have cross-industry applications.

Cambridge Instruments introduced its automated Scanline-CD Electron Optical Comparator at SEMICON/West this year. The nondestructive electron-beam comparator can measure linewidths from 0.1 to 30 microns and has a throughput of 12 wafers per hour at five sites per wafer. The Scanline system has cassette-to-cassette automatic wafer loading, and the price of the system is less than $200,000.

Heidelberg Instruments

Heidelberg Instruments introduced its fully automated, LPM Line Profile Measurement system. The LPM is a confocal laser scanning microscope designed for three-dimensional measurement of line geometries with measurement capability down to 0.3 micron for linewidth and 0.05 micron for lineheight. Typical throughput for 150mm wafers is 30 wafers per hour based on 10 chips per wafer, 5 measurements per chip. The LPM was first introduced at SEMICON/Europa in March 1987, and the first system was shipped to Siemens in late May. Additional orders were received in mid-May. The price of the Heidelberg LPM system is $340,000.

Heidelberg Instruments was formed in 1984 by five researchers from Heidelberg University and four industrial partners. One of the major investors in Heidelberg Instruments is E. Leitz, a West German manufacturer of wafer inspection and mask metrology equipment for the semiconductor industry. Other products from Heidelberg Instruments include laser scanning microscope systems for biological, chemical, and medical applications.

Insystems

Insystems introduced its Model 8600 wafer defect inspection system, a fully automated, full wafer, submicron defect detection tool that utilizes holography and spatial filtering technology. The Model 8600 has been designed for in-process patterned wafer inspection, and can inspect an entire wafer surface for defects in less than 30 minutes. This is in comparison with the several hours required for conventional optical- or SEM- (scanning electron microscope) based inspection tools. This reduction in measurement time is achieved because the Model 8600 relies on parallel optical processing rather than a serial analysis of the wafer on a die-by-die basis.

The Model 8600, with up to 150mm wafer capability, can detect submicron defects in high-density, repetitive areas in single and multiple-process levels in photoresist; oxides; polysilicon; metal; and other films, such as nitride, phosphosilicate glass, and polyimide. The Model 8600 is priced at slightly more than $1 million. Insystems first introduced the tool at SEMICON/Europa in March 1987. The Model 8600 was in beta site during 1986, the first systems were shipped in the May/June time frame of 1987.

Insystems, founded in 1981, is a privately held company. Insystem's first product was the Model 8405 Automatic Photomask Inspection system. The first unit, at a price of $800,000, was shipped to Motorola in April 1986. Insystems views the Model 8405 as an interim product and plans to focus on wafer inspection as its primary market.

IVS, Inc.

IVS, Inc. introduced a fully automated, cassette-to-cassette, CD/linewidth and registration alignment measurement system. The AccuVision 4 (ACV4), priced at $250,000, utilizes digital image processing techniques to enhance the signal-to-noise ratio, and achieves a linewidth resolution down to 0.3 micron with 0.003 micron repeatability. The ACV4 has a throughput of 35 wafers per hour at five sites per wafer. The first shipment of the ACV4 is expected to go to a semiconductor manufacturer in Texas in the third quarter of 1987.

IVS first introduced its AccuVision family of digital imaging process tools at SEMICON/West 1986. The AccuVision family currently includes the ACV, ACV1, ACV2, ACV3, and ACV4 which range in price from $50,000 to $250,000. The AccuVision systems are modular in hardware and software design, and each member of the AccuVision system can be upgraded to the next system level without price penalty.

In addition to linewidth and registration alignment measurement, the IVS tools also provide defect detection, inspection, and analysis. To implement this function, the operator identifies a given area of the wafer as a "golden" image. Then the system, with its pattern recognition capability, performs a comparison analysis of selected portions of the wafer with the "golden" image. The difference between the two digitized signals is presented on a color monitor--areas in red represent what is present on the wafer but should not be, while areas in green identify what is missing on the wafer but should be there.

IVS, Inc. received its first round of venture funding in early 1985. The first investors were Charles River Partners, First Chicago, and Turner Revis. IVS received a second round of venture financing for $2.3 million in March 1987 from Memorial Drive Trust, Venture Founders, and Zero Stage Capital Corporation.

KLA Instruments

At SEMICON/West this year, KLA Instruments introduced a software enhancement for its KLA 2020 Wafer Inspector. The software package, known as KLASS, is an applications package for optimizing stepper setup parameters. The software loads on the KLOUT (KLA Utility Terminal) computer system which is used to collect and process data from the KLA 2020. The software package is priced at $20,000.

The KLA 2020 is an automated in-process wafer inspection system which integrates CD, registration, and area measurements with defect monitoring and macro inspection. The KLA 2020 was introduced in 1984 and the first systems were shipped in February 1985. The price of this system is approximately $1 million.

At the show this year, KLA also displayed the KLA/Holon 2711, a low-voltage, electron-beam, submicron metrology system designed for automated critical dimension and registration measurements. Its primary application is in the characterization of process parameters in the initial stages of process development and for process control monitoring as device volumes increase. Wafer throughput is about 20 wafers per hour at five sites per wafer, and the system can handle 100mm through 200mm wafers. This nondestructive measurement system has a precision less than or equal to 0.05 micron (three standard deviation) for automatic CD measurement. The price of this system, depending on options, is less than $500,000. The KLA/Holon 2711 is the first product to be introduced under an agreement announced in November 1986 by KLA and Holon Co., Ltd. of Japan. KLA is the exclusive distributor of this product in the United States and Europe.

Nanometrics

Nanometrics introduced the Model 400 Linewidth and Registration Measurement Station at SEMICON/West this year. This fully automated, cassette-to-cassette tool provides both bright field and fluorescence measurement capability for CD and overlay registration measurements. The price of the Model 400 is $150,000, which includes material handling capability. Wafer throughput for the fully automated system is approximately 20 wafers per hour at five sites per wafer. The fluorescence capability of the Model 400 tool is specific to fluorescing resists. Nanometrics has demonstrated a performance of 5 percent precision on 0.4 micron measurements when operating in this mode. Nanometrics has developed a proprietary CCD (charged couple device) camera to collect the characteristically weak fluorescing signals. The Nanometrics Model 400 tool shown at the show this year is a post-engineering prototype system.

Nanometrics also introduced the Model 51, a fluorescence CD measurement system. This is a manual version of the Model 400, and utilizes a scanning PMT (photomultiplier tube) to form a high-resolution reflectance profile. The Model 51 has programmable sensitivity and 200mm wafer capability. This microscope-based system is priced at less than $45,000.

Optical Specialties, Inc.

Optical Specialties, Inc. (OSI) announced several new products at SEMICON/West this year. In the category of defect inspection, OSI announced its Micropatterning Process Control System. The new system is designed to perform a variety of tasks without operator intervention. The tool automatically receives wafers from robotic material handling equipment, reads the wafer's identification code (alphanumeric optical character reader), creates a wafer pattern array map, performs macroscopic defect inspection and classification, reads the photo mask layer identifier (optical character verification), measures registration overlay and linewidths, detects and classifies microscopic defects, and displays macro or micro images and test data. The OSI systems uses proprietary software algorithms for defect inspection and classification.

The Micropatterning Process Control System has been designed for use in the production environment as well as for the setup and qualification of new processes. The equipment can handle 100mm through 200mm wafers. The system will be in beta site during fourth quarter 1987. First product shipments are expected in first quarter 1988. The tool's target selling price will be approximately $500,000.

The second new product announced at the show this year is the MV-360CD, a fully integrated linewidth and defect wafer inspection system. The MV-360CD combines the functionality of two existing OSI tools: the Video Linewidth System (VLS-I) and the Microvision 360 (MV-360). The system features a robotic wafer handling system which is characterized by a very low contaminant count, as verified by VLSI Standards, a contamination analysis firm in the Silicon Valley. The price of the MV-360CD is approximately $120,000. Several systems have been shipped.

The third product announcement from OSI this year is an applications software package, the Metrology Analysis Program I (MAP-I), which is used to optimize stepper/aligner operating parameters. The software analysis package operates on a dedicated IBM PC, XT, AT or compatible system and receives measurement data from OSI's MV-PLUS, a fully automatic optical linewidth system. The MAP-I software package for OSI's MV-PLUS is priced at $20,000.

SiScan Systems

SiScan Systems displayed the SiScan-IIA wafer measurement system this year at SEMICON/West. The SiScan-IIA, like its predecessor the SiScan-I, utilizes confocal scanning laser technology to measure registration overlay and critical dimensions of circuit features including metal layers, nitrides, and photoresist. The SiScan-IIA was designed to measure and inspect submicron circuit features in a Class 10 clean room environment. SiScan-IIA system enhancements include a smaller footprint, a new focus mechanism, and improvements in the speed of stage movements. In addition, the SiScan-IIA features an automatic robotic wafer-handling system.

Wafer throughput is greater than 20 wafers per hour at five sites per wafer, and linewidths can be measured down to 0.3 micron with 0.005-micron repeatability. The price of the SiScan-IIA is $350,000. The first two units will be shipped in August 1987. The SiScan-IIM, at a price of $267,000, is the manual version of the SiScan-IIA. Several units of the SiScan-IIM are already in the field.

SiScan Systems was founded in 1982. Its first product, the SiScan-I, was first introduced at SEMICON/West in 1986. There are a number of units in the installed base including systems at Cypress Semiconductor, IDT, and Motorola. SiScan Systems received its seed funding from Bay Ventures Corporation. Investors in the second round of funding included EG&G Venture Partners, Mitsubishi Corporation, Sevin Rosen Bayless Borovoy, and Shaw Venture Partners, while third round investors were Oscco Ventures and Rothschild Unterberg Towbin. SiScan has received a total of $10 million in venture funding.

Vickers Instruments

Vickers Instruments introduced its Nanolab SR Series at SEMICON/West this year. The Nanolab SR Series is an automatic, nondestructive, submicron CD and inspection system. The tool utilizes SEM (scanning electron microscope) technology, and has been designed to operate in the production environment. The wafer throughput rate is greater than 15 wafers per hour assuming 100 percent sampling at five sites per wafer. The linewidth measurement range is from 0.1 to 10.0 microns. Inspection capability is based on visual observations made by an operator. The first shipment for the Nanolab SR Series was in late 1986. The price for this system is $500,000.

Vickers also offers a sister tool to the Nanolab SR Series. This system, the Nanolab DL3206 SEM, is based on the same SEM technology as the Nanolab SR tool. The difference in the two systems is that the Nanolab DL3206 SEM has been designed for use in process development and troubleshooting, such as in the early stages of setting up a production line. In contrast, the Nanolab SR Series has been designed for in-line processing in a production environment. The price of the DL3602 system is $280,000.

At the show this year, Vickers Instruments displayed its Quaestor CD07A, a fully automatic, optical-based, CD measurement and inspection system. The tool has a wafer throughput rate of 20 to 25 wafers per hour at five sites per wafer, and can reliably measure down to 0.7 micron. The Quaestor CD07A can handle wafers sizes from three inches to 150mm, with upgrade capability to 200mm wafers. Inspection capability is based on visual observations made by an operator. The system was introduced one year ago, and several systems have been shipped. The price of the Quaestor CD07A is approximately $200,000.

Waterloo Scientific

Waterloo Scientific introduced its new automatic CD measurement system based on confocal laser scanning microscopy. The system (model WSI-1000CD) is priced at approximately $300,000 which includes robotic material handling capability. The tool shown at SEMICON/West was a prototype model. The full production system is expected to be available in the third quarter of 1987.

Waterloo Scientific is a small, privately owned, Canadian firm. The company was formed in 1983. Its main products are laser scanning microscopes. In addition to its automatic CD measurement tool, Waterloo Scientific has a second laser scanning microscope system, the WSI 100, which features optical beam induced current (OBIC) measurements for semiconductor material and device characterization.

Other Inspection Systems

Information is presented in the following section on new equipment announcements and enhancements in the areas of film thickness measurement, mask metrology, resistivity mapping, and surface defect inspection. This information is not meant to be a thorough investigation of the other categories of inspection tools at SEMICON/West this year. Rather, it has been presented to add some additional perspective on the diversity of inspection products available today.

Estek

Estek, an Eastman Kodak subsidiary, displayed the Aeronca wafer inspection equipment at SEMICON/West this year. (Eastman Kodak acquired Aeronca in early 1987.) New to the show this year is the WIS 800, a laser-based wafer inspection tool, that can conduct a variety of surface flaw analyses. The WIS 800 is 200mm compatible, and is priced at $120,000. The WIS 600 is similar in design to the WIS 800 but is 150mm compatible. Its price is $100,000. Both the WIS 600 and 800 systems are designed for measuring surface flaws and defects in films on unpatterned wafers.

The AE 1000 is a patterned wafer inspection system. An operator can accept or reject wafers based on visual inspection. Up to 300 points can be programmed in memory for specific site inspection. The price of the AE 1000 is approximately $80,000.

The Estek ISD LIS 5000 was also introduced at SEMICON/West. This system is an acoustic cleaning system integrated with an inspection station, the WIS 600 system. With this integrated system, it is possible to accept or reject wafers based on parameter analysis which uses input from the WIS tool. The ISD LIS 5000 is currently in beta site. The price for this system is approximately $250,000.

Inspex

Inspex announced the EX 3000, a patterned wafer inspection system for particle measurement. The Inspex EX 3000 provides both count and particle size distribution information in a color graphics representation. The particle size measurement sensitivity can range from 0.3 micron and more, depending upon the type of film and the number of preceding mask levels. System throughput is difficult to quantify because sampling amounts and procedures may vary, however, typically it takes 1.5 seconds to analyze a 10mm x 10mm field of view. It is possible to program the area to be sampled, in both random sampling mode and from 10 to 100 percent of the wafer surface. Software is included for statistical analysis. The EX 3000 is 200mm compatible and is priced at $300,000. The system was developed approximately 18 months ago and currently, Inspex has 20 systems installed at one customer's facilities. Inspex, a Japanese inspection company, was previously named Hamamatsu.

Lasertec

Lasertec displayed two new products this year: the 1LM11 Laser Scanning Microscope and the 2LM11 Color Laser Scanning Microscope, with CD measurement capability. The 1LM11 Laser Scanning Microscope utilizes confocal optics to provide a high-quality image capable of 0.3-micron resolution. The 1LM11 is best suited for the R&D environment or in the area of quality and process control applications as the 1LM11 has no automatic wafer-handling capability. The price of this system is approximately $78,000.

The 2LM11 Color Scanning Laser Microscope, also designed with confocal optics, utilizes beam output from both helium-neon and argon ion lasers to produce a real-time high-quality color image. The system, which includes a CD measurement system, has a resolution of 0.3 micron and an optional OBIC display. An optical beam induced current, OBIC, is produced when a light beam is focused on the surface of P-N junction. When viewing the OBIC image, it is possible to observe real-time internal current flow by varying the TTL input signal. Applications for both the 1LM11 and 2LM11 systems outside of the semiconductor industry include the study of metal surfaces, ceramics, polymers, synthetic textiles, and biological/biomedical specimens. Lasertec (formerly named NJS Corporation) also manufactures automatic mask/reticle inspection systems.

Leitz-Image Micro Systems Company

The LMS-2000 Laser Metrology System was displayed at SEMICON/West this year. The advanced high-speed mask/reticle metrology tool was developed by Letiz-IMS, a partnership between Ernst Leitz Wetzlar GmbH of West Germany and Image Micro Systems, Inc., of Billerica, Massachusetts. The LMS-2000 uses a light scanning system to provide critical dimensions and pattern dimensional integrity data with nanometer accuracy and repeatability over an 8 x 8-square-inch area. The LMS-2000 can support the output of several e-beam mask generating systems.

Siemens AG was the first beta test site for the LMS-2000 in the summer of 1986. In addition to Siemens, Leitz-IMS has shipped one additional system to Tau Laboratories, a U.S. maskmaking company. While the LMS-2000 is approximately one year old, the first commercial product was available in first quarter 1987. The price of the LMS-2000 system is approximately $1 million.

Nanometrics

In addition to its announcements of advanced CD tools, Nanometrics introduced the Model 300 Automatic Film Thickness Measurement Station. This tool is a fully automated, microcomputer-controlled system. Wafer throughput is a nominal 20 wafers per hour. The Model 300 has 100mm, 125mm, and 150mm multicassette capability and can perform measurements in an unattended operations mode. First shipments of this system will begin in the June/July time frame to customers in the United States. The price is approximately $140,000.

Prometrix

Multilayer film thickness capability has been added to the SpectraMap SM200, a film thickness mapping system available from Prometrix. The SM200 uses a spectral response technique to measure the thickness of single or multilayer films in a range from 100 angstroms to 4 microns; films include oxide, nitride, polysilicon, photoresist, as well as others. The multilayer film thickness capability particularly lends itself to the measurement of poly-on-oxide film thickness. The SM200 measures and determines the poly thickness based on first-principle calculations, rather than relying on look-up tables of previously prepared samples. The system presents summary information in three-dimensional contour maps and control charts, and utilizes StatTrax, Prometrix's proprietary data base management system, for statistical quality control and trend chart analysis. The SM200 was first introduced at SEMICON/West 1986 and is priced at approximately $80,000. It handles 2-inch to 200mm wafers and can be configured cassette-to-cassette as an option. The SM200 has received acceptance from both sides of the industry; systems have been installed at both semiconductor and equipment manufacturers' facilities.

Prometrix introduced the OmniMap RS30 mapping system at the show this year. OmniMap is a resistivity mapping system which measures sheet resistance electrically at a number of preprogrammed locations on a fabricated wafer, stores the data, and generates a resistivity contour map. Resistivity changes as small as 0.1 percent can be detected. The OmniMap RS30 replaces the OmniMap RS20 system, which was introduced at SEMICON/West 1985. As part of the RS30 upgrade, a 20-Mbyte hard drive has replaced one of the previous 3-1/2-inch micro floppy drives. In addition, trend parameter and charting capability have been added to the system. The price of the RS30 is the same as the RS20 system at $56,000. Two of the new systems were shipped to European customers in May 1987. Upgrades to RS20 systems in the field are available.

AUTOMATION

Manufacturing automation continues to be a topic of interest within the industry, even though many semiconductor automation programs have been on hold during the recent recession. Companies exhibiting automation products at the show this year were cautiously optimistic that their semiconductor markets were starting to turn upward. However, many companies have opted to pursue automation markets outside the semiconductor industry as a strategy for surviving the "boom-bust" business cycles of semiconductor manufacturers. Market opportunities for semiconductor automation software and equipment companies include printed circuit board assembly and pharmaceutical operations. The philosophy of the automation vendors is that the knowledge and products required to meet the rigorous cleanliness and complexity requirements of the semiconductor industry will translate to any automation environment. While these firms have adopted customer base diversification as a growth strategy, they consider the semiconductor industry as the primary market for their products.

This section of the newsletter reviews some of the new products and activities in semiconductor automation. Major topics discussed are automation software systems, a cell/station controller, fixed wafer transport equipment, and robotics.

Automation Software

The two major vendors of manufacturing automation software in the semiconductor industry are Consilium and PROMIS Systems. This year at SEMICON/West, Consilium announced a new module for its COMETS software package. The Short Interval Scheduling (SIS) module provides dynamic dispatch capability and is priced at $65,000. PROMIS Systems introduced two new modules for the PROMIS software package: Advanced Production Reporting, which provides a broad scope and flexibility in report generation, and the Translator module which allows the user interface, both screen and hardcopy, to be translated and presented in non-English languages. Both modules were part of the PROMIS 4.2 software release announced in second quarter 1987. Cameo Systems, a third vendor of automation software, announced an enhancement to its CAM (computer-aided manufacturing) software package, CAMEO II. The new module, called Manufacturing Forecasting and Simulation, simulates the behavior of the factory floor in terms of material movement, process flow, and lot processing.

Qronos Technology is a new start-up in the manufacturing automation software market. This year, Qronos introduced the Qronos Production Master, a software product for manufacturing automation. The Production Master consists of three modules: WIP tracking, area planning and dispatch, and engineering data collection. The software system runs on IBM System 88 hardware. The total price for the Production Master (including software, hardware, and installation) is $1.2 million. Qronos expects to introduce three additional "Master" products later this year: order management, sales and marketing, and corporate planning. The entire system of "Master" products is known as the Qronos Advantage. Qronos software is currently in beta site at a Silicon Valley semiconductor company.

The semiconductor automation software packages are available on various computer hardware systems. For the software and hardware vendors, such alliances are important strategic decisions, since both groups are striving to increase the visibility and market share of their products within the semiconductor industry. Digital Equipment Corporation has been particularly successful in this respect since the software packages of both Consilium and PROMIS Systems, the two market leaders, run on DEC hardware. However, last year at SEMICON/West, PROMIS Systems announced the availability of IBM-compatible software, and recently, Qronos Technology became an Industrial Marketing Partner of IBM. Table 4 identifies the computer hardware for the software packages from Cameo Systems, Consilium, PROMIS Systems, and Qronos Technology.

Table 4

SEMICONDUCTOR AUTOMATION SOFTWARE PRODUCTS AND HARDWARE

	Computer Hardware Systems			
Software Vendors (Packages)	Data General	Digital Equipment	Hewlett-Packard	IBM
Cameo Systems (CAMEO II)	X	X	X	
Consilium (COMETS)		X		
PROMIS Systems (PROMIS)		X		X
Qronos Technology (Qronos Advantage)				X

Source: Dataquest
June 1987

Cell/Station Controller

CTX International introduced its CTX 1100 Station Controller. This system provides a step toward factory automation by automating data collection and recipe downloading to metrology equipment; statistical process control on collected data; and automating host data upload transactions. Current metrology interfaces include Nanometrics' Nanoline and Nanospec tools and Rudolph Auto LF Ellipsometer. The CTX 1100 has 16 ports that can be interfaced to up to 7 metrology tools, as well as to host (or multiple host) systems and off-site terminals. The price for CTX 1100 can range from $40,000 to $100,000, depending on the number of ports utilized. The system was completed in first quarter 1987. The beta site for the CTX 1100 was at Intel in Santa Clara, California. Four units of the CTX 1100 have been installed as of May 1987.

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Fixed Wafer Transport

Toshiba exhibited Space Linear, its magnetically levitated carrier system for automated wafer transport; this system was first introduced at SEMICON/Japan in December 1986, as reported in our January 1987 newsletter. The system is an elevated wafer transport track which utilizes a ferro-magnetic guide rail to achieve a completely contactless suspension system. The Space Linear system is priced at approximately $3,500 per foot of track; a typical system is approximately 1000 feet long. The price of the typical system would include 10 elevators, a traffic controller computer, and the guide rail system. This system is currently being used at a Toshiba semi-conductor facility in Japan.

Robotics

Robotic systems were exhibited at SEMICON/West this year by processing equipment manufacturers and robotics companies that both OEM and direct supply their products to the semiconductor industry. Over the last few years, robotics companies have worked together with the front-end processing equipment vendors, particularly those firms that manufacture wet processing stations and diffusion equipment. These have been two popular fab areas where operator-intensive tasks have been replaced by robotics for reasons of both safety and manufacturing efficiency. (See the "Diffusion" section for more information on new product announcements, which include robotics and automation activities of diffusion equipment companies.) Table 5 contains a list of robotics companies at the show this year and identifies those equipment vendors displaying their products.

George Burns
Joseph Grenier
Robert McGeary
Mark Reagan
Peggy Marie Wood

Table 5

ROBOTICS COMPANIES AT SEMICON/WEST

Robotics Company	Equipment Company	Equipment Category
Intelledex	Thermco	Diffusion furnace
	FSI	Wet processing equipment
	Integrated Air Systems	Wet processing equipment
	Universal Plastics	Wet processing equipment
	Flexible Manufacturing Systems (FMS)	OEM supplier to FMS for automatic guided vehicle
Precision Robots, Inc.	ASM America	PECVD furnace
	Pacific Western	PECVD furnace
Unimation, A Westinghouse Company	Applied Materials	Epitaxial reactor
	ASM America	LPCVD furnace
	Quartz International	OEM supplier to Quartz International for diffusion furnace load/unload station
	Semitherm	Diffusion furnace
	Veeco	OEM supplier to Veeco for automatic guided vehicle
United States Robots	(United States Robots company product)	AB110 - Automated wet process station; (OEM for wet bench is Desert Technologies)
Wollman Engineering	Tempress	Diffusion furnace

Source: Dataquest
June 1987

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THE SEMICONDUCTOR GAS INDUSTRY: OUTLOOK ON THE U.S. MARKET

INTRODUCTION

In the semiconductor industry, process gases represent one category of consumable materials that are used throughout the fabrication of semiconductor devices, from polysilicon manufacturing and the growing of single silicon crystals, through the many steps of wafer fabrication, to the final stages of assembly and test. Dataquest recently completed an analysis of the 1985 and 1986 semiconductor gas markets in the United States. This newsletter provides a summary of the results from our study, including estimates of the nitrogen and silicon-precursor gas market segments in 1986, and our forecast of semiconductor gas consumption in the United States through 1991. Please note that the regional designation, United States, includes Canadian semiconductor manufacturing operations.

MARKET SUMMARY

In 1986, the U.S. bulk and specialty gas market was $215.5 million, up 8.0 percent from 1985 sales of $199.6 million. Four companies—Airco Industrial Gases, Air Products and Chemicals, Liquid Air Corporation, and Union Carbide Corporation—dominated the market with more than 90 percent of semiconductor gas sales in 1986. Table 1 summarizes Dataquest's estimates of the 1985 and 1986 bulk and specialty gas markets.

Table 1

U.S. 1985 and 1986 Bulk and Specialty Gas Markets
(Millions of Dollars)

Gas Category	1985	1986	% Growth 1985-1986
Bulk Gases	$160.4	$173.8	8.4%
Specialty Gases	39.2	41.7	6.4%
Total	$199.6	$215.5	8.0%

Source: Dataquest
December 1987

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MARKET DEFINITIONS

An important part of any analysis of the semiconductor gas industry is a clear understanding of the definitions that are used to describe market segments, suppliers, and applications.

Gas Categories

Semiconductor gases are generally divided into two categories: bulk and specialty gases. The bulk semiconductor gases are nitrogen, oxygen, hydrogen, and argon. The designation of "bulk" typically refers to a discrete delivery of a large volume of gas by truck transport. These gases typically are delivered as cryogenic liquids because of the efficiency of transportation and storage prior to the vaporization stage at the semiconductor manufacturer's facility. Nitrogen gas provided through direct pipeline delivery, as well as customer on-site nitrogen generation plants, is also considered as part of the bulk gas category, even though the supply of nitrogen, in this sense, cannot be classified as discrete.

There are a large number of gases (more than 35) that are classified as semiconductor specialty gases. For that reason, a further segmentation of this category is necessary and is based on the chemical reactivity and functionality of the various specialty gases. Dataquest segments the specialty gas market into six categories: silicon-precursor gases, dopants, etchant gases, reactant gases, atmospheric/purge cylinder gases, and others. Specialty gases are used in comparatively smaller volumes than the bulk gases and, thus, are delivered in high-pressure cylinders.

Who Supplies?

In the United States, the major suppliers of bulk gases to the semiconductor industry include Airco, Air Products, Liquid Air, and the Linde division of Union Carbide. Some of the smaller bulk gas suppliers include Big Three (acquired by Liquid Air in 1987), Liquid Carbonic, and MG Industries/Scientific Gases. The major specialty gas suppliers to the U.S. semiconductor industry are Airco, Air Products, Matheson, Scientific Gas Products (acquired by Scott Environmental Technology in 1987), and Union Carbide. Smaller players in the specialty gas market are Big Three, Liquid Air (Alphagaz Division), Liquid Carbonic, MG Industries/Scientific Gases, Southland Cryogenic, and Synthatron (acquired by Solkatronic in 1986). While the major suppliers of specialty gas to the semiconductor industry typically supply the full complement of specialty gases, it is interesting to note that no one company has complete primary manufacturing capability. Therefore, in the specialty gas industry, it is necessary that companies sell products among themselves.

Who Buys?

For most gas companies, the semiconductor industry represents part of a loosely defined category of "electronics" customers. Because the designation of electronics is ambiguous, Dataquest has defined the customer base for semiconductor bulk and specialty gases to include the following:

- Polysilicon, silicon, and gallium arsenide operations
- Semiconductor manufacturers (both merchant and captive)
- Research cooperatives, government labs, and university semiconductor programs

Dataquest's gas market estimates reflect direct sales of bulk and specialty gases to the U.S. semiconductor industry. Sales of gases between companies are excluded because of the problems that arise from double- if not triple-counting of gas molecules along the distribution chain. In addition, revenue from gas-handling equipment sales and from those gases sold to semiconductor equipment companies is excluded; the exception is tungsten hexafluoride. Gases that are used in nonsemiconductor industry segments such as fiber optics, solar applications, or the printed circuit board industry are also excluded from our analysis.

It is important to note that direct comparison is not appropriate between Dataquest's 1984 market estimates and the 1985/1986 market estimates presented in this newsletter. The reason lies in the difficulty of defining the appropriate customer base and gas applications that constitute the semiconductor bulk and specialty gas markets. There was some confusion regarding these definitions in our 1984 study. For example, our 1984 U.S. specialty gas market estimate is likely on the high side due to the inclusion of some revenue from gas-handling equipment and sales of specialty gases between companies. As another example, our 1984 estimate of U.S. oxygen consumption is much higher than expected when compared with 1985 and 1986 estimates. In this case, oxygen consumption in nonsemiconductor applications was incorrectly included in our estimates.

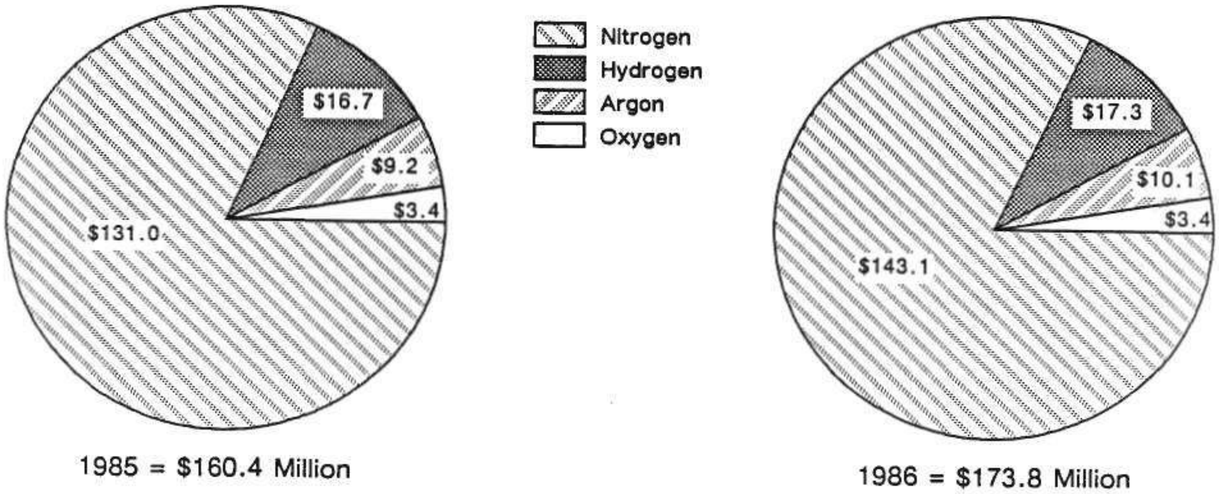
SEMICONDUCTOR BULK GASES

Market Overview

In 1986, the U.S. semiconductor bulk gas market was $173.8 million, up 8.4 percent from 1985 sales of $160.4 million. Figure 1 presents the 1985 and 1986 bulk gas markets, segmented by individual gas revenue. Table 2 presents volume estimates and average selling prices for the individual bulk gases in those same years. Nitrogen remains the major gas within this category, representing 82.3 percent of the dollar market in 1986 and 96.7 percent of the total bulk gas volume. Note, however, that while the volume of argon consumed in 1986 represents a mere 0.6 percent of the total bulk gas volume, it accounts for 5.8 percent of total bulk gas revenue.

Figure 1

U.S. 1985 and 1986 Bulk Gas Market
(Millions of Dollars)



Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
December 1987

Table 2

U.S. 1985 and 1986 Bulk Gas Market
Volumes and Average Selling Prices
(Billion Cubic Feet and Dollars per Hundred Cubic Feet)

	1985		1986	
Bulk Gas	Volume	ASP	Volume	ASP
Nitrogen (Total)	51.9		55.4	
On-Site	23.0	$ 0.14	24.7	$ 0.15
Pipeline	9.0	$ 0.23	9.5	$ 0.23
Liquid	19.9	$ 0.39	21.2	$ 0.40
Hydrogen	1.05	$ 1.59	1.09	$ 1.59
Oxygen	0.39	$ 0.88	0.41	$ 0.84
Argon	0.34	$ 2.74	0.37	$ 2.71
Total Bulk Gas Market	53.7	$160.4M	57.3	$173.8M

Source: Dataquest
December 1987

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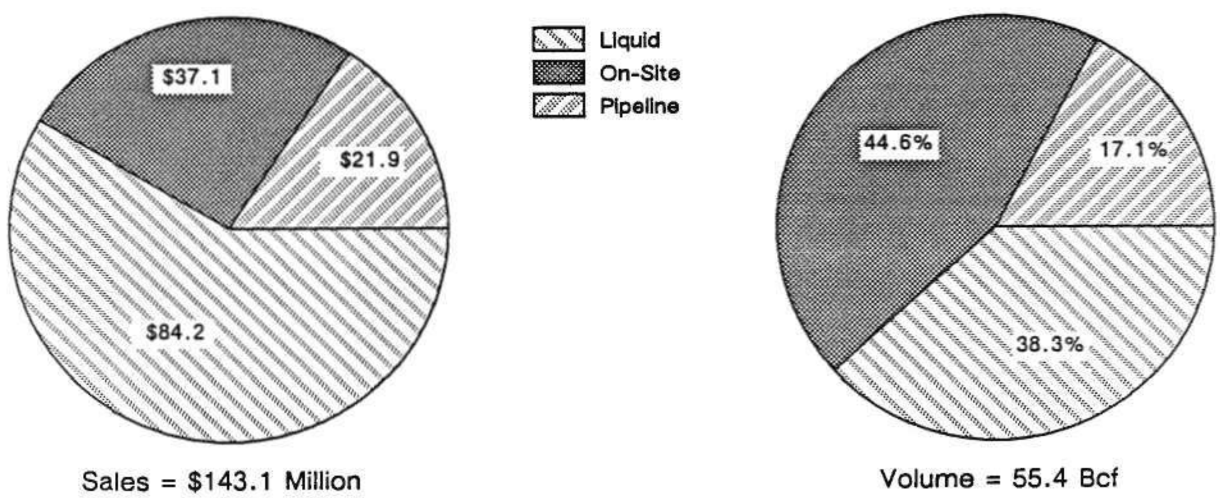
In general, the average selling price of the bulk gases in 1986 remained at or close to the 1985 level. This was due, in part, to sluggish market conditions within the semiconductor industry but also was influenced by low inflation rates holding down the cost of power production in the United States. The cost of power is a major factor in bulk gas pricing because nitrogen, oxygen, and argon generated from air separation plants, and hydrogen obtained from industrial processes such as thermal cracking or steam reforming of natural gas, all represent power-intensive manufacturing operations.

Nitrogen Markets

Nitrogen represents the largest dollar-value and volume segments of the U.S. semiconductor bulk gas market and, therefore, deserves special note. There are three different modes of delivering high-purity nitrogen to a semiconductor facility in the United States: an on-site air separation plant, a multicustomer pipeline network, and merchant deliveries of liquid nitrogen. (Dedicated single-customer pipeline delivery of nitrogen is included in on-site nitrogen generation.) Dataquest estimates that approximately 55.4 billion cubic feet (Bcf) of nitrogen were supplied to the U.S. semiconductor industry in 1986, up 6.7 percent over the 1985 consumption figure of 51.9 Bcf. Figure 2 presents the volume percentage and corresponding sales associated with each type of delivery mode for the 1986 nitrogen market. Between 1985 and 1986, there was no measurable change in the percentage of volume distribution of nitrogen among the three delivery modes.

Figure 2

1986 U.S. Nitrogen Market
(Billion Cubic Feet, Millions of Dollars)



Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
December 1987

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Company Market Share

Table 3 ranks the leading bulk gas suppliers by 1985 and 1986 sales in the United States. Air Products had a substantial share of the bulk gas market, with sales of $77.4 million in 1986, or 44.5 percent of the $173.8 million market. Air Products' two nitrogen pipeline networks (in the Silicon Valley and Chandler, Arizona) accounted for approximately $21.9 million of that $77.4 million, or 28.3 percent of Air Products' bulk gas revenue from the U.S. semiconductor industry. The pipeline networks, evaluated on their own, correspond to 15.3 percent of 1986 nitrogen revenue and 12.6 percent of the total U.S. bulk gas revenue. It is clear that these two pipeline networks represent a strategic segment within Air Products' semiconductor bulk gas business.

Table 3

U.S. Bulk Gas Market—1985 and 1986 Company Rankings
(Millions of Dollars, Percent Market Share)

	1985		1986	
Company	Sales	Share	Sales	Share
Air Products	$ 71.6	44.7%	$ 77.4	44.5%
Linde/UCC	42.4	26.5	46.1	26.5
Liquid Air	21.0	13.1	23.1	13.3
Airco	20.3	12.7	21.8	12.5
Others	5.0	3.1	5.5	3.2
Total	$160.4	100.0%	$173.8	100.0%

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
December 1987

The Linde division of Union Carbide ranked a strong second in the 1986 bulk gas market, with sales of $46.1 million, or 26.5 percent share. The Linde high-purity nitrogen pipeline system in the International Business Park in San Jose, California, still represents a very small portion of the overall nitrogen delivered by pipeline; however, volume usage along this pipeline is increasing. Liquid Air and Airco were closely ranked, with 13.3 percent and 12.5 percent of the 1986 bulk gas market, respectively.

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Market Overview

In 1986, the U.S. specialty gas market was $41.7 million, up 6.4 percent over the 1985 market of $39.2 million. Silicon-precursor gases (silane, dichlorosilane, trichlorosilane, and silicon tetrachloride) continue to represent the largest revenue category within the specialty gas market, followed by the etchant gas category, which includes carbon tetrafluoride, a variety of halocarbon gases, as well as others. Table 4 presents the 1985 and 1986 U.S. specialty gas markets by gas category. In Table 4, atmospheric/purge cylinder gases and other gases have been combined into a single category.

Table 4

U.S. 1985 and 1986 Specialty Gas Market (Millions of Dollars)

	1985		1986	
Gas Category	Sales	Percent	Sales	Percent
Silicon Precursors	$13.3	33.9%	$14.0	33.6%
Etchants	10.7	27.3	11.5	27.6
Atmospheric/Other*	6.2	15.8	7.0	16.8
Reactants	5.5	14.0	5.7	13.7
Dopants	3.5	8.9	3.5	8.4
Total	$39.2	100.0%	$41.7	100.0%

*Atmospheric/Other contains both the atmospheric/purge cylinder gases and the "other gases" categories.

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
December 1987

Silicon-Precursor Gases

Dataquest has chosen to examine the market for individual gases within the silicon-precursor gas segment. The silicon-precursor gases are used in epitaxial and chemical vapor deposition processes to deposit layers of silicon or silicon compounds (i.e., silicon dioxide, silicon nitride) onto silicon substrates. In 1986, the silicon-precursor gases represented $14.0 million of the $41.7 million U.S. specialty gas market. Figure 3 presents the silicon-precursor gas segment, by individual gas revenue in the context of the total 1986 specialty gas market. Silane sales in 1986 were

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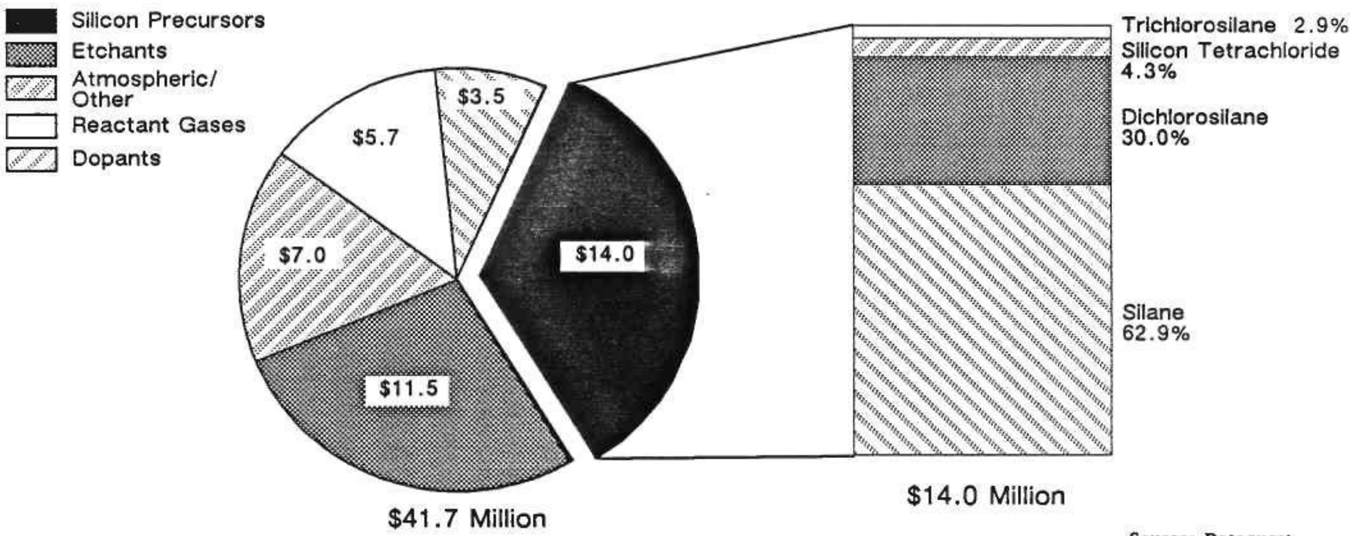
$8.8 million, or 62.9 percent of the silicon-precursor market, while dichlorosilane sales were $4.2 million, or 30.0 percent of the $14.0 million market. These two gases combined represented almost 93.0 percent of the silicon-precursor gas segment and 31.2 percent of the total U.S. specialty gas market in 1986.

Figure 3

1986 U.S. Specialty and Silicon-Precursor Gas Markets
(Millions of Dollars)



Source: Dataquest
December 1987

Company Market Share

Table 5 presents Dataquest's market share estimates for the major suppliers of specialty gases to the U.S. semiconductor industry in 1985 and 1986. Airco was the market leader in 1986 with $11.0 million in sales, or 26.4 percent of the $41.7 million market. Airco and Air Products experienced a slight increase in market share in 1986 over 1985, while Union Carbide's market position remained essentially constant. The three top players in the specialty gas market are also major bulk gas suppliers to the semiconductor industry, and Dataquest believes that the infrastructure and service support networks of those companies were significant factors in gaining or maintaining specialty gas market share in 1986, a recession year in the industry. Both Matheson and Scientific Gas Products dropped a small amount in market share in 1986.

The Alphagaz specialty gas division of Liquid Air, the third major bulk gas supplier in the United States, was still a small player in the 1986 specialty gas market and is included in the "Others" category. However, Dataquest believes that the company will become a more significant player in the next few years, since Liquid Air is committed to expanding its semiconductor customer and applications bases.

Table 5

U.S. Specialty Gas Market—1985 and 1986 Company Rankings
(Millions of Dollars)

Company	1985 Sales	1985 Share	1986 Sales	1986 Share
Airco	$10.2	26.0%	$11.0	26.4%
Linde/UCC	8.6	21.9	9.1	21.8
Air Products	6.0	15.3	7.5	18.0
Matheson	6.0	15.3	6.1	14.6
Scientific Gas Products	4.7	12.0	4.2	10.1
Others	3.7	9.4	3.8	9.1
Total	$39.2	100.0%	$41.7	100.0%

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
December 1987

TOTAL U.S. SEMICONDUCTOR GAS MARKET

Table 6 presents total bulk and specialty semiconductor gas sales in the United States for 1985 and 1986 and ranks the major suppliers by overall market share. The two major players in this market continued to be Air Products and Union Carbide, which had a combined market share of 65 percent of the 1986 U.S. semiconductor bulk and specialty gas industry.

Table 6

U.S. Semiconductor Gas Market—1985 and 1986 Company Rankings
(Millions of Dollars)

Company	1985 Sales	1985 Share	1986 Sales	1986 Share
Air Products	$ 77.6	38.9%	$ 84.9	39.4%
Linde/UCC	51.0	25.6	55.2	25.6
Airco	30.5	15.3	32.8	15.2
Liquid Air	21.0	10.5	23.1	10.7
Matheson	6.0	3.0	6.1	2.8
Scientific Gas Products	4.7	2.4	4.2	2.0
Others	8.7	4.4	9.3	4.3
Total	$199.6	100.0%	$215.5	100.0%

Note: Numbers may not add to totals shown due to rounding.

Source: Dataquest
December 1987

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SEMICONDUCTOR GAS FORECAST

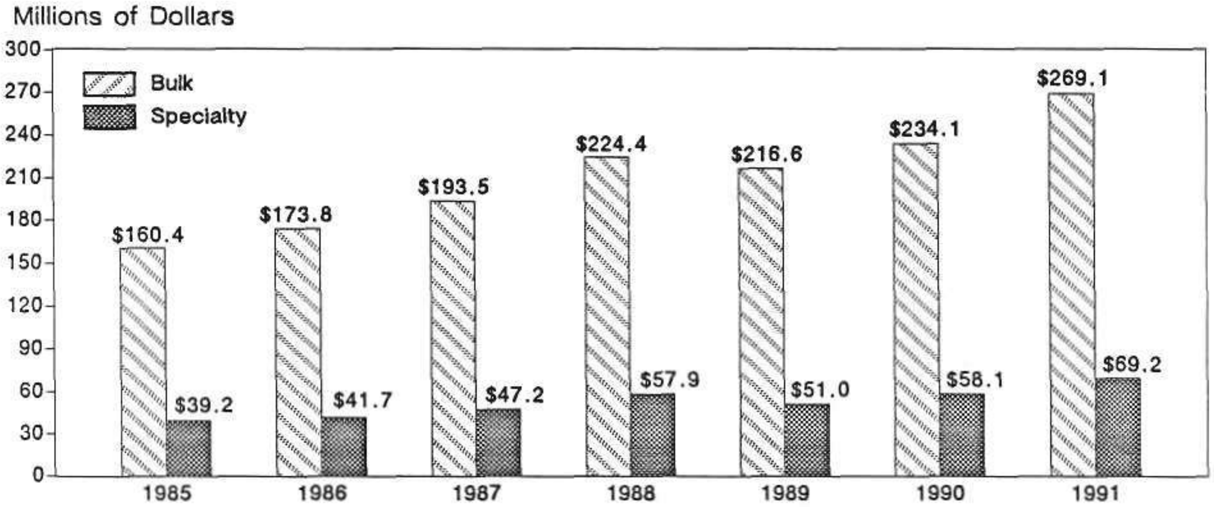
Dataquest's U.S. bulk and specialty gas forecast is based on our silicon forecast, in particular, the forecast of silicon consumption, as measured in wafer starts and the trend in increasing wafer size. For the bulk gas forecast, our forecast includes a factor that depends upon the installed base of equipment, since a large volume of nitrogen is used to maintain the integrity of processing equipment, even in times of low production levels. This means that nitrogen consumption has a stabilizing influence on the bulk gas market during times of industry recession.

It has been assumed that gas pricing remains constant at 1986 levels, and no inflationary factors have been included. This is not an unreasonable assumption, since power costs are not expected to increase substantially over the next few years. In general, while new higher-purity gases will command higher prices, competitive market pressures will keep prices relatively stable at their 1986 values.

Figure 4 presents the U.S. bulk and specialty gas forecast through 1991. Bulk gases are expected to grow at a compound annual growth rate (CAGR) of 9.0 percent between 1985 and 1991, while specialty gases are expected to grow at a CAGR of 9.9 percent. The combined semiconductor bulk and specialty gas market in the United States is projected at $338.3 million in 1991.

Figure 4

U.S. 1985–1991 Semiconductor Gas Markets (Millions of Dollars)



Source: Dataquest
December 1987

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DATAQUEST ANALYSIS

Insight Into Specialty Gases

The specialty gas companies are unique when compared with other electronic materials companies that sell products to the semiconductor industry. What makes this market different is that no one specialty gas company has primary manufacturing capability for all of the specialty gases that it provides to the industry. Thus, a specialty gas company typically must buy some of its products from a competitor.

In contrast to the bulk gas market, where a single gas company supplies a given fab facility, multiple specialty gas vendors per fab are the norm, rather than the exception. Dataquest estimates that, on the average, there are two to three specialty gas companies supplying a given fabrication facility in the United States; however, in some cases, this number can be as high as five or six. Because of this practice of multiple vendors per facility, a semiconductor manufacturer can select and choose between specialty gas companies in order to obtain the lower possible price for a given specialty gas product.

In light of these factors, an important question facing specialty gas suppliers is whether it is a cost-effective practice and makes good market sense for a company to compete in all specialty gas segments, if that company does not have the cost-competitive advantage of being a primary manufacturer of certain gases. Dataquest believes that Air Products recently went through just such an analysis as part of its decision to discontinue supplying dopant gases to the semiconductor industry in early 1987. This strategic reassessment of market opportunities by a major vendor is worthy of further examination.

Departure from Gaseous Dopant Market

Dataquest believes that several factors that affected Air Products' decision to depart the gaseous dopant market include the following:

- Lack of primary manufacturing capability for gaseous dopants
- Small market size—$3.5 million in the United States in 1986
- Toxic and hazardous nature of dopant gases
- Strong market position in liquid and solid dopants through acquisition of J.C. Schumacher in 1986

The question is: What impact will the decision to discontinue dopants have first on Air Products, and second, on other specialty gas companies within the industry? Dataquest believes that, with this decision, Air Products management has decided that multiple vendors per fab are accepted today, and will continue to be in the future. The company has gambled that vendor base consolidation, where a semiconductor manufacturer will favor a single-supplier relationship, will not occur, at least in this electronic materials segment. The company has, in a sense, decided to play to its strengths rather than finance what was probably a less-than-profitable product segment.

Dataquest believes that this decision probably will not have a negative impact on Air Products' specialty gas sales to the semiconductor industry. The company is very strong in the bulk gas industry, fluorine gas chemistry, and the etchant gas segment. There likely will be some transition period while purchasing agents readjust their procedures to accommodate a specialty gas supplier that will not place a bid on every specialty gas that a customer requires. In the long run, however, we do not believe that this decision will seriously affect Air Products' position within the industry.

Finally, Dataquest believes that a potential impact on other specialty gas suppliers will be a domino effect, in that other players may decide to follow suit and stress their strengths rather than invest in their weaknesses. This will continue to be an interesting area to watch in the specialty gas market in the months to come.

Peggy Marie Wood

American Semiconductor Equipment Technologies

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American Semiconductor Equipment Technologies

American Semiconductor Equipment Technologies
6110 Variel Avenue
Woodland Hills, California 91367
Telephone: (818) 884-5050
(Thousands of Dollars)

Balance Sheet (Fiscal year ending 3/31/86)

Working Capital	$4,375
Long-Term Debt	$2,000
Net Worth	$3,446
Current Liability to Net Worth	183.75%
Current Liability to Inventory	131.89%
Total Liability to Net Worth	241.79%
Fixed Assets to Net Worth	241.79%
Total Employees	150

Operating performance data are not available

Source: Dun & Bradstreet

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American Semiconductor Equipment Technologies

(Material in this section has been compiled from Dun & Bradstreet financials, Dataquest's SEMS data base, and company literature supplied by ASET. For more information on this start-up company, Dataquest clients are invited to use their inquiry privileges.)

THE COMPANY

Background

American Semiconductor Equipment Technologies (ASET) was formed in February 1986 to pursue both ongoing and newly developing markets for lithographic systems. The Company was organized by Greg Reyes and Ralph Miller with funding of $3.9 million from four venture capital firms. ASET's product line includes i-line wafer steppers, g-line wafer steppers, substrate steppers, standalone image repeaters and pattern generators, and combination systems.

Operations and Strategy

ASET Corporation currently serves the semiconductor equipment markets in the image patterning area. The Company also looks to develop business in alternate industries, including laser cards, flat panel displays, and hybrid substrates. ASET maintains research efforts directed toward expanding micro-lithographic technology.

ASET acquired the assets of TRE Corporation's wafer stepper and pattern generation manufacturing unit early in 1986. Dataquest estimates that TRE shipped $18 million in wafer steppers in 1982. Stepper revenue declined to $8 million in 1985 and rose to $10 million by year-end 1986.

Products

ASET's current product line is shown in Table 1.

Table 1

ASET PRODUCT TABLE

Product Family	Product Name	Features	Alignment Accuracy	Wave-length	Field Diameter
Lithography	802 Wafer Stepper		0.2um	432um	29, 14.5nm
Lithography	803 Wafer Stepper		0.2um	436um	20, 29, 14.5nm
Lithography	804 Wafer Stepper		0.2um	365um	13, 23nm
Lithography	900 SLR Wafer Stepper Series	i-line and g-line steppers for silicon and GaAs. Auto wafer-to-reticle alignment, auto wafer and reticle handling, system diagnostics, high-volume 1um production.	0.2um	365um	13, 23nm
Maskmaking Systems	600 Series Pattern Generator/ Image Repeator Systems	Auto air gauge focus camera, extended stage travel, independent reticle edge masking, four-position reticle chamber	.	436um	14.5, 20 29nm

Source: Dataquest
May 1987

Company Management

Greg Reyes is President and CEO of ASET. He has 20 years of experience in the semiconductor industry and held executive management positions at Eaton Corporation, Fairchild Semiconductor, Motorola Semiconductor, and National Semiconductor.

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Ralph Miller is Senior Vice President of Marketing. His background includes 33 years in the semiconductor, semiconductor equipment, and magnetic media industries. His previous positions have included President of National Micronetics Disc Inc., President of the Optimetrix Division of Eaton Corporation, and President of TRE Semiconductor.

Dr. Boris Meshman was employed at ASET's antecedent, TRE Semiconductor, since 1981, and is now Vice President of Engineering at ASET. He is responsible for advanced wafer stepper and laser pattern generator development.

Chris Van Peski, ASET's Vice President of Special Products, was also previously employed at TRE Semiconductor; he had been with TRE since 1967. He has 28 years of experience in electrical engineering and controls, including 18 years in the semiconductor equipment field.

Dr. Harry Stover, Vice President of Technologies and Applications, was previously Vice President of Technology for ASM Lithography. Dr. Stover also worked with Bell Labs and Texas Instruments and held R&D management positions at Hughes Research Labs, Signetics Advanced Technology Center, and TRE Semiconductor.

Rick Walter, Vice President of Operations, came to ASET from the Reichert-McGain Division of Warner-Lambert, where he was Vice President of Operations and General Manager. Mr. Walter has also worked for Bausch-Lomb and served as Vice President of Operations for the Optimetrix Division of Eaton Corporation.

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Anelva Corporation

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Anelva Corporation

Anelva Corporation
8-1 Yotsuya 5-chome, Fuchu-shi, Tokyo
Tel (0423) 64-2111
Telex 2832558 ANELVA 3

California Branch Office
121 East Brokaw Road
San Jose, California 95112
Tel (408)998-7311
Telex 352123

Anelva Corporation is a wholly owned subsidiary of Nippon Electric Corporation; therefore, balance sheet data and income statements are not available.

Anelva Corporation

THE COMPANY

Background

Anelva Corporation is a subsidiary of Nippon Electric Corporation (NEC). Anelva began in 1967 as a joint venture between NEC and Varian Associates. Its name then was NEVA (Nippon Electric Varian). In 1979, Varian relinquished managerial control to NEC; in September 1985, Varian sold its final 18 percent of interest to NEC.

ANELVA is an acronym for what the Company sees as its three main areas of expertise: AN from analysis, EL from electronics, and VA from vacuum.

The Company's first products were analytical instruments newly introduced from Varian and vacuum equipment produced by NEC. Anelva has continued the research and development of vacuum equipment, particularly on thin film deposition for electronic devices and on surface analysis using ultrahigh-vacuum technology.

Anelva believes that its technology is especially viable in the following fields:

- The development and production of LSI and compound semiconductor devices
- Vacuum thin film deposition
- The fields of atomic energy, high-energy physics, and new exotic materials and space science

Presently, Anelva manufactures and markets analytical instruments, vacuum instruments, and thin film products (see Table 1).

Table 1

Anelva Corporation
MAIN PRODUCTS

Category	Product
Analytical Instruments	Mass Spectrometer
	GC/QMS
	Surface Analysis (Auger)
	Auger Spectrometer
Vacuum Instruments	Vacuum Pumps
	Ion Pump
	Combination Pump
	Ti-Sublimation Pump
	Sorption Pump
	Diffusion Pump
	Mechanical Pump
	Film Thickness Monitor
	Vacuum Gauges
	Valves and Fittings
	HV or UHV Evaporation System
	Sputtering System
	Reactive Ion Etching System
	Plasma CVD System
	Molecular Beam Epitaxy System
Thin Film Products	Plastic Metalizing

Source: DATAQUEST
February 1986

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Anelva Corporation

Operations

All of the Company's production facilities are located in Japan. Anelva has its main factory in Fuchu, Japan, and in 1984 it opened its Fuji plant in Yamanashi prefecture.

In 1980, Anelva opened a California branch sales office.

International Operations

For the fiscal year ended in March 1985, the Company's sales outside of Japan accounted for approximately 5 percent of sales (see Table 2).

Table 2

Anelva Corporation
PERCENTAGE OF SALES OUTSIDE OF JAPAN

Year	Percentage
1981*	3.2%
1982*	5.8%
1983*	5.1%
1984*	4.7%
1985*	5.0%

*Fiscal year ends March 31

Source: DATAQUEST February 1986

Marketing

Presently, Anelva does not have a direct sales force in the United States and does not plan to have one before the end of 1986. Preparatory to hiring such a force, the Company wants to develop a total customer support system during 1986. The elements of such a system are: technical training (courses are already being offered at the San Jose, California, office), service, maintenance, and documentation.

Anelva Corporation

Research and Development

In 1975, Anelva discovered that by introducing reactive gas into a sputtering system, it was possible to achieve anisotropic dry etching. Anelva claims that this was one of the discoveries that led to the development of reactive ion etch (RIE). From this discovery, the Company developed the ILD-4000 series of RIE systems.

Anelva is presently devoting resources to the manufacture of molecular beam epitaxy (MBE) for use in the manufacture of GaAs ICs and super-lattice devices.

The Company is also directing research into the development of a third main product line, plasma CVD equipment.

Employees

Anelva has approximately 1,000 employees worldwide: 601 at the Company's main factory in Fuchu, Japan; 376 at the Fuji plant in Japan; 28 at the Osaka branch office in Japan; 8 at the Kyushu sales office in Japan; and 6 at the San Jose, California, office.

PRODUCTS AND SALES

Until 1975, Anelva's products were used primarily in the universities and research and development labs of various enterprises. However, with the growing popularity of thin film deposition, especially in LSI and VLSI, Anelva has been able to develop a series of thin film deposition systems for mass production use: the ILC-1000 series of sputter systems. These systems feature four vacuum chambers and are used for thin film application in 256K devices.

Anelva claims to be one of the world's leading manufacturers of dry etch equipment and of sputtering equipment, both in terms of technical know-how and in terms of sales results. Presently, the only equipment that Anelva markets in the United States is its etching and sputtering equipment. The Company markets three models of etchers and two sputtering systems. Average selling prices (ASPs) of this equipment are shown in Table 3.

Table 3

Anelva Corporation
AVERAGE SELLING PRICE OF EQUIPMENT
SOLD IN THE UNITED STATES
(Thousands of Dollars)

Type	Model	Description	Average Selling Price
Etching System	506	R&D use	$135
Etching System	4003	4" and 5" wafers	$370
Etching System	4013	6" wafers	$600
Sputtering System	1012	4" and 5" wafers	$570
Sputtering System	1013	6" wafers	$640

Source: DATAQUEST
February 1986

Products

Anelva is planning to introduce three MBE systems in the United States in the second half of 1986. They are the following:

- A research and development application model that will have an ASP of approximately $400,000
- A preproduction application model that will have an ASP of approximately $600,000
- A production application model that also will have an ASP of approximately $600,000

In addition, during the second half of 1986, Anelva also plans to introduce in the United States an electron cyclotron resonance (ECR) system. An ECR system employs a remote ECR plasma to generate radicals for low-temperature deposition. This system was developed jointly by the Japanese government and Anelva. The Company estimates that this system will have an ASP of approximately $250,000.

The Company also markets a scanning microprobe Auger spectrometer, the EMAS-II, with the capability of a scanning electron microscope. It is used for contamination analysis on metal and semiconductor surfaces and in-depth profiling of surface layers or multilayer film boundaries.

Anelva Corporation

Outside of the semiconductor area, Anelva also makes the quadrupole mass spectrometer (QMS), which is used for residual gas analysis in an ultrahigh vacuum. The QMS can be used in combination with a gas chromatograph (GC) as a GC/QMS, a trace gas analyzer with a capability of detecting 10 parts per billion.

Sales

Anelva's sales for the fiscal year ended in March 1985 were $140 million (see Table 4). The Company claims that for the three years ending in March 1985, its sales of vacuum equipment grew at the rate of 40 percent. More than 60 percent of Anelva's product sales are for sputtering and etching systems (see Table 5). Approximately 80 percent of the Company's sales are to the semiconductor industry and electronic device industries; about 20 percent of sales are outside the semiconductor industry.

Table 4

Anelva Corporation
SALES HISTORY
(Millions of Dollars)

Year	Sales
1980*	$ 48
1981*	$ 57
1982*	$ 66
1983*	$ 90
1984*	$120
1985*	$140

*Fiscal year ends March 31

Source: DATAQUEST
February 1986

Sales to Anelva's parent company, NEC, make up only 25 percent of its total sales. No other company accounts for more than 10 percent of Anelva's sales (see Table 6). Anelva's sales into the United States were approximately $5.75 million for the fiscal year ended in March 1985. Of this $5.75 million, approximately $1.15 million was for sputtering equipment and approximately $4.6 million was for etching systems.

Table 5

Anelva Corporation
PRODUCT SALES AS A PERCENT OF TOTAL SALES

Product	Total Sales (%)
Sputtering Equipment	38%
Etching Systems	28
Plasma CVD	4
Evaporation Systems	3
Molecular Beam Epitaxy	3
Other Systems	
(Surface and Gas Analysis Systems)	3
Component	21
Total	100%

Table 6

Anelva Corporation
SALES TO MAJOR CUSTOMERS

Customer	Total Sales (%)
NEC	25%
Matsushita	7
Fujitsu	3
Sharp	3
Hitachi	2
Sony	2
Other Japanese Companies	53
United States	4
Rest of World	1
Total	100%

Source: Anelva Corporation

Applied Materials

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Applied Materials

Applied Materials, Inc.
3050 Bowers Avenue
Santa Clara, California 95054
Telephone: (408) 727-5555
(Thousands of Dollars Except Per Share Data)

Balance Sheet (October 28)

	1982	1983	1984	1985	1986
Current Assets	$56,995	$ 93,516	$107,298	$107,482	$104,166
Current Liabilities	$39,381	$ 34,812	$ 41,684	$ 37,582	$ 32,384
Current Ratio	1.45	2.69	2.57	2.86	3.22
Working Capital	$17,614	$ 58,704	$ 65,614	$ 69,900	$ 71,782
Long-Term Debt	$16,226	$ 16,250	$ 18,573	$ 16,880	$ 19,615
Debt/Equity	47%	26%	25%	20%	21%
Shareholders' Equity	$34,656	$ 61,553	$ 74,299	$ 86,426	$ 92,758
After-Tax Return on Average Equity	(28.54%)	6.35%	19.88%	11.54%	1.39%
Capital Expenditures	$ 5,249	$ 7,825	$ 14,567	$ 12,930	$ 11,541

Operating Performance (Fiscal Year Ending October 28)

	1982	1983	1984	1985	1986
Revenue	$90,830	$105,527	$168,400	$174,595	$149,261
Gross Margin	27%	39%	49%	46%	40%
Cost of Revenue	$66,697	$ 64,128	$ 85,207	$ 94,210	$ 88,902
RD&E Expense	$14,689	$ 16,436	$ 31,219	$ 31,519	$ 24,621
RD&E/Revenue	16%	16%	19%	18%	16%
GA&S Expense	$19,599	$ 18,373	$ 27,736	$ 15,927	$ 13,514
G&A/Revenue	22%	17%	16%	9%	9%
Other Expenses (Income)	$ 3,663	$ 1,537	($ 320)	$ 120	$ 1,786
Pretax Income	($13,818)	$ 5,053	$ 24,558	$ 15,983	$ 2,141
Pretax Margin	(15.21%)	4.79%	14.58%	9.15%	1.43%
Effective Tax Rate	33.15%	39.58%	45.01%	42.00%	41.99%
Net Income	($ 9,237)	$ 3,053	$ 13,504	$ 9,270	$ 1,242
Average Shares Outstanding (Thousands)*	9,944	12,328	13,076	13,160	13,322
Per Share Earnings	($ 0.93)	$ 0.25	$ 1.03	$ 0.70	$ 0.09
Total Employees	1,038	1,130	1,474	1,359	1,415

*Restated 1982 through 1986 to reflect a two-for-one stock split effective April 25, 1986

Source: Applied Materials, Inc.
Annual Reports and
Forms 10-K
Dataquest
May 1987

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Applied Materials

(Material in this section has been excerpted from the Applied Materials, Inc., Annual Report for the fiscal year ended October 1986 and from Company press releases and product information. For more detailed information and opinions about Applied Materials, Dataquest clients are invited to use their inquiry privileges.)

THE COMPANY

Background

Applied Materials, Inc., is the largest independent company in the world whose sole business is to supply wafer fabrication equipment and related products and services to the semiconductor industry. When the Company was founded in 1967, its first products were chemical vapor deposition (CVD) systems. Dry plasma etch systems were introduced in 1981, and high-current ion implantation systems were added in 1985. Company revenue has increased at a compound annual growth rate (CAGR) of 10.4 percent from $90.8 million in 1982 to $149.3 million in 1986.

Operations

Applied Materials focuses on leading-edge semiconductor process technology and historically has worked to develop processes and production equipment to meet advanced processing requirements. It is the leading supplier worldwide of both epitaxial processing systems and plasma etch systems. The Company has shown a record of stable financial management, leveraging a capital infusion of slightly more than $20 million from General Electric Venture Capital Corporation in 1982 to launch itself from the number one position in the etch market into new product areas.

Strategy and International Competitiveness

Applied Materials' product strategy is focused on development of new products and technologies in order to ride the product life cycle for as long as possible, and to concentrate on advanced device niches in order to minimize price competition and market downturns.

The Company maintains a strong worldwide presence. It has production and development facilities in the United States, Japan, and the United Kingdom. Applied Materials Japan, Inc., a wholly owned subsidiary, was formed as a joint venture with several Japanese electronics executives in 1979 to provide the Company with access to the rapidly growing Japanese semiconductor manufacturing equipment market. This was the first company not wholly Japanese owned that received funding from the Japan Development Bank.

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Applied Materials Japan has also allowed the Company to build a strong marketing presence in the rapidly growing Far East markets. It has restarted production of some early-generation CVD products targeted for the semiconductor industry in China.

Research and Development

Applied Materials conducts a global research and development (R&D) effort. It maintains product development organizations in the United States and in the United Kingdom. It also has process support and demonstration laboratories in the United States, Japan, and the United Kingdom. In 1984, the Company built the Japan Technology Center outside of Narita. This 57,000-square-foot facility includes a research and development laboratory, a Class 10 clean room, and a customer service and training facility.

Research, development, and engineering (RD&E) investment in 1986 was 16.5 percent of sales. The Company has invested an average of 17.0 percent of its annual revenue in RD&E for the past five years. RD&E activities are directed primarily toward the development of new wafer processing systems and new process applications for existing CVD, epitaxial processing, dry processing, and ion implant products. Applied has developed more than 100 processes for use on its installed base of more than 500 plasma etch systems worldwide. The Company also has an ongoing program for development of new applications for epitaxial layers, with a current focus on CMOS.

EXECUTIVE MANAGEMENT

Applied Materials' executive management is as follows:

- James C. Morgan--President and CEO--Previous experience includes senior partner with WestVen Management, corporate staff at Textron in two high-technology divisions, officer and 1983-84 president of SEMI--B.S.M.E. and M.B.A., Cornell University, Ithaca, New York (Mr. Morgan has been with the Company since 1976.)

- James W. Bagley--Senior Vice President, Operations--Previous experience includes 15 years with Texas Instruments, during which he became assistant vice president and manager of Automation Systems Division--B.S.E.E. and M.S.E.E., Mississippi State Univ. (Mr. Bagley has been with the Company since 1981.)

- Robert F. Graham--Senior Vice President--Vice president and founder of Intel; management positions at Fairchild Camera and Instrument and at ITT--B.S.E.E., Univ. of California, Los Angeles (Mr. Graham has been with the Company since 1974.)

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Applied Materials

- Gerald F. Taylor--Senior Vice President and CFO--International and domestic controllerships at Schlumberger, Fairchild Camera and Instrument, and Honeywell; controller of Schlumberger Well Services--B.S., Univ. of Nebraska; M.B.A., Univ. of So. California (Mr. Taylor has been with the Company since 1974.)

- Walter C. Benzing--Technical Advisor to the President--Previous experience includes director of technology for Union Carbide Electronics; Coinventor of first radiantly heated, multiwafer epitaxial reactor--B.S. and M.S. in Chemical Engineering from MIT; Ph.D., Princeton Univ. (Dr. Benzing has been with the Company since 1968.)

- Dana C. Ditmore--Vice President, Corporate Quality and Services, Customer Services Div.--Engineering and management posts at General Electric's Nuclear Energy Division--B.S. and M.S. in Mechanical Engineering, Univ. of California, Berkeley (Mr. Ditmore has been with the Company since 1980.)

- Peter R. Hanley--Vice President, Etch Products Div.--President of Tegal Corporation and vice president of technology for the semiconductor equipment group at Varian Associates--B.S.M.E., Northeastern Univ.; Ph.D. in Engineering Physics from Cornell Univ. (Dr. Hanley has been with the Company since 1985.)

- Tetsuo Iwasaki--Vice President, Applied Materials Japan--Sales and management positions with Kanematsu Gosho, a Japanese trading company specializing in marketing semiconductor production equipment for U.S. companies (Mr. Iwasaki has been with the Company since 1979.)

- Dan Maydan--Vice President and President, Applied Deposition Technology--Previous experience includes 13 years at Bell Laboratories--B.S.E.E. and M.S.E.E., Israel Institute of Technology; Ph.D. in Physics, Edinburgh Univ. (Dr. Maydan has been with the Company since 1980.)

- Howard L. Neff--Vice President, Epitaxial Products Div.--Previous experience includes 12 years with Johnson and Johnson in manufacturing and management positions--B.A. in Economics, Dartmouth College, Hannover, New Hampshire (Mr. Neff has been with the Company since 1980.)

- Glen O. Toney--Vice President, Human Resources--Previous experience includes 11 years in human relations, as assistant to superintendent of a unified school district and as personnel counselor for Lucky Stores, Inc--B.A. and M.A. in Curriculum Development; Ph.D. in Education (Dr. Toney has been with the Company since 1979.)

Applied Materials

PRODUCTS

Applied Materials is a leading U.S. developer and producer of chemical vapor deposition systems, including epitaxial CVD systems. The Company also develops and manufactures dry plasma etching equipment and ion implantation systems.

In the course of the past two years, in spite of the general industry downturn, the Company has introduced three new-generation products. In 1985, it introduced the Precision Etch 8300, a new-generation reactive ion etch system. Its Precision Epi 7010, one of the industry's first fully automated epi reactors, came out in early 1986.

The third major new product resulting from ongoing efforts to developing products based on leading-edge semiconductor processing technology is the Precision Implant 9000. In 1979, Applied Materials reached an agreement to purchase the ion implantation business of Lintott Engineering Ltd., a British company. The acquisition was completed in 1980, and this business became the subsidiary Applied Implant Technology, which conducts R&D efforts in implant technology in Horsham, England. As of April 1987, the Company has shipped two systems, one to Siemens and one to a Japanese customer.

Applied Materials has followed a plan of continuing to supply customers with new products and process support. It is now pursuing contractual agreements with key customers that specify long-range cooperation on process and hardware development. This policy has proved to be successful; 45 percent of the Company's 1986 sales came from new-generation products.

Products of Applied Materials are listed in Table 1. Table 2 shows the Company's sales history by product, and Table 3 shows its sales history by region.

Table 1

Applied Materials, Inc.
PRODUCTS

Product Family	Product Name	Date of Introduction	Average Selling Price	Features	Maximum Wafer Size	Throughput Wafers/Hour
Deposition	AMC 7810/20	1978 (series 7800)	N/A	Barrel chamber; silicon epi films	8-inch	36/4-inch
	Precision EPI 7010	1986	$1.2 million to $1.5 million	Silicon epi films; single-chamber, dual susceptor design; full automation; closed-loop computer control	8-inch	27/6-inch
	AMV-1284	N/A	N/A	Silicon epi; dual-chamber, vertical track	4-inch	15/4-inch
	AMS-2100	1978 (2000 series) 1986 (fully automated version)	$420,000 for fully automated	Silicon dioxide; track; automated cassette-to-cassette wafer handling	6-inch	50/6-inch
	AMP 3300	1978	N/A	Pancake chamber; plasma nitride and oxide films	8-inch	25/4-inch
Etch and Clean	AME 8100 Series	1981	$400,000	Batch processing RIE; end-point detection; auto cassette-to-cassette wafer handling; hexode chamber	6-inch	40-80/5-inch
	PE 8300	1985	$675,000	Batch processing; low-pressure RIE; end-point detection; auto cassette-to-cassette wafer handling; vacuum-controlled load lock	6-inch	40-100/5-inch
Ion Implant	PI 9000	1985	N/A	Batch processing; high current; fully automated; acceleration energy range 10-180 KeV	8-inch	N/A

N/A = Not Available

Source: Dataquest
May 1987

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Applied Materials

Table 2

Applied Materials, Inc.
SALES HISTORY BY PRODUCT
(Millions of Dollars)

Product Family	1982	1983	1984	1985	1986	CAGR
Ion Implant	0	0	0	0	4.4	N/A
Dry Etch	31.7	46.8	69.0	69.6	73.4	23.4%
Epitaxy	26.0	41.1	70.0	44.0	34.3	7.2%
PECVD	5.5	6.3	8.0	6.3	5.2	(1.4%)
APCVD	4.8	8.0	9.8	9.5	6.3	7.0%
Total	68.0	102.2	156.8	129.4	123.6	16.1%

(Percentage of Total)

Product Family	1982	1983	1984	1985	1986
Ion Implant	0	0	0	0	3.6%
Dry Etch	46.6%	45.8%	44.0%	53.8%	59.4
Epitaxy	38.2	40.2	44.6	34.0	27.8
PECVD	8.1	6.2	5.1	4.9	4.2
APCVD	7.1	7.8	6.3	7.3	5.1
Total	100.0%	100.0%	100.0%	100.0%	100.0%

N/A = Not Available
Note: Columns may not add to totals shown due to rounding.

Source: Dataquest
May 1987

Table 3

Applied Materials, Inc.
SALES HISTORY BY REGION
(Thousands of Dollars)

Net Sales by Region*	1984	1985	1986
United States	$111,762	$118,395	$102,627
Europe	4,179	3,707	4,549
Japan	52,459	52,493	42,085
Total	$168,400	$174,595	$149,261

(Percentage of Total)

Net Sales by Region*	1984	1985	1986
United States	66.4%	67.8%	68.8%
Europe	2.5	2.1	3.0
Japan	31.2	30.1	28.2
Total	100.0%	100.0%	100.0%

*Does not include transfers between regions
Note: Columns may not add to totals shown due to rounding.

Source: Applied Materials
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ASM International N.V.

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ASM International N.V.

ASM International N.V.
Jan Steenlaan 9
3723 BS Bilthoven
The Netherlands
Telephone: (030) 781836
(Thousands of Guilders, except Per Share Data)

Balance Sheet for Year Ending December 31

	1983	1984	1985	1986
Total Assets	F 266.40	F 380.10	F 374.80	F 369.20
Accounts Receivable	F 64.60	F 91.40	F 67.50	F 84.30
Inventory	F 70.70	F 148.30	F 145.00	F 127.10
Other Current Assets	F 80.10	F 58.30	F 48.80	F 44.10
Total Current Assets	F 215.40	F 298.00	F 261.30	F 255.50
Property, Plant & Equip., Net Depr.	F 48.90	F 80.80	F 108.10	F 110.60
Other Assets	F 2.10	F 1.30	F 5.40	F 3.10
Total Liability	F 104.30	F 177.00	F 217.80	F 288.20
Accounts Payable	F 56.50	F 109.50	F 115.00	F 146.20
Other Current Liability	F 37.6	F 56.3	F 56.1	F 50.3
Total Current Liability	F 94.10	F 165.80	F 171.10	F 196.50
Long Term Debt	F 7.00	F 7.10	F 44.30	F 59.00
Other Long Term Liability	F 3.20	F 4.10	F 2.40	F 32.70
Total Long Term Liability	F 10.20	F 11.20	F 46.70	F 91.70
Shareholder Equity	F 162.10	F 203.10	F 157.00	F 81.00

Income Statement for Year Ending December 31

	1983	1984	1985	1986
Net Sales	F 217.00	F 352.90	F 350.80	F 328.40
Cost of Goods Sold	F 126.20	F 202.50	F 220.60	F 227.20
Selling & General	F 52.70	F 80.50	F 104.00	F 102.10
R&D	F 17.40	F 37.00	F 39.90	F 50.10
Special Expenses	(F 1.40)	F 1.20	F 1.00	(F 0.10)
Income from Operations				
Interest Expenses	F 2.20	F 0.40	F 6.70	F 11.60
EBT	F 19.90	F 31.40	(F 21.30)	(F 62.60)
Income Taxes	F 4.10	F 11.40	(F 1.20)	(F 0.90)
Net Income	F 18.30	F 23.30	(F 19.20)	(F 61.70)
EPS	F 3.00	F 3.35	(F 2.77)	(F 8.87)
Shares Outstanding (in Millions)	F 6.11	F 6.95	F 6.96	F 6.96

Operating Ratios				
Profit Margin	8%	(7%)	(5%)	(19%)
Return on Equity	11%	(12%)	(12%)	(77%)
Return on Assets	7%	(6%)	(5%)	(17%)
Gross Margin	42%	43%	37%	31%
Asset Turnover	0.81	0.93	0.94	0.89
Working Capital Turnover	1.79	2.67	3.89	5.57
Inventory to Working Capital	0.58	1.12	1.61	2.15
Current Ratio	2.29	1.80	1.53	1.30
Quick Ratio	1.44	0.81	0.51	0.50
Inventory Turnover	3.07	2.38	2.42	2.58
Fixed Assets to Tangible Net Worth	0.30	0.40	0.69	1.38
Current Liability to Tangible Net Worth	0.58	0.82	1.10	2.44
Total Liability to Tangible Net Worth	0.65	0.88	1.39	3.58
Exchange Rate	2.85	3.21	3.32	2.45

Source: ASM International N.V.
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ASM International N.V.

ASM International N.V.
Jan Steenlaan 9
3723 BS Bilthoven
The Netherlands
Telephone: (030) 781836
(Thousands of Dollars, except Per Share Data)

Balance Sheet for Year Ending December 31

	1983	1984	1985	1986
Total Assets	$759	$1,220	$1,244	$905
Accounts Receivable	$184	$ 293	$ 224	$207
Inventory	$201	$ 476	$ 481	$311
Other Current Assets	$228	$ 187	$ 162	$108
Total Current Assets	$614	$ 957	$ 868	$626
Property, Plant & Equip., Net Depr.	$139	$ 259	$ 359	$271
Other Assets	$ 6	$ 4	$ 18	$ 8
Total Liability	$297	$ 568	$ 723	$706
Accounts Payable	$161	$ 351	$ 382	$358
Other Current Liability	$107	$ 181	$ 186	$123
Total Current Liability	$268	$ 532	$ 568	$481
Long-Term Debt	$ 20	$ 23	$ 147	$145
Other Long-Term Liability	$ 9	$ 13	$ 8	$ 80
Total Long-Term Liability	$ 29	$ 36	$ 155	$225
Shareholder Equity	$462	$ 652	$ 521	$198

Income Statement for Year Ending December 31

	1983	1984	1985	1986
Net Sales	$618	$1,133	$1,165	$805
Cost of Goods Sold	$360	$ 650	$ 732	$557
Selling & General	$150	$ 258	$ 345	$250
R&D	$ 50	$ 119	$ 132	$123
Special Expenses	($ 4)	$ 4	$ 3	0
Income from Operations	0	0	0	0
Interest Expenses	$ 6	$ 1	$ 22	$ 28
EBT	$ 57	$ 101	($ 71)	($153)
Income Taxes	$ 12	$ 37	($ 4)	($ 2)
Net Income	$ 52	$ 75	($ 64)	($151)
EPS	$ 9	$ 11	($ 9)	($ 22)
Shares Outstanding (in Millions)	$ 6	$ 7	$ 7	$ 7

Operating Ratios	1983	1984	1985	1986
Profit Margin	8%	7%	(5%)	(19%)
Return on Equity	11%	12%	(12%)	(77%)
Return on Assets	7%	6%	(5%)	(17%)
Gross Margin	42%	43%	37%	31%
Asset Turnover	0.81	0.93	0.94	0.89
Working Capital Turnover	1.79	2.67	3.89	5.57
Inventory to Working Capital	0.58	1.12	1.61	2.15
Current Ratio	2.29	1.80	1.53	1.30
Quick Ratio	1.44	0.81	0.51	0.50
Inventory Turnover	3.07	2.38	2.42	2.58
Fixed Assets to Tangible Net Worth	0.30	0.40	0.69	1.38
Current Liability to Tangible Net Worth	0.58	0.82	1.10	2.44
Total Liability to Tangible Net Worth	0.65	0.88	1.39	3.58

Source: ASM International N.V.
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ASM International N.V.

THE COMPANY

Background

Advanced Semiconductor Material International N.V. was established in 1968 and is headquartered in the Netherlands. ASM International N.V. and its subsidiaries (collectively referred to as ASMI) design, manufacture, and market semiconductor production equipment and materials. The scope of this equipment includes wafer processing, assembly, and encapsulation. ASM is the world leader in plasma-enhanced chemical vapor deposition, or CVD. The Company also produces assembly and encapsulation products.

Operations

The semiconductor equipment business has been poor during the last two years, and 1986 was exceptionally so for ASM International. Losses from U.S. and Japanese operations accompanied large outlays in research. Strategically, however, R&D investments are necessary for market positioning in the future, and the Company's research work is expected to pay off in the near future. Efficiency cuts were also made at all levels of the organization. As a result, business has been streamlined going into 1987.

ASM International has dedicated manufacturing and marketing facilities in the regions of Europe, Hong Kong, Japan, and the United States. In Hong Kong, Japan, and the United States, manufacturing operations are run through the Company's wholly owned subsidiaries. In Hong Kong, this is ASM Asia Ltd.; in Japan, ASM Japan K.K.; and in the United States, ASM America, Inc. See Table 1 for the Company's major facilities and their activities.

ASM International calls upon its world research network and has formed technology-driven joint ventures and partnerships in its aim to advance state-of-the-art manufacturing equipment. A discussion of some of these joint ventures and partnerships follows.

ASM Lithography, Inc., is a joint venture between ASM International and N.V. Philips of the Netherlands. Founded in 1984, it has facilities in Tempe, Arizona, and Veldhoven, the Netherlands. Both centers have complete process and analytical equipment, as well as a staff of process engineers. The Company was founded to develop and market advanced lithography equipment.

ASM Ion Implant is a division of ASM International N.V. This division is headquartered in Beverly, Massachusetts, and was formed in early 1986 to develop and market a new generation of advanced ion implantation equipment.

Epsilon Technology was formed through a limited R&D partnership by ASM America in 1982 in order to develop and manufacture an advanced silicon epitaxial reactor.

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Table 1

ASM International N.V.
MAJOR FACILITIES

Location	Primary Uses
Bilthoven, the Netherlands	Wafer processing manufacturing, research, and executive offices
Brunssum, the Netherlands	Encapsulation manufacturing and offices
Eindhoven, the Netherlands	Lithography equipment manufacturing, research, and offices
Herwen, the Netherlands	Encapsulation manufacturing, research, and offices
Zevenaar, the Netherlands	Lead-frame stamping and offices
Montpellier, France	Gas component manufacturing and offices
Hung Hom, Hong Kong	Lead-frame stamping
Kwai Chung, N.T., Hong Kong	Assembly automation encapsulation and plating manufacturing, research, and offices
Kwun Tong, Kowloon, Hong Kong	Plating manufacturing
Tokyo, Japan	Wafer processing equipment, assembly, research, and offices
Phoeniz, Arizona United States	Assembly and wafer processing manufacturing, research, and offices
Tempe, Arizona United States	Research and offices

Source: ASM International N.V.
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Strategy and International Competitiveness

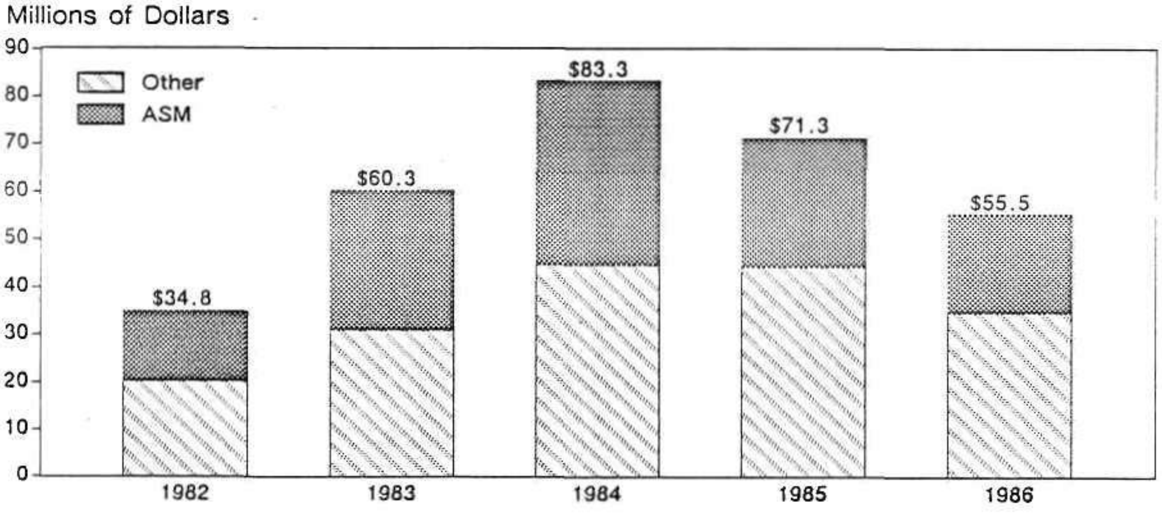
The Company perceives that the principal factors affecting its competitive position include product diversification, quality and performance, reliability, service and support, delivery, and price. With respect to these factors, the Company believes that it is competitive. Its products are generally on the high side of the price range, but they are cost-effective over the product's life cycle.

Competition from one or more companies is present in each segment of ASM International's markets. No one company is considered dominant in the industry, however, and the Company's diversified product line is considered to be an advantage over its competitors. The Company can also manufacture, market, and service its products on a worldwide basis from each of its principal facilities in Europe, Hong Kong, Japan, and the United States.

The Company is the world's leader in the manufacture of plasma-enhanced CVD (see Figure 1). This area is increasingly important to the manufacture of VLSI devices, since it operates in lower pressure and temperature environments. ASMI introduced its first CVD reactor in 1979 for deposition of nitride thin-film layers. The Company is continually expanding the applications of its CVD equipment into other areas, including deposition of other thin films such as oxide, polysilicon, and silicides.

Figure 1

WORLDWIDE MARKET SHARE OF PECVD
ASM versus Total Market



Source: Dataquest
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ASMI's diffusion system allows close control of wafer fabrication parameters and resultant close-tolerance production. The Company also manufactures epitaxial reactors that are used to form low- and high-resistivity epitaxial silicon used for bipolar technology. ASMI manufactures the critical components that go into its CVD reactors, which allows quality control. It makes high-integrity valves, electronic gas flow meters, and flow controllers used in gas control systems.

The Company's international sales are shown in Table 2.

Table 2

ASM International N.V.
WORLDWIDE SALES BY MAJOR GEOGRAPHIC REGION
(Thousands of Dollars)

	1982	1983	1984	1985	1986
Europe	$18,649	$20,632	$ 21,189	$ 29,234	$ 62,716
Far East/Japan	17,055	33,138	51,075	44,645	50,243
United States	16,979	22,389	37,680	31,799	21,067
Total	$52,683	$76,159	$109,944	$105,678	$134,026
Exchange Rate (Guilders per Dollar)	2.67	2.85	3.21	3.32	2.45

Source: ASM International N.V.
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ASM's dedicated manufacturing and marketing facilities in Europe, Hong Kong, Japan, and the United States permit the Company to tailor its products to regional equipment markets, and to assure timely delivery and quality.

Research and Development

ASMI participates in research and development in a number of areas to remain competitive in its diverse markets. Recent research activity has focused on chemical vapor deposition, lithography, epitaxy, and ion implant, which are the Company's highest growth markets. Research activity involves physics, electrical engineering, process technology, precision mechanical engineering, and software.

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ASM International N.V.

The Company has separate R&D centers in each of its manufacturing locations. These centers participate in both separate and shared research activities aimed at customer-oriented marketing. The Company also enjoys a unique relationship with Philips; its numerous joint ventures and research sharing with Philips are beneficial to its leading edge.

<u>**Company Management**</u>

ASMI's top management personnel are listed below:

- Arthur del Prado--Founder of the Company; managing director, president, and CEO since Company's formation in 1968

- Richard H.J. Fierkens--Vice president of European Tooling Operations and managing director of ASM FICO Tooling B.V. and ASM FICO Tooling (Limburg) B.V. since 1981; has served in various positions within Tooling Operations (Mr. Fierkens has been with the Company since 1972.)

- John E. Krickl--President of ASM America, Inc., and Epsilon Technology, Inc., an R&D subsidiary; previously served as vice president of VTR Division of Silicon Valley Group, Inc., and president of Thermco Products (Mr. Krickl has been with the Company since December 1986.)

- Patrick Lam See-Pong--Vice president of the Company's Asian Operations and managing director of ASM Assembly Automation Limited, ASM Asia Limited, and ASM Assembly Materials Limited; formerly held various positions within the Company (Mr. See-Pong has been with the Company since 1975.)

- Willem H. de Leeuw--Director of Technology of ASM International; previously with Fokker Aircraft Company in various capacities, including director of Space Division and manager of Aircraft Engineering (Mr. de Leeuw has been with the Company since March 1983.)

- Joop Wallenburg--General manager of ASM Europe B.V.

- Yo Miyazaki--Vice president of Japanese Operations and managing director of ASM Japan; previously was general manager of the semiconductor manufacturing equipment business of a Marubeni Corporation subsidiary (Mr. Miyazaki has been with the Company since August 1982.)

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ASM International N.V.

PRODUCTS

ASMI manufactures products in the three major categories of semiconductor production: wafer processing, assembly, and encapsulation. ASMI has various subsidiary and venture organizations focusing on specific market segments. A discussion of the activities of some of these segments follows.

The first product of ASM Lithography, the PAS-2000 wafer stepper, was developed by a team of scientists from Philips. The third generation of this product, the PAS-2500, was introduced in 1985. This product is the first fully automatic wafer stepper capable of submicron working resolution with an overlay accuracy of 0.15 microns and throughput of over 55 six-inch wafers per hour. The company continues to add Philips' products to its lines. A fourth-generation EBPG-4 Beamwriter vectorscan electron-beam pattern generator is being marketed by ASM Lithography.

ASM Ion Implanter's first product, the ASM-220 Medium-Current Serial Process Ion Implanter, was recently released. This product is fully automated for wafer sizes up to 8 inches and for the small geometries encountered in VLSI environments.

Epsilon Technology will introduce a CMOS epitaxial single-wafer reactor in the second half of 1987. This product will be compatible with wafer sizes up through 8 inches and will provide high uniformity and low-particulate contamination. Full production is expected in 1988.

Table 3 is a list of ASM International's products.

Table 3

ASM International N.V.
PRODUCTS

Category	Product Class	Description
Processing	Plasma-enhanced micro-pressure CVD systems	Deposits silicon nitride, silicon dioxide, and other films at low temperature
	Micropressure CVD systems	Deposits silicon dioxide, silicon nitride, and polycrystalline silicon films at low temperature and low pressure

(Continued)

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Table 3 (Continued)

ASM International N.V.
PRODUCTS

Category	Product Class	Description
Processing (Continued)	Integrated computer-controlled diffusion systems	Fully computerized large-scale systems for diffusion of electrically active impurities
	Lithographic equipment	Advanced wafer stepper
Assembly	Automatic die saws	High-speed diamond saws that automatically separate die in a wafer
	Automatic die inspection	High-speed computerized visual inspection of finished die
	Automatic die bonding equipment	High-speed selection and bonding of die chips to various carriers
	Loading stations	Convert existing manual inspection and bonding operations to semiautomatic operation
	Automated wire bonders and bonder automation conversion kits	Precise welding and positioning of wire between the die and pins on the metal lead frame
	Inspection stations	Facilitate rapid visual microscope inspection of lead frames with die attached and wire bond
Encapsulation	High-precision transfer molds	Encapsulation of devices in plastic of epoxy materials
	High-speed automated trim-and-form tooling	Separation of individual devices from lead frames

(Continued)

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Table 3 (Continued)

ASM International N.V.
PRODUCTS

Category	Product Class	Description
Encapsulation (Continued)	Stamping die and tooling	Fabrication of precision lead frames
	Automatic molding systems	In-line molding systems to automate the sealing of the semiconductor device and lead frame in plastic

Source: ASM International N.V.
Dataquest
August 1987

ASMI's product revenue is shown in Table 4.

Table 4

ASM International N.V.
WORLDWIDE SALES BY PRODUCT
(Millions of Dollars)

Product	1982	1983	1984	1985	1986
Wafer Processing Equipment	$29.8	$51.3	$ 60.4	$ 47.0	$ 44.7
Plasma-Enhanced CVD (PECVD)	14.6	29.4	38.7	27.1	20.8
Low-Pressure CVD (LPCVD)	7.1	5.6	8.3	7.6	5.3
Diffusion Systems	6.9	15.0	10.6	9.5	8.8
Wafer Steppers	1.2	1.3	2.8	2.8	9.8
Other Products	$22.9	$24.9	$ 49.5	$ 58.7	$ 89.3
Total Sales	$52.7	$76.2	$109.9	$105.7	$134.0
Exchange Rate (Guilders per Dollar)	2.67	2.85	3.21	3.32	2.45

Source: Dataquest
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Eaton Corporation

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Eaton Corporation

Eaton Corporation
Eaton Center
Cleveland, Ohio 44114
Telephone: (216) 523-5000
(Millions of Dollars, Except Per Share Data)

Balance Sheet (Calendar Year Ending December 31)

	1982	1983	1984	1985	1986
Total Assets	$2,030	$2,279	$2,612	$2,814	$3,025
Total Current Assets	$ 970	$1,339	$1,685	$1,843	$1,677
Total Liabilities	$1,228	$1,292	$1,410	$1,419	$1,770
Total Current Liabilities	$ 575	$ 596	$ 630	$ 572	$ 646
Shareholders Equity	$ 803	$ 987	$1,202	$1,395	$1,256

Income Statement

	1982	1983	1984	1985	1986
Net Sales	$2,453	$2.674	$3,510	$3,675	$3,812
COGS	$1,870	$1,986	$2,517	$2,703	$2,871
Selling and Administrative	$ 408	$ 420	$ 475	$ 482	$ 498
R&D	$ 100	$ 94	$ 113	$ 124	$ 134
Special Expenses	0	0	0	0	$ 75
Income from Operations	$ 74	$ 174	$ 406	$ 366	$ 235
Other Income Expenses	($ 213)	($ 85)	$ 11	$ 42	($ 29)
EBIT	($ 213)	$ 116	$ 411	$ 387	$ 220
Income Taxes	($ 52)	$ 23	$ 157	$ 156	$ 83
Net Income	($ 190)	$ 93	$ 254	$ 231	$ 138
EPS	($ 6.74)	$ 2.95	$ 7.50	$ 6.72	$ 4.17
DPS	$ 1.72	$ 0.80	$ 1.10	$ 1.35	$ 1.60
Shares Outstanding (Thousands)	28,263	31,723	34,371	34,869	33,797
Ratios					
Profit Margin (%)	(0.08)	0.03	0.07	0.06	0.04
Return on Equity (%)	(0.25)	0.10	0.22	0.17	0.11
Return on Assets (%)	(0.09)	0.04	0.10	0.08	0.05
Gross Margin (%)	0.24	0.26	0.28	0.26	0.25

Source: Eaton Corporation
Annual Reports
Dataquest
July 1987

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Eaton Corporation

THE COMPANY

Background

Eaton Corporation, which was incorporated in 1916, manufactures more than 5,000 products and employs more than 43,000 people worldwide. Its products serve the following markets:

- Truck powertrain components
- Automotive components
- Controls and electrical equipment
- Defense systems
- Semiconductor capital equipment

The Company divides its business into two segments:

- Electronic and electrical
- Vehicle components

In 1986, Eaton decided to concentrate its resources on its core businesses and to exit those businesses that have been unprofitable or have lacked strategic links to its core businesses. The Company has identified its control operations as the foundation on which it wishes to build. In addition to the controls business, Eaton believes that its automotive and truck powertrain businesses will continue to be strong markets.

Eaton's decision to exit unprofitable businesses or strategically marginal businesses caused it to discontinue its stepper operations and test operations in 1986. The Company no longer manufactures or markets the Waferspec product line, although it does maintain support for this product.

The Company continues, however, to reaffirm its commitment to the ion implant, automatic photoresist, rapid optical annealer, and thin-film products. Semiconductor equipment is manufactured and marketed by the Semiconductor Equipment Division (SED).

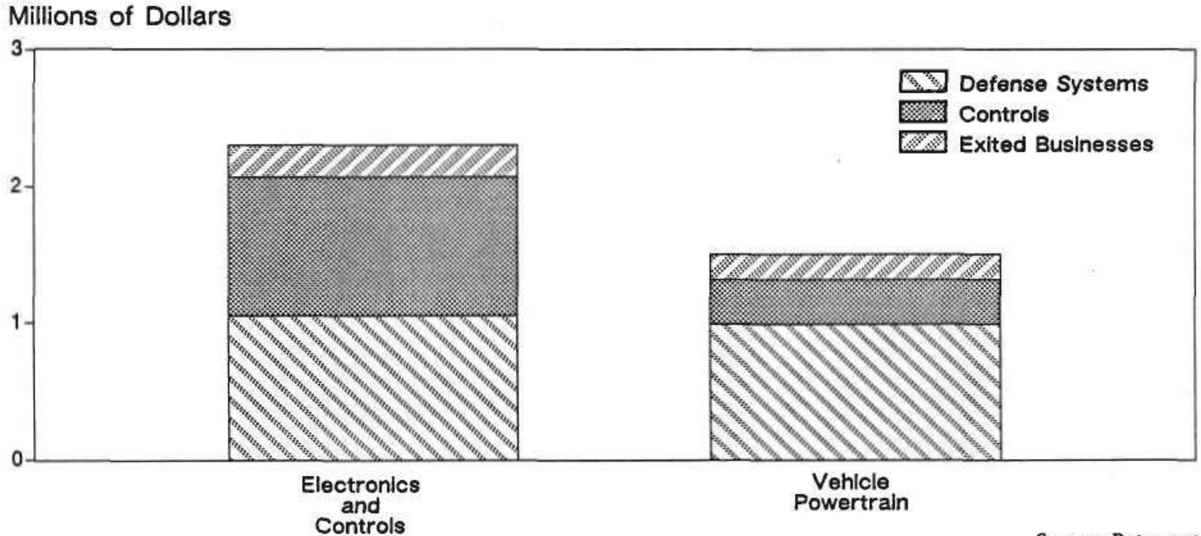
Operations

Total sales for Eaton Corporation were $3,812 million in 1986, 4 percent higher than in 1985. Electronics and controls accounted for 60 percent of these sales, or $2,308 million (See Figure 1). Vehicle powertrains, however, accounted for a much larger share of operating profits (See Figure 2).

Eaton Corporation

Figure 1

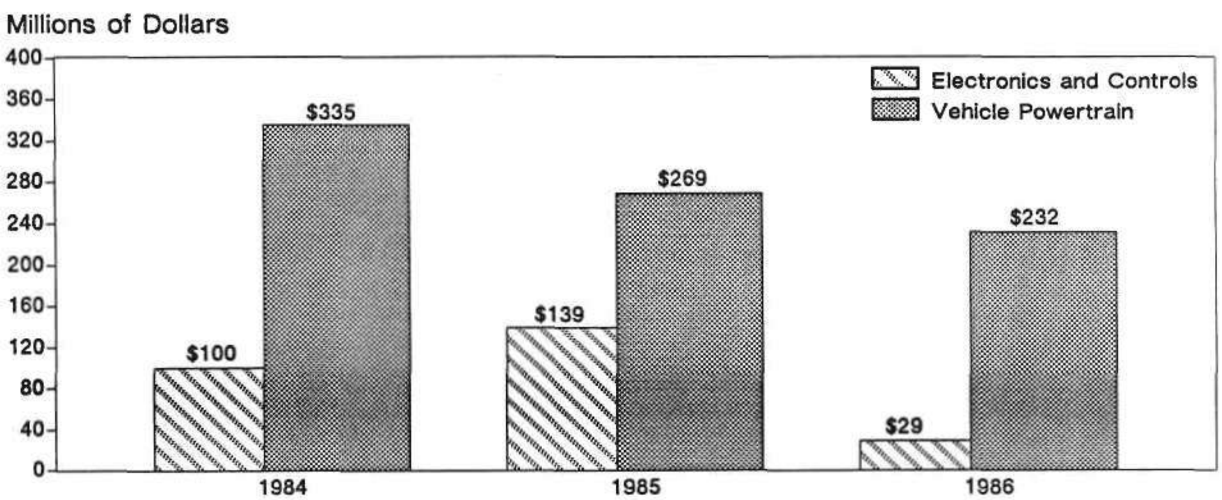
NET SALES BY MAJOR PRODUCT CATEGORY



Source: Dataquest
July 1987

Figure 2

OPERATING PROFIT



Source: Dataquest
July 1987

Gross margin for the Company was 25 percent of sales in 1986, compared with 26 percent in 1985. The Company attributes this decrease to a general change in sales mix between business segments and to operating losses in its semiconductor businesses.

As a result of the Company's decision to discontinue production of wafer steppers, in-process testers, automatic test equipment, and microwave instrumentation, the Company took a write-down of $74.7 million in 1986.

Table 1 lists SED's major manufacturing locations.

Table 1

SED MANUFACTURING LOCATIONS

Location	Products
Beverly, Massachusetts	High-current implanters
	High-voltage implanters
Austin, Texas	Medium-current implanters
Danders, Massachusetts	Thin film
San Jose, California	Track equipment
Japan	High-Current Implanters

Source: Dataquest
July, 1987

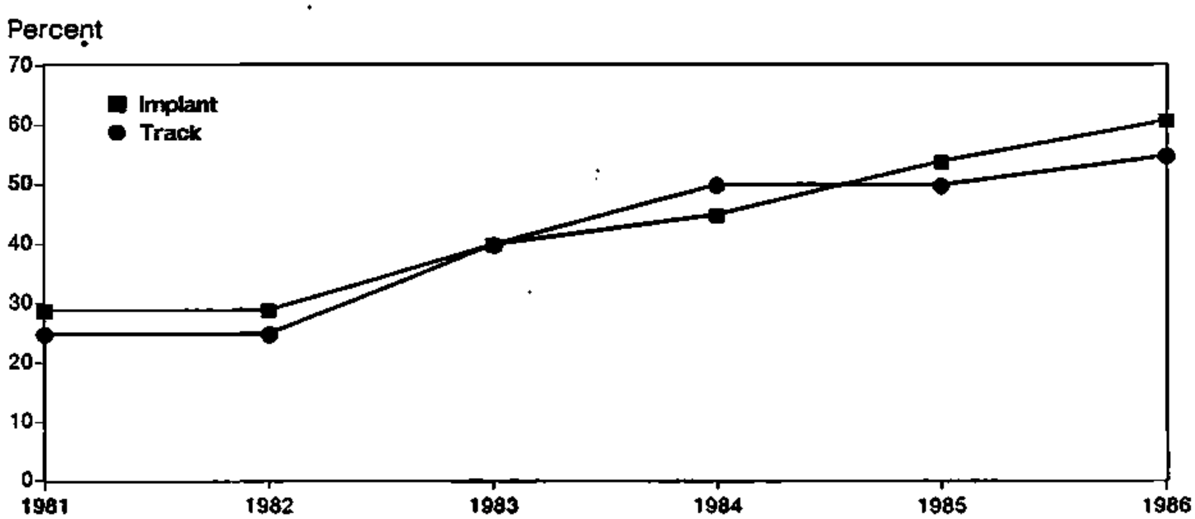
Strategy and International Competitiveness

More than 50 percent of the SED's sales were outside the United States. Figure 3 shows the international sales as a percentage of the total for implant and track equipment, Eaton's two major semiconductor equipment product lines.

Track equipment sales by region are shown in Table 2. Eaton has yet to establish a market in Japan. European sales, on the other hand, were 51 percent of total track sales in 1986.

Figure 3

INTERNATIONAL SALES AS PERCENT OF TOTAL
TRACK AND IMPLANT EQUIPMENT



Source: Dataquest
July 1987

Table 2

REGIONAL SHARE OF EATON'S TRACK EQUIPMENT SALES
(Millions of Dollars)

	1980	1981	1982	1983	1984	1985	1986
United States	$18.0	$13.5	$ 9.0	$ 6.0	$ 7.2	$ 6.0	$ 5.4
Europe	6.0	4.5	3.0	4.0	6.1	5.0	6.1
ROW	0	0	0	0	1.2	1.0	0.5
Total Sales	$24.0	$18.0	$12.0	$10.0	$14.5	$12.0	$12.0
(Percent)							
United States	75%	75%	75%	60%	50%	50%	45%
Europe	25%	25%	25%	40%	42%	42%	51%
ROW	0	0	0	0	8%	8%	4%
International	25%	25%	25%	40%	50%	50%	55%

Source: Dataquest
July 1987

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Eaton Corporation

Implant equipment sales by region are shown in Table 3. European sales of implanters almost equaled sales into the U.S. market in 1986. ROW has become an important market for Eaton's implanters, accounting for 12 percent and 17 percent of total implant sales in 1985 and 1986, respectively. In Japan, Eaton's total implant sales fell rather sharply in 1986, from 23 percent of total sales in 1985 to 12 percent in 1986. This decline is partly due to the severe recession in semiconductor equipment in Japan and partly to an increase of share by Japanese companies in their home market. Nissan, Hitachi, Tel/Varian, and Ulvac have all experienced large gains in market share recently.

Table 3

REGIONAL SHARE OF EATON'S IMPLANT EQUIPMENT SALES
(Millions of Dollars)

	1981	1982	1983	1984	1985	1986
United States	$15.0	$26.0	$38.0	$ 63.0	$ 50.0	$ 17.0
Japan	5.3	7.7	17.6	33.3	24.9	5.4
Europe	1.7	3.3	7.0	14.6	22.1	15.3
ROW	0	0	1.0	3.2	12.9	7.8
Total Sales	$22.0	$37.0	$64.0	$114.0	$110.0	$ 46.0
(Percent)						
United States	68%	70%	60%	55%	45%	38%
Japan	24%	21%	28%	29%	23%	12%
Europe	8%	9%	11%	13%	20%	33%
ROW	0	0	2%	3%	12%	17%
International	32%	30%	41%	45%	55%	62%

Source: Dataquest
July 1987

Eaton has a joint manufacturing and marketing venture in Japan with Sumitomo Heavy Industries for Eaton's high-current implanters.

SED is now building a service support organization in Korea and Taiwan. Worldwide, Eaton employs 150 to 200 people in its service organization.

International sales account for more than 50 percent of Eaton's rapid optical annealing (ROA) sales, as shown in Table 4.

Eaton Corporation

Table 4

RAPID OPTICAL ANNEALING PRODUCT SALES
(Thousands of Dollars)

	1986	1985	1984
North America	$200	$ 700	$ 700
Japan	200	0	0
Europe	300	500	800
ROW	0	200	0
Total	$700	$1,400	$1,500

Source: Dataquest
July 1987

Semiconductor Equipment Division

Eaton's SED executive management team consists of:

- Peter Rose, General Manager, (and one of the founders of Eaton's implanter business), has been with the Company since 1978.
- Geoffry Ryding, Vice President of Marketing (also one of the founders of Eaton's implanter business), has been with the company since 1978.
- Peter Young, Operations Manager, has been with SED since 1982.
- David Schmitz, Controller, has been with SED since 1983.
- Patrick Collins is Human Resources Manager.

Research and Development

Automation, particulate control, and equipment reliability are the main targets of SED's research and development. Dataquest estimates that the SED spent 20 percent ($12 million to $15 million) of its 1986 revenue on research and development.

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Eaton Corporation

Eaton had scheduled introduction of a sputtering system for spring 1986. In March, however, the Company announced that it was postponing its introduction due to weak demand in the sputtering market and due to weak sales in its implanter product line.

Eaton remains committed to the product it is designing for the production of 4Mb devices.

PRODUCTS

Eaton's market share for rapid optical annealers is shown in Table 5.

Table 5

EATON ROA SHARE

	1986	1985	1984
Eaton	$ 700	$ 1,400	$ 1,500
Total ROA Market	$16,000	$14,500	$10,200
Eaton Share	4%	10%	15%

Source: Dataquest
July 1987

Eaton introduced the ROA-500 at Semicon/West in May 1987. The ROA-500 has a footprint that is almost one-half the size of an earlier model, the ROA-400. The price of the ROA-500 is $240,000. First deliveries are expected to begin at the end of 1987.

Eaton's track product offerings are shown in Table 6.

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Table 6

AUTOMATIC PHOTORESIST PRODUCTS

6000XL Series

Model	Type	Features
System 6000XL	Bake	Hot/cool or hot/ hot 3"-6" wafers, cassette-cassette
	Coater	Coat and spray prime 3"-6" wafers, cassette-cassette
	Develop	Negative and positive, 3"-6" wafers, cassette-cassette
	Scrubber	Brush or high-pressure 3"-6" wafers, cassette-cassette
	Spin-on-Glass	Variable temperature, teflon tub bowl, 3"-6" wafers, cassette-cassette

Note: Eaton also makes a 6000 series of track equipment that is quite similar to the XL Series. The major differences are that the XL has optical sensors and has oven exhaust.

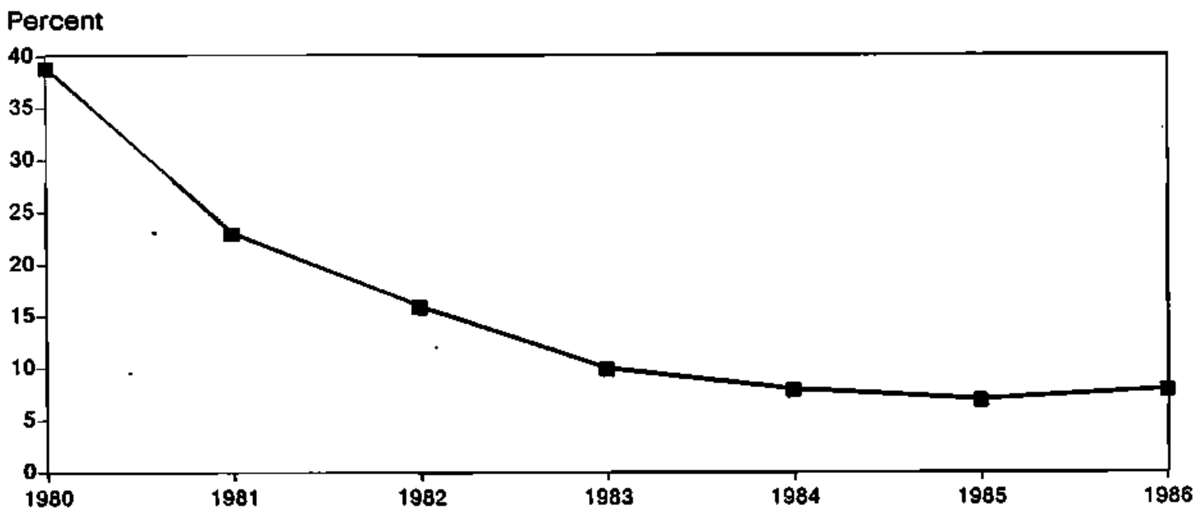
Source: Dataquest
July 1987

Eaton's market share for automatic photoresist processing equipment (track) has declined from 39 percent in 1980 to 7 percent in 1985. However, in 1986, Eaton's share of the track market increased to 8 percent (see Figure 4). The Company was able to increase share by keeping its sales constant while the total track market declined in 1986. The Company's goal is to regain its lead in the track equipment market.

Eaton Corporation

Figure 4

TRACK EQUIPMENT MARKET SHARE



Source: Dataquest
July 1987

Eaton's track product offerings are shown in Table 7.

Table 7

IMPLANTER PRODUCT OFFERINGS

Type	Model	Introductory Date	KeV	(microamps) Beam Current	ASP	Wafer Size
MC	NV-6208	1986	200	3,000	$ 890	4"-8"
MC	NV-6200	1984	200	3,000	$ 685	3"-6"
MC	GA-4204	1985	200	3,000	$ 555	2"-4" GaAs wafers
MC	NV-4206	1985	200	3,000	$ 555	3"-6"
MC	NV-3200	1980	200	3,000	$ 450	2"-4"
HC	NV-10-80	1979	80	12,500	$ 825	3"-6"
HC	NV-10-160	1982	160	10,000	$1,100	3"-6"
HC	NV-20-200	1985	200	20,000	$1,400	4"-8"
OXYGEN	NV-200	1985	200	8,500	$2,400	3"-6"
HV	NV-1000	1986	1,500	1,000	$2,500	4"-8"

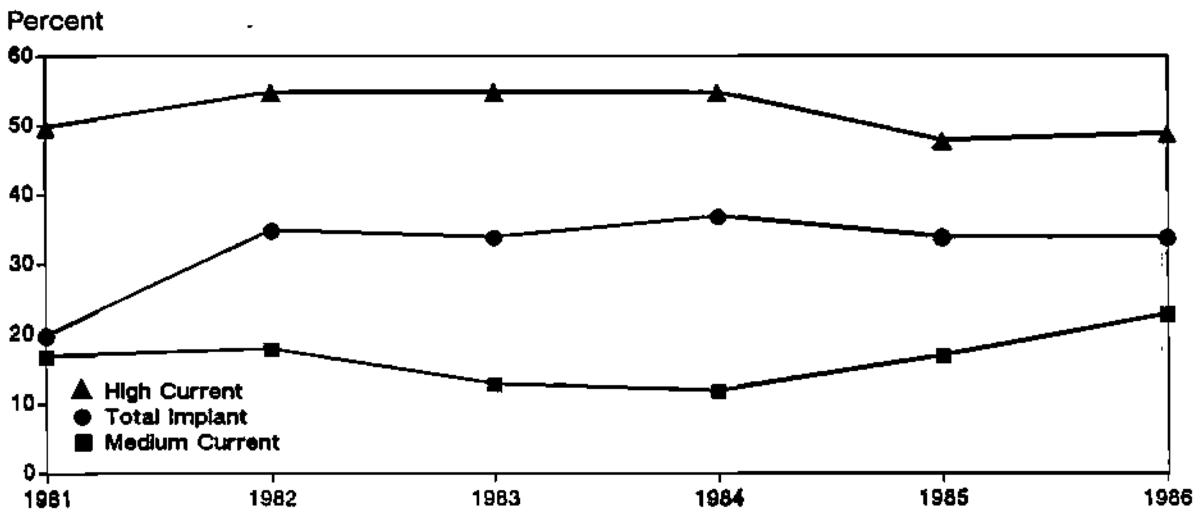
Source: Dataquest
July 1987

Eaton Corporation

Eaton's share of the implanter market is shown in Figure 5. Eaton gained substantial share in 1982. Since then, however, Eaton's share has fluctuated around the 35 percent level. Eaton has had a dominant position in the high-current market with a share of 55 percent until 1985, when its share fell rather sharply to 48 percent. Coincident with this drop in high-current share was a rise in medium-current share from 12 percent to 17 percent in 1985. Eaton's share of the medium-current market rose substantially again in 1986 to 23 percent.

Figure 5

IMPLANTER EQUIPMENT MARKET SHARE



Source: Dataquest
July 1987

Focus Semiconductor Systems

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Focus Semiconductor Systems

Focus Semiconductor Systems
570 Maude Court
Sunnyvale, California 94086
Telephone: (408) 738-0600
(Thousands of Dollars)

Balance Sheet (Fiscal year ending 12/31)

	1984	1985
Working Capital	$1,745	$1,633
Long-Term Debt	$ 23	$ 483
Net Worth	$1,822	$3,438
Current Liability to Net Worth	0	20%
Current Liability to Inventory	N/A	240%
Total Liability to Net Worth	2%	34%
Fixed Assets to Net Worth	3%	57%

Operating Performance (Fiscal year ending 12/31)

Net Profit after Taxes	($ 103)	($3,454)
Total Employees	N/A	34

N/A = Not Available

Source: Dun & Bradstreet

Focus Semiconductor Systems

THE COMPANY

Background

Focus Semiconductor Systems, Inc., founded in 1984, manufactures low-pressure chemical vapor deposition (LPCVD) systems for the semiconductor production equipment industry.

Products and Operations

Focus is targeting high-throughput, multilevel, submicron-geometry LPCVD processing for the new generation of ULSI (ultralarge-scale integrated circuits). Focus' LPCVD system, the F1000, employs a new, single-wafer chamber technology, which combined with patented heating methods, is expected to provide film uniformity of ±2 percent, low defect density, excellent step coverage, and throughput of 70 wafers per hour. It employs a high degree of automation that allows simultaneous deposition in multiple chambers capable of handling wafers up to 8 inches in diameter.

The F1000 is designed with interchangeable, process-specific reactor modules, enabling the system to produce the entire range of CVD films from low temperature oxides to silicon epitaxy. The F1000's selling price is approximately $400,000.

As of April 1987, the Company had shipped beta site units, and it expects to begin volume production later this year. It has added 20,000 square feet of manufacturing capacity that is scheduled to come on-line in 1987, bringing its total capacity to 40,000 square feet.

Strategy and International Competitiveness

The Company is building an international organization and directing efforts toward cooperation with its customers in process development and customization.

It has established a wholly owned subsidiary in Japan, Focus Japan, KKK, that comprises a marketing office, a technology center, and an applications engineering group.

The Company is also launching European operations with the formation of a Netherlands-based subsidiary, to be called Focus Europe B.V. In January 1987, Focus announced that it had received $5 million in funding from MIP Equity Fund, a Dutch venture capital firm. This gave MIP approximately a 13 percent interest in Focus, and will enable Focus to establish its European operations. This recent round of financing brings the Company's total capitalization to $17.2 million since its founding in 1984.

Research and Development

Focus Semiconductor's Sunnyvale, California, facility is equipped with a Class 10 clean room. The Company offers customers deposition and evaluation before system purchase.

Focus Europe will establish a laboratory for development of advanced thin-film deposition methods that are of specific interest to the European market. Focus Japan also offers process development and applications engineering support for Far Eastern customers.

Company Management

Dr. Imad Mahawili is President of Focus. His background includes 15 years of working in chemical reactor technology. His experience in reactor design, transport processes, and fluid dynamics are fundamental to the design of the next generation of CVD products.

Richard Tetschlag is Vice President of Marketing and Sales. He brings to Focus a combination of marketing, quality control, technical, and general management skills and an orientation toward customer service and quality. He has more than 15 years of management experience in related semiconductor markets.

James Hansell is Vice President of Operations. His background includes 20 years of acquiring industry knowledge and operations skills as president of a public company, as well as material management and financial management responsibilities in the semiconductor equipment area.

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GCA Corporation

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GCA Corporation

GCA Corporation
209 Burlington Road
Bedford, Massachusetts 01730
Telephone: (617) 975-0000
(Thousands of Dollars except Per Share Data)

Balance Sheet (December 31)

	1982	1983	1984	1985	1986
Current Assets	$131,614	$153,738	$213,207	$133,530	$ 88,049
Current Liabilities	$ 35,180	$ 49,755	$ 71,804	$202,933	$165,806
Current Ratio (%)	374.1	309.0	296.9	65.8	53.1
Working Capital	$ 96,434	$103,983	$141,403	($ 69,403)	($ 77,757)
Long-Term Debt	$ 62,055	$ 65,104	$ 89,187	$ 7,049	$ 6,920
Debt/Equity (%)	75.3	72.0	69.8	(50.3)	(18.4)
Shareholders' Equity	$ 82,366	$ 90,458	$127,685	($ 14,027)	($ 37,534)
After-Tax Return on Average Equity (%)	(35.9)	1.6	26.2	(256.0)	96.7
Capital Expenditures	$ 15,395	$ 7,339	$ 17,286	$ 38,077	$ 2,137

Operating Performance (Fiscal Year Ending December 31)

	1982	1983	1984	1985	1986
Revenue	$ 69,260	$136,520	$240,097	$156,484	$123,147
Gross Margin (%)	N/A	40.9	50.8	15.4	21.8
Cost of Revenue	N/A	$ 80,685	$118,127	$132,318	$ 96,255
R&D Expense	$ 18,890	$ 21,683	$ 33,633	$ 38,077	$ 18,228
R&D/Revenue (%)	27.3	15.9	14.0	24.3	14.8
SG&A Expense	N/A	$ 22,400	$ 30,712	$ 36,228	$ 27,245
SG&A/Revenue (%)	N/A	16.4	12.8	23.2	22.1
Other Expenses*	$ 6,209	$ 6,808	$ 8,633	$ 58,213	$ 13,115
Pretax Income	($ 41,902)	$ 4,963	$ 48,992	($108,352)	($ 31,696)
Pretax Margin (%)	(60.5)	3.6	20.4	(69.2)	(25.7)
Effective Tax Rate (%)	64.7	72.2	41.7	(34.3)	21.4
Net Income	($ 14,775)	$ 1,378	$ 28,569	($145,472)	($ 24,920)
Average Shares Outstanding (Thousands)	12,521	13,304	13,584	13,899	14,077
Per Share Earnings	($ 1.18)	$ 0.10	$ 2.10	($ 10.47)	($ 1.77)
Total Employees	2,200	2,700	3,300	2,200	1,050

*In 1985, the Company incurred an expense of $46.6 million relating to its realignment of operations.

Source: GCA Corporation Annual Report and 10K
Dataquest
June 1987

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GCA Corporation

THE COMPANY

Background

GCA Corporation was founded in 1958 and incorporated in Delaware in 1960. The Company manufactures wafer steppers, wafertrack systems, photo-repeater systems, pattern generators, autosort systems, waferetch systems, and industrial lenses.

Poor business conditions in the semiconductor equipment market and the Company's weak financial situation made it necessary for it to take some strong measures in 1986. The Company discontinued operations in areas that did not relate directly to its main line of business--semiconductor manufacturing equipment. The discontinued groups included Scientific and Analytical Equipment, Factory Automation, and the GCA Technology Division, which focused on environmental waste. Two new members were brought into senior management in 1986, a new chairman of the board/chief executive officer/president and a new chief financial officer. Three divisional managers were also promoted to corporate executive positions, and the board of directors experienced a total turnover. The new management implemented several strategies intended to reduce costs and restore profits to company operations.

OPERATIONS

In 1986, GCA operated under the threat of bankruptcy. However, GCA has recently been recapitalized under the direction of the Hallwood Group and the Company is no longer in that danger.

GCA believes that its competitive advantages--having the world's largest wafer stepper installed base, technological leadership, quality of products, and extensive service capabilities--will more than offset its recent financial difficulties.

In 1986, sales for continuing operations declined 21 percent, from $156 million to $123 million. The Company's backlog also decreased from $63 million in December 1985 to $18.2 million in December 1986.

PRODUCTS

Table 1 lists the steppers and track systems that GCA manufactures and sells.

GCA Corporation

Table 1

GCA Corporation
PRODUCT LIST

Product	Intro. Date	Linewidth	Price
Wafer Stepper Systems:			
DSW 4800	1978	1.25 micron	N/A
DSW 6300	1983	1.1 micron	N/A
DSW 6700	Late 1986	1.0-1.1 micron	$ 700,000
DSW 8000	Late 1985	0.9 micron	$ 900,000
DSW 8500 I	Nov. 1986	0.7 micron	$1,200,000
Wafertrac System (full system)	N/A	Not Applicable	$ 170,000

N/A = Not Available

Source: GCA 10K
Dataquest
June 1987

GCA's revenue by product is shown in Table 2.

Table 2

GCA Corporation
PRODUCT REVENUE
(Millions of Dollars)

Product	1982	1983	1984	1985	1986
Wafer Steppers	$45.8	$111.3	$201.2	$118.0	$ 71.5
Track Equipment	18.0	18.0	25.5	15.0	12.3
Dry Etchers	0.0	0.0	0.0	1.2	2.8
Other Products	5.5	7.2	13.4	22.3	30.0
Total Equipment	$69.3	$136.5	$240.1	$156.5	$116.6

Source: Dataquest
June 1987

GCA Corporation

STRATEGY AND INTERNATIONAL COMPETITION

In all its product areas, GCA competes with companies that belong to organizations with much larger resources. Several of its competitors also have more diverse businesses, which means that they are less subject to business cyclicity. GCA depends upon its reputation for technical know-how, excellence, and new product enhancements for its sales.

Internationally, GCA's competitors are Nippon Kogaku KK (Nikon) and Canon. These companies are increasing their penetration in the wafer stepper market, mainly in Japan. In the domestic market, GCA is encountering Perkin-Elmer Corporation and General Signal Corporation's Ultratech Stepper.

GCA is focusing on finer resolution of lithography and compatibility with 8-inch lines. The Company has recently sold its advanced DSW 8500 stepper to Rockwell and IBM.

GCA's domestic marketing organization consists of direct sales forces and 175 service representatives stationed throughout the United States. There are 18 additional locations for direct sales and customer support.

Internationally, GCA has a series of marketing arrangements. Direct sales forces have established a presence in the Pacific Rim outside Japan, and GCA has signed a contract with the PRC Ministry of Electronics to open a sales and service center in Beijing.

The Japanese market is served through a 50/50 joint venture arrangement with Sumitomo Corporation of Japan. The venture employs about 45 service engineers who are trained in the United States by GCA. This arrangement has evolved to include final assembly operations, quality assurance, installation, warranty service, and demonstration and technical applications support. Development and engineering responsibility also aids GCA in its global product development strategy.

In the European market, GCA had a joint venture with Matra SA of France. While the venture has not been profitable financially, it is perceived as a major inroad to market share penetration in Europe. Under the company restructuring, this joint venture became a wholly owned subsidiary of GCA.

Table 3 gives GCA's sales by region.

GCA Corporation

Table 3

GCA Corporation
WORLDWIDE SALES BY MAJOR GEOGRAPHICAL REGION
(Millions of Dollars)

	1982*	1983	1984	1985	1986
Foreign Sales					
Far East**	$11,082	$ 33,225	$ 70,742	$ 45,615	$ 10,234
West. Europe	6,233	8,635	21,183	17,710	24,636
Rest of World	4,848	112	1,620	2,913	1,172
Subtotal	$22,163	$ 41,972	$ 93,545	$ 66,238	$ 36,042
U.S./Canada	$47,097	$ 94,548	$146,552	$ 90,246	$ 87,105
Total Sales	$69,260	$136,520	$240,097	$156,484	$123,147

*Dataquest estimates
**Far East includes Japan, PRC, Korea, Taiwan, Hong Kong, Singapore, Thailand, and Maylasia.

Source: GCA Corporation Annual Report and 10K
Dataquest
June 1987

RESEARCH AND DEVELOPMENT

In 1986, GCA spent $18.2 million on R&D, with a research staff of about 180; 125 of which were engineers. GCA concentrates its research activity in the areas of optics, high-resolution wide field imagery, and advanced alignment systems. The Company continually focuses on productivity increases to the DSW Wafer Stepper, Wafertrac, Waferetch, optical maskmaking, and other systems.

During 1986, several product enhancements were made. These included new "I" line lenses capable of 0.7-micron lithography; a new "G" line lens called the 2035, which will retrofit DSW systems in the field to 1.0-micron capabilities; a new Maximus 2000 light source, which provides a 3x increase in exposure energy on the DSW; improvements in the alignment system; and a new backside contact wafer handler, which reduces contamination.

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GCA Corporation

GCA's strategy is to reach better than 0.5-micron lithography capability. The Company has recently introduced an excimer laser stepper, which was developed under a VHSIC contract. With the use of excimer laser sources, resolutions of 0.5 microns or better can be obtained.

Other areas of research focus include increased automation in the front end of the manufacturing process, prevention of microcontamination, and environmental control.

COMPANY MANAGEMENT

A new chairman and CEO has just been appointed to the company. A veteran of the industry, the new CEO joins the Company in July 1987, with the termination of the restructuring.

Peter Simone, GCA's president and director, has held various operating and management positions in the Company. He recently served as senior vice president of the Commercial and Product Operations and has also served as a director of Sumitomo GCA Corporation since 1983 and of Matra GCA SA since May 1986. Mr. Simone joined the Company in 1975.

In April 1986, Philip Ablove was named senior vice president and chief financial officer of the Company. He has been a director of the Company since March 1986. Previously, he served as president and CEO of Distributed Control Systems, Inc., a designer and manufacturer of microprocessor-based building automation and lighting control systems.

GCA's senior vice president is Dr. John Bruning, who also holds the positions of chief technical officer and president of GCA/Tropel Division. His previous experience includes working with GCA and AT&T Bell Laboratories, where he worked for 15 years, as the Manager of New Lithographic Systems. Dr. Bruning joined the Company in 1984.

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General Signal Corporation

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General Signal

Semiconductor Equipment Group

CIRCUIT/MASK DESIGN

Xynetics Products
2962 Stender Way
Santa Clara, California 95054
408/988-4549
Xynetics motor systems, flatbed plotting systems, wire harnessing systems, CAD/CAM peripherals

WAFER PREPARATION

Kayex Corporation
1000 Millstead Way
Rochester, New York 14624
716/235-2524

KAYEX-CAPCO
Annular Saws

KAYEX-HAMCO
Crystal-growing systems, automatic growth-control systems, diagnostic control systems

KAYEX-SPITFIRE
4020 North Tripp Avenue
Chicago, Illinois 60641
312/286-1610
Single and double-sided lapping and polishing systems, accessories and supplies, automated cassette-to-cassette backgrinding and backlapping systems

MASK PREPARATION

Ultraglas
2266 Trade Zone Boulevard
San Jose, California 95131
408/946-6353
Photo blanks for optical and electron beam photomask production

PATTERN AND MASK GENERATION

Ultratech Photomask
2970 Coronado Drive
Santa Clara, California 95054
408/727-0451
Photomasks, reticles, electron beam products and direct-write services

WAFER IMAGING

Ultratech Stepper
3230 Scott Boulevard
Santa Clara, California 95054
408/727-4930
Cost-effective wafer steppers for VLSI production

WAFER PROCESSING

Blue M Electric
138th and Chatham Streets
Blue Island, Illinois 60406
312/385-9000
Environmental test chambers, burn-in ovens, clean room ovens, baths, furnaces

Circuits Processing Apparatus
47003 Mission Falls Court
Fremont, California 94539
415/490-8741
In-line planar magnetron sputtering systems for thin film deposition

Drytek
16 Jonspin Road
Wilmington, Massachusetts 01887
617/657-3933
Complete range of automatic planar etching equipment

Kinney Vacuum
495 Turnpike Street
Canton, Massachusetts 02021
617/828-9500
Vacuum pumps, vacuum systems

Semiconductor Systems
2206 Trade Zone Boulevard
San Jose, California 95131
408/942-8600
Resist processing equipment, spin/bake systems

Tempress
3111 Coronado Drive
Santa Clara, California 95054
408/970-0980
Diffusion systems, LPCVD products, digital process and temperature controllers, chemical deposition reactor

Ultratech Equipment
2972 Stender Way
Santa Clara, California 95054
408/727-3600
Mask and wafer cleaners/scrubbers, positive resist developers, emulsion processors, rigid disk and hybrid substrate cleaners and systems, photoresist spinners, double-sided plate cleaners.

TEST AND MEASUREMENT

Electroglas
2901 Coronado Drive
Santa Clara, California 95054
408/727-6500
Fully and semi-automatic wafer probing systems, X-Y positioning systems

Ionscan
48625 Warm Springs Boulevard
Fremont, California 94539
415/659-8330
Ion implantation and thin film process monitoring equipment

Optoscan
1250 Charleston Road
Mountain View, California 94043
415/961-9451
Fully and semi-automatic submicron wafer metrology systems

Rucker & Kolls
3151 Coronado Drive
Santa Clara, California 95054
408/986-8120
Automatic, semi-automatic and manual wafer probers and systems, wafer inspection systems, fixed-point probe cards and equipment, test head hardware

ASSEMBLY

Advanced Mechanization
795 Horsham Road
Horsham, Pennsylvania 19044
215/672-9000
Automatic die-attach systems, automatic die sort systems, second optical wafer inspection equipment, and wafer management systems

Lindberg
2450 West Hubbard Street
Chicago, Illinois 60612
312/942-2500
Heat-processing systems and induction heating equipment

Micro Automation
48603 Warm Springs Boulevard
Fremont, California 94539
415/656-8400
Automatic dicing saws, Microwash™ cleaning stations, automatic die-separation systems, dicing wheels

FINAL TEST

Blue M Electric
(See "WAFER PROCESSING")

General Signal Corporation

General Signal Corporation
High Ridge Park
P.O. Box 10010
Stamford, Connecticut 06904
Telephone: (203) 357-8800
(Millions of Dollars except Per Share Data)

Balance Sheet (December 31)

	1986	1985	1984	1983	1982
Total Assets	$ 1,458	$ 1,483	$ 1,438	$ 1,314	$ 1,222
Accounts Receivable	$ 296	$ 324	$ 313	$ 310	$ 263
Total Current Assets	$ 887	$ 927	$ 958	$ 869	$ 827
Property, Plant & Equipment, Net	$ 346	$ 361	$ 345	$ 314	$ 281
Total Liabilities	$ 531	$ 579	$ 537	$ 468	$ 418
Accounts Payable	$ 95	$ 111	$ 120	$ 113	$ 96
Total Current Liabilities	$ 351	$ 406	$ 387	$ 347	$ 304
Long-Term Debt	$ 124	$ 124	$ 97	$ 75	$ 76
Shareholders' Equity	$ 927	$ 904	$ 902	$ 846	$ 804

Operating Performance (Fiscal Year Ending December 31)

	1986	1985	1984	1983	1982
Net Sales	$ 1,583	$ 1,801	$ 1,787	$ 1,575	$ 1,622
Cost of Goods Sold	$ 1,115	$ 1,279	$ 1,240	$ 1,097	$ 1,110
Selling & Administrative Expense	$ 349	$ 372	$ 362	$ 326	$ 322
R&D Expense	$ 98	$ 101	$ 92	$ 79	$ 71
Provision for Restructuring	0	$ 72	$ 0	0	0
Income from Operations	$ 120	$ 78	$ 186	$ 151	$ 189
Interest Expense	$ 12	$ 9	$ 7	$ 8	$ 11
Interest Income	$ 9	$ 12	$ 12	$ 12	$ 14
EBT	$ 118	$ 80	$ 188	$ 155	$ 193
Income Taxes	$ 43	$ 31	$ 80	$ 65	$ 85
Net Income	$ 75	$ 49	$ 109	$ 90	$ 108
EPS	$ 2.60	$ 1.72	$ 3.80	$ 3.06	$ 3.85
DPS	$ 1.80	$ 1.80	$ 1.71	$ 1.68	$ 1.60
Shares Outstanding (Thousands)	27,930	28,706	28,568	28,414	28,013

Ratios

	1986	1985	1984	1983	1982
Profit Margin	7%	6%	6%	3%	5%
Return on Equity	15%	12%	13%	7%	10%
Return on Assets	9%	7%	8%	3%	5%
Gross Margin	32%	30%	31%	29%	30%
Current Ratio	2.72	2.50	2.48	2.28	2.53
Quick Ratio	1.37	1.24	1.19	0.99	1.20

Source: General Signal Corporation
Annual Reports
Dataquest
December 1987

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General Signal Corporation

THE COMPANY

Background

General Signal Corporation, incorporated in New York in 1904, produces instrumentation and control technology for semiconductor production, telecommunications, industrial automation, energy management, and rail transportation.

Prior to the third quarter of 1987, General Signal reported its activities through these three product sectors:

- Electronic Controls and Systems
- Electrical Controls and Equipment
- Fluid Controls and Equipment

Annual report data listed in this profile are based on the above three product sectors.

Beginning in the third quarter of 1987 (ending September 30), however, General Signal's operations are reported through four product groups, or sectors. These four sectors portray operations consistent with the Company's product marketing and reflect General Signal's ongoing strategic restructuring.

These four new business sectors are as follows:

- Process Controls (41 percent of the Company's 1987 estimated sales)
- Technology Industries, which includes semiconductor equipment (20 percent)
- Electrical Controls (21 percent)
- Transportation Controls (18 percent)

The Process Controls sector serves the process industries by supplying valves, pumps, control systems, mixers and aerators, corrosion-control materials, heat-treating equipment, electronic feeders and scales, and instrumentation.

The Technology Industries sector is an equipment supplier for semiconductor manufacturing and telecommunications, as well as for defense electronics.

Electrical Controls serves the nonresidential and residential construction, electric utilities, computer and other sensitive electronic equipment, and petroleum and petrochemical markets with fire protection and building signaling systems, power distribution equipment, switch gear, electric motors, conduit fittings, and power conditioning equipment.

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General Signal Corporation

The Transportation Controls sector produces control systems and braking and other equipment for the mainline railroad and rail and bus mass transit industries. It also supplies cold-forged components to the truck, auto, and bicycle markets, as well as fluid power systems for construction equipment and military vehicles.

The names and locations of General Signal's operating units are provided in Table 1.

Table 1

General Signal Corporation
Operating Units

Company	Location
Advanced Mechanization, Inc.	Horsham, Pennsylvania
Aurora Pump	North Aurora, Illinois
Axel Electronics	Jamaica, New York
BIF	West Warwick, Rhode Island
Blue M Electric	Blue Island, Illinois
Cellcote	Beaea, Ohio
Dezurik	Sartell, Minnesota
Dielectric Communications	Raymond, Maine
Dowzer Electric	Mt. Vernon, Illinois
Drytek	Wilmington, Massachusetts
Dynapower/Stratopower	Watertown, New York
Edwards	Farmington, Connecticut
GS Electric	Carlisle, Pennsylvania
General Railway Signal	Rochester, New York
Henschel	Newburyport, Massachusetts
Hevi-Duty Electric	Goldsbora, North Carolina
Karkar Electronics	San Francisco, California
Kinney Vacuum	Canton, Massachusetts
Leeds & Northrup Instruments	North Wales, Pennsylvania
Leeds & Northrup International	North Wales, Pennsylvania
Leeds & Northrup Systems	North Wales, Pennsylvania
Lindberg	Chicago, Illinois
Marsh Instrument	Skokie, Illinois
Metal Forge	Columbus, Ohio
Metallurgical Products	Warrendale, Pennsylvania
Mixing Equipment Company	Rochester, New York
Nelson Electric	Tulsa, Oklahoma
New York Air Brake	Watertown, New York
O-Z/Gedney	Terryville, Connecticut
Semiconductor Systems, Inc.	San Jose, California
Sola Electric	Elk Grove Village, Illinois
Stock Equipment Company	Chagrin Falls, Ohio
Tau-Tron	Westford, Massachusetts
Telecommunications Technology, Inc.	Milpitas, California
Telenex	Mt. Laurel, New Jersey
General Signal Thinfilm	Fremont, California
Ultratech Stepper	Santa Clara, California
Xynetics, Inc.	Santa Clara, California

Source: General Signal Corporation
Dataquest
December 1987

General Signal Corporation

Restructuring

During the fourth quarter of 1985, the Company initiated a restructuring plan that includes divesting certain nonstrategic business units and product lines, consolidating selected production facilities, and disposing of, or revaluing, certain assets. The Company believes that these actions will allow it to focus its efforts and resources on business lines generating the greatest returns for the long term and to continue its strategic emphasis on higher technology growth businesses. As a result of this plan, the Company took a pretax charge against 1985 earnings of $72 million.

Operations

Operating performance, stated in terms of the Company's former sector format, was down in 1986 compared to 1985. General Signal's sales for 1986 totaled $1.58 billion, down $220 million from 1985. The Company attributes all but $60 million of this sales decline to the restructuring. Net earnings rose 51.5 percent to $74.6 million, compared to restructured earnings of $49.3 million in 1985. Earnings per share of $2.60 gained 51.2 percent on the same basis.

Before restructuring, however, the Company's net earnings and earnings per share in 1985 were $93.3 million and $3.25, respectively, higher than 1986's results. The Company attributes this shortfall to overoptimism in estimating the timing of the semiconductor recovery, the belief that its telecommunications operations would continue to post record results, and, finally, the belief that capital spending would be better in 1986 than in fact it turned out to be.

The Electronic sector's operating earnings fell sharply in 1986, declining 50.9 percent to $39.8 million, compared with 1985's $81.1 million. Sales after restructuring of $754.3 million were down 13 percent, compared with sales of $867.5 million in 1985. Sector operating margins were 5.3 percent in 1986, down from 9.3 percent in 1985. The Company attributes approximately three-fourths of the sector's sales and earnings decline to continued weakness in the semiconductor industry.

The Company's telecommunications operations weakened in the latter part of 1986 as the domestic telephone industry curtailed spending. General Signal is looking forward to a resumption of growth in telecommunications in late 1987 or early 1988, when it expects that user demand will catch up with network offerings.

The Electrical sector's operating earnings improved in 1986 following declines in 1985 and 1984. Stronger performances in power distribution, fire protection and building signaling, and fractional horsepower motor operations more than offset flat-to-down results in conduit and cable fittings, heat treating, and petroleum-related businesses. Operating earnings increased 12.3 percent to $40.8 million, compared with $36.3 million in 1985. Due principally to restructuring, sales declined 12.9 percent to $325.6 million, compared with $373.7 million in 1985.

General Signal Corporation

The Fluid Controls and Equipment sector improved its performance in 1986, due to gains in General Signal's mixing equipment and cold-forged component operations, as well as the return to profitability of its railroad air brake unit. Other product areas such as valves, pumps, and instrumentation recorded generally lower results, as they were affected once again by the restricted capital spending programs of many industrial users. Operating earnings rose 22.4 percent to $55.1 million in 1986, which compares with $45.0 million in 1985. Sector sales fell 10.0 percent to $503.4 million, due almost entirely to restructuring.

For the nine months ended September 30, net earnings were off 15.3 percent, at $48.2 million, from the year-earlier results of $57.0 million. Sales of $1.18 billion were 2.3 percent below the previous year's levels, and earnings per share were down 14.1 percent to $1.70.

Although operating earnings for the Company as a whole have not been very strong in 1987, General Signal is encouraged by the fact that operating earnings have been increasing since the first quarter of 1987. Of particular note has been the performance of the Semiconductor Equipment Group (SEG). Throughout the year, SEG has posted increasing volumes and decreasing losses. In fact, SEG recorded a profit in the third quarter of 1987 and expects sales to increase in 1987 from 10 to 15 percent.

The results of operations in terms of the new format are shown in Table 2 for the nine months ending September 30, 1987. Table 3 presents a five-year summary of the Company's operations under the new sector reporting format.

Table 2

General Signal Corporation
Sector Performance (Unaudited)
For 9 Months Ended September 30
(Millions of Dollars)

Net Sales	1987	1986
Process Controls	$ 482	$ 506
Technology Industries	222	233
Electrical Controls	263	261
Transportation Controls	214	209
	$1,181	$1,209
Operating Earnings		
Process Controls	$ 37	$ 43
Technology Industries	(10)	6
Electrical Controls	30	34
Transportation Controls	23	27
	$ 81	$ 110

Source: General Signal Corporation
Quarterly Reports
Dataquest
December 1987

General Signal Corporation

Table 3

General Signal Corporation
Five-Year Summary New Sector Reporting Format (Unaudited)
(Millions of Dollars)

Net Sales	1986	1985*	1984	1983	1982
Process Controls	$ 659	$ 702	$ 679	$ 668	$ 783
Technology Industries	311	417	413	262	197
Electrical Controls	333	386	418	416	409
Transportation Controls	280	296	277	230	233
	$1,583	$1,801	$1,787	$1,575	$1,622
Operating Earnings					
Process Controls	$ 53	$ 59	$ 52	$ 59	$ 97
Technology Industries	6	36	80	36	29
Electrical Controls	42	38	41	47	45
Transportation Controls	34	29	27	21	31
	$ 136	$ 162	$ 200	$ 164	$ 201

*Tabular data do not include the allocation of restructuring charges to each of the sector's operating earnings. Such charges were: Process Controls, $15; Technology Industries, $35; Electrical Controls, $11; and Transportation Controls, $11. The total restructuring charge to operating earnings was $72.

Note: Columns may not add to totals shown because of rounding.

Source: General Signal Corporation
Quarterly Reports
Dataquest
December 1987

General Signal Corporation

Acquisitions

In the year ended December 31, 1986, the Company made several acquisitions. These acquisitions are listed in Table 4.

Table 4

General Signal Corporation
1986 Acquisitions

Company	Principal Business	Date Acquired
Aerotronic Associates, Inc.	Stress-Screening Systems for Electronics	March 1986
Aerotron, Inc.	Mobile Radio Systems	May 1984
Drytek, Inc.	Plasma Etching & Stripping Equipment	August 1986
Nord Engineering Co., Inc.	Precision Polishing Equipment	June 1986
Northeast Electronics (Instruments Product Line of Northern Telecom, Inc.)	Test Instruments for Telecommunications	September 1985
Optoscan Corporation	Wafer-Feature Measurement Equipment	March 1985
RCA Broadcast Systems Division's Antenna Product Line	Broadcast Antennas	January 1986
Rockcor, Inc's Ionscan Product Line	Semiconductor Device Test Instruments	June 1985
Sideband Technology, Inc.	Mobile Radio Equipment	September 1984
Telnex Corporation	Data Communications Network Management Systems & Products	September 1986

Source: General Signal Corporation
Annual Reports
Dataquest
December 1987

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General Signal Corporation

SEMICONDUCTOR EQUIPMENT

General Signal's Semiconductor Equipment Group (SEG) manufactures and markets semiconductor capital equipment. SEG is a part of the Technology Industries sector. In addition to SEG companies, other General Signal companies also manufacture and market semiconductor capital equipment. Table 5 lists SEG and non-SEG General Signal companies that sell equipment to the semiconductor industry.

In April 1987, General Signal shut down its wafer-inspection subsidiary, Optoscan Corporation, and withdrew its products from the market.

Table 5

General Signal Corporation
Semiconductor Equipment Companies

Company	Location
Advanced Mechanization, Inc.	Horsham, Pennsylvania
Blue M Electric*	Blue Island, Illinois
Circuits Processing Apparatus, A Division of the Thinfilm Company	Fremont, California
Drytek	Wilmington, Massachusetts
Electroglas, A Division of Xynetics, Inc.	Santa Clara, California
Ionscan, A Division of the Thinfilm Co.	Mountain View, California
Kayex, A Division of Drytek	Wilmington, Massachusetts
Kinney Vacuum*	Canton, Massachusetts
Lindberg*	Chicago, Illinois
Micro Automation, A Division of Xynetics, Inc.	Fremont, California
Rucker & Kolls, A Division of Xynetics, Inc.	Santa Clara, California
Semiconductor Systems, Inc.	San Jose, California
Tempress, A Division of the Thinfilm Co.	Fremont, California
The Thinfilm Company	Fremont, California
Ultraglas, A Division of Xynetics, Inc.	Santa Clara, California
Ultratech Equipment, A Division of Semiconductor Systems, Inc.	San Jose, California
Ultratech Photolytics, A Division of the Thinfilm Co.	Fremont, California
Ultratech Photomask, A Division of Xynetics, Inc.	Santa Clara, California
Ultratech Stepper	Santa Clara, California
Xynetics, Inc.	Santa Clara, California
Xynetics Products, A Division of Electroglas	Santa Clara, California

*Denotes a non-SEG company

Source: General Signal Corporation
Dataquest
December 1987

General Signal Corporation

International Companies

In 1985, General Signal established a Japanese subsidiary in Tokyo, Japan--General Signal K.K. This subsidiary will coordinate the Company's semiconductor equipment sales and service efforts in Japan. The Company also plans for General Signal K.K. to pave the way toward establishing manufacturing operations in Japan, which it intends to set up by the end of 1988. Initially, the new organization will have responsibility for the direct sales efforts of Ultratech Stepper and Electroglas.

In addition to General Signal K.K., the Company also has a manufacturing joint venture in Japan--Koyo Lindberg--for the manufacture of diffusion furnaces, oxidation, CVD, industrial treating equipment, and conveyor furnaces.

General Signal Thinfilm

General Signal Thinfilm was created in June 1987 by combining the operations of Tempress, which makes diffusion and CVD equipment; Ionscan, which makes ion implantation uniformity measuring equipment; Circuits Processing Apparatus, which makes sputtering equipment; and an excimer laser CVD known as Ultratech Photolytics.

Industry sources report that General Signal Thinfilm is working on an all-in-one system that would combine deposition, etch, and thermal processing capabilities in a single unit.

Tempress

Tempress produces diffusion systems, LPCVD products, digital process and temperature controllers, and chemical vapor deposition reactors. In 1987, Tempress was combined with CPA & Ionscan, along with a thinfilm development group, to form General Signal Thinfilm.

In both the APCVD market and LPCVD market, Tempress has lost share in recent years (see Figures 1 and 2). In APCVD, Tempress' share of the total worldwide market fell from almost 13 percent in 1982 to just slightly more than 8 percent in 1986. In 1982, Tempress had sales of $2.5 million in a $19.6 million market (see Table 6). By 1986, Tempress sales had declined to $2.2 million as the market climbed to $26.8 million.

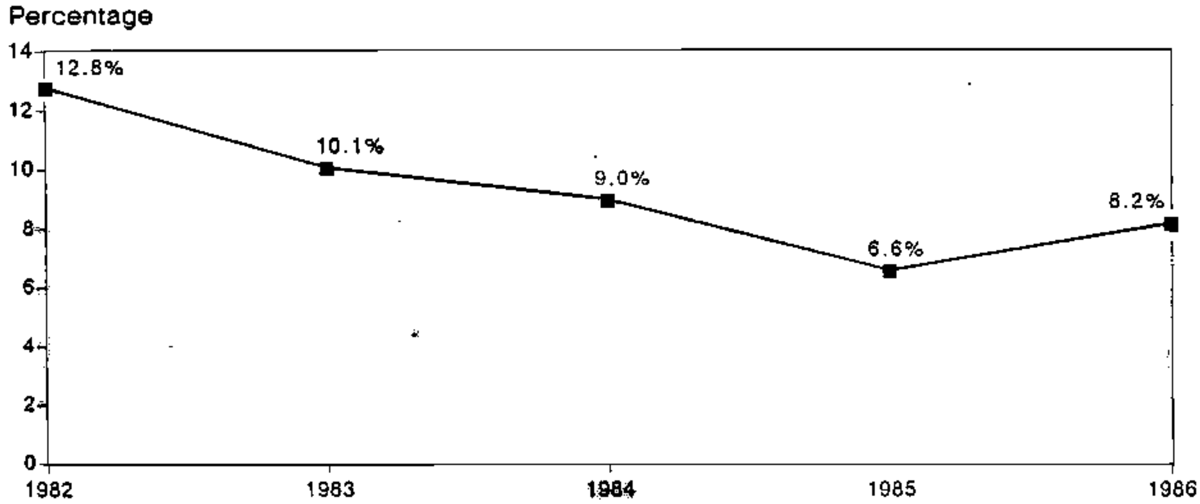
In LPCVD, the Tempress share fell from approximately 9 percent in 1982 to approximately 4 percent in 1986. In 1982, Tempress had sales of $3.6 million in a $39.4 million market. By 1986, Tempress sales had risen only slightly to $3.8 million as the market soared to $96.6 million.

Although Tempress lost share between 1982 and 1986, its products became more international. In 1982, only approximately 22 percent of Tempress LPCVD revenue was generated outside of the United States; by 1986, this percentage had risen to about 34 percent. In 1982, only 24 percent of Tempress APCVD revenue was generated outside of the United States; by 1986, this percentage had risen to nearly 41 percent (see Figures 3 and 4).

General Signal Corporation

Figure 1

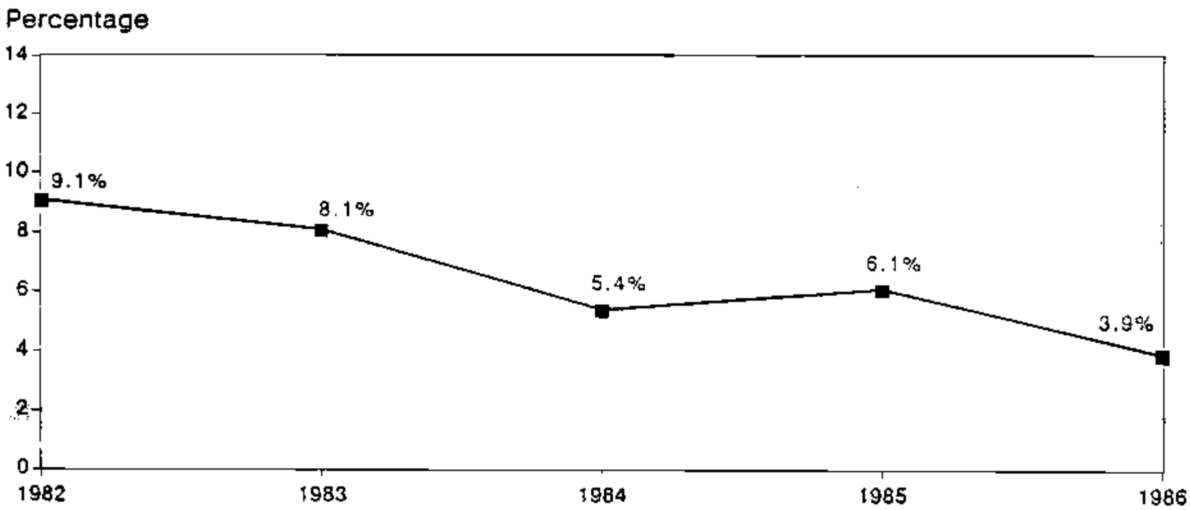
Tempress Share of Worldwide APCVD Market



Source: Dataquest
December 1987

Figure 2

Tempress Share of Worldwide LPCVD Market



Source: Dataquest
December 1987

Table 6

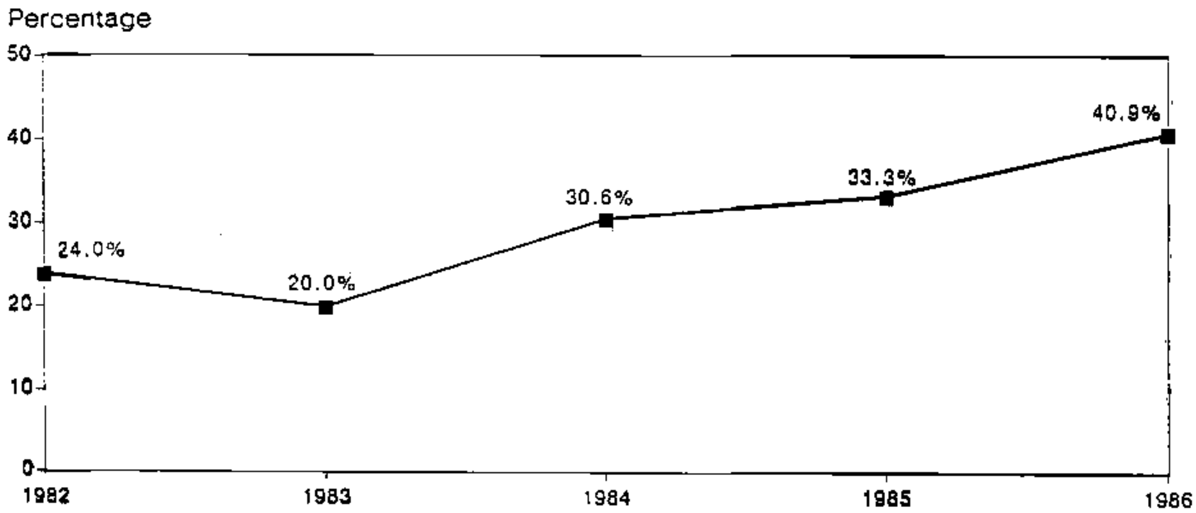
Tempress' APCVD & LPCVD Revenue
(Millions of Dollars)

	1982	1983	1984	1985	1986
Tempress APCVD	$ 2.5	$ 3.0	$ 3.6	$ 2.1	$ 2.2
Total APCVD Market	$19.6	$ 29.6	$ 40.2	$ 31.8	$ 26.8
Tempress LPCVD	$ 3.6	$ 4.9	$ 5.9	$ 7.6	$ 3.8
Total LPCVD Market	$39.4	$ 60.5	$110.1	$123.7	$ 96.6

Source: Dataquest
December 1987

Figure 3

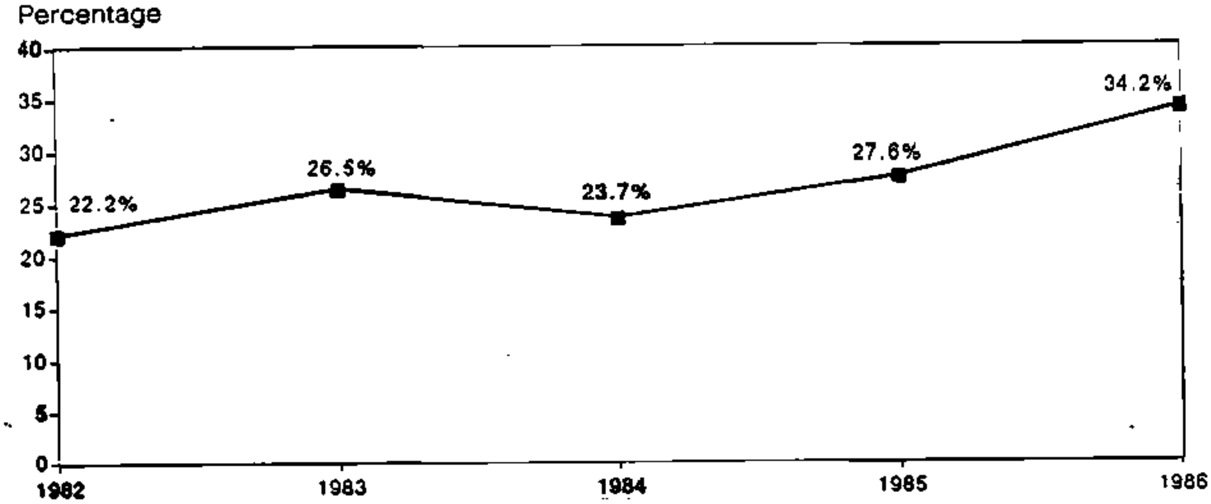
Tempress APCVD International Sales
as a Percent of Total Tempress APCVD Sales



Source: Dataquest
December 1987

Figure 4

Tempress LPCVD International Sales
as a Percent of Total Tempress LPCVD Sales



Source: Dataquest
December 1987

Circuits Processing Apparatus

Circuits Processing Apparatus (CPA) manufactures in-line planar magnetron sputtering systems for thinfilm deposition. In 1987, CPA was combined with Tempress & Ionscan, along with a thinfilm development group, to form the Thinfilm Company.

CPA's sales, which have been mainly in the United States, have declined from $6 million in 1982 to $2 million in 1986; over this same period, their market share has declined from 6 percent to 2 percent (see Figure 5).

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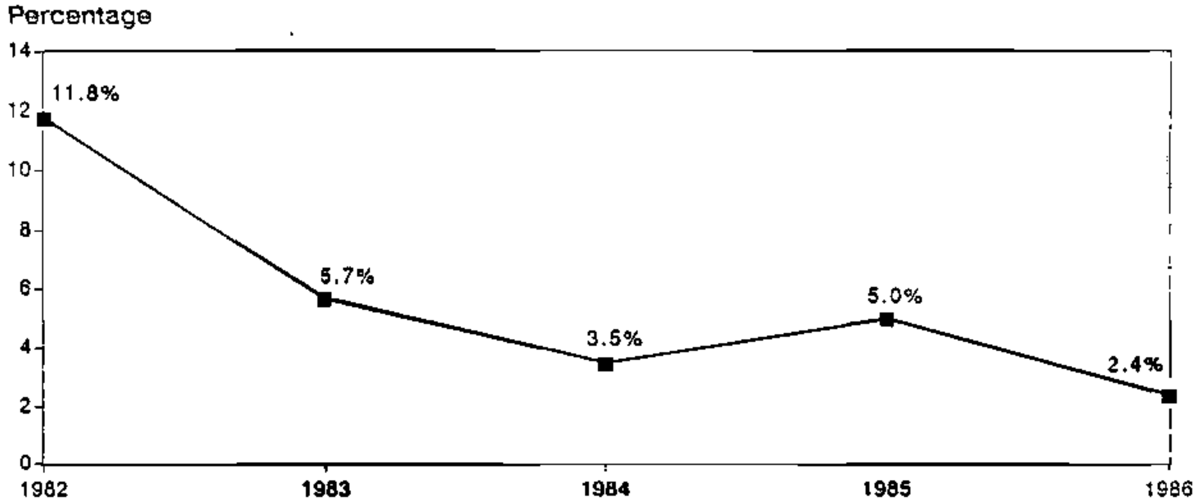
Figure 5

Circuits Processing Share
of U.S. Sputtering Market



Source: Dataquest
December 1987

Ionscan

Ionscan produces process equipment monitoring instrumentation for product quality and efficiency improvement, including implantation dose and thinfilm uniformity monitors.

Ultratech Photolytics

Industry sources say that Ultratech Photolytics has been developing for the past two years an excimer laser-based single-wafer, single-chamber CVD system that will be capable of depositing oxides and nitrides on both silicon and gallium arsenide wafers.

Xynetics, Inc.

Xynetics, Inc., consists of Electroglas, Micro Automation, Rucker & Kolls, Ultratech Photomask, Ultraglas, and Xynetics Products.

General Signal Corporation

Electroglas

Electroglas claims to be the world's largest producer of automatic wafer-probing systems designed for locating, marking, and mapping the imperfect die on wafers. They also manufacture X-Y positioning systems. In September 1987, Electroglas signed a $12 million agreement with Cognex Corporation under which Cognex will supply its machine-vision systems to Electroglas' wafer-prober product lines.

Micro Automation

Micro Automation manufactures automatic dicing saws, microwash cleaning stations, automatic die-separation systems, and dicing blades.

Rucker & Kolls

Rucker & Kolls manufactures test head hardware and fixed-point probe cards for the semiconductor industry.

Ultratech Photomask

Ultratech Photomask claims to be the United States' leading independent photomask supplier. It fabricates the mask from which each wafer will be patterned. Ultratech Photomask has incurred losses in the last two years, and the company attributes these losses to the downturn in the industry and to intense pricing pressure.

Ultraglas

Ultraglas manufactures photo blanks for optical and electron beam photomask production.

Xynetics Products

Xynetics Products is a division of Electroglas and manufactures a complete line of precision linear motors, electronics, and positioning systems for automated equipment in semiconductor and other industrial applications. Xynetics Products also manufactures automatic flatbed plotting systems for the conversion of engineering drawings into precisely rendered circuit master designs.

Advanced Mechanization, Inc.

Advanced Mechanization, Inc. (AMI), manufactures automatic die-attach systems, automatic die-sort systems, second optical wafer-inspection equipment, and wafer-management systems.

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Drytek

General Signal acquired Drytek, a privately held manufacturer of plasma etching systems and photoresist strippers in August 1986. In the dry strip market, Drytek's worldwide revenue in 1986 was approximately equal to its 1983 revenue of $2.0 million (see Table 7). Drytek's share of the total worldwide dry strip market in 1983 and in 1986 was 6 percent.

In the dry etch market, Drytek's revenue was $7 million in 1982 and had risen to $16 million in 1986. During this same period, however, Drytek's share of the total worldwide market declined slightly from 8 percent in 1982 to 7 percent in 1986.

Table 7

Drytek's Dry Strip & Dry Etch Revenue
(Millions of Dollars)

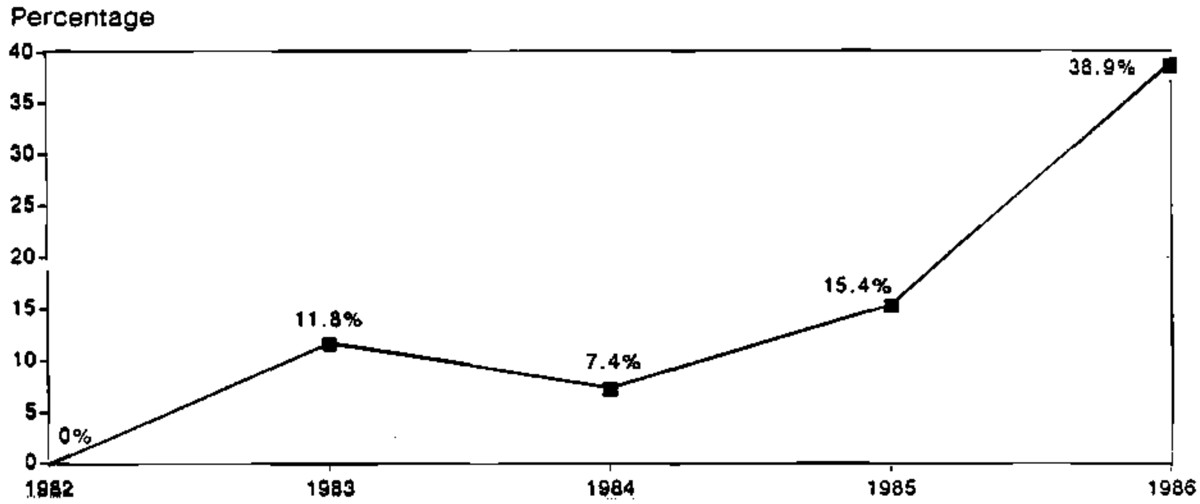
	1982	1983	1984	1985	1986
Drytek Dry Strip	$ N/A	$ 2.0	$ 3.0	$ 3.0	$ 2.0
Total Dry Strip Mkt.	$19.5	$ 33.9	$ 44.6	$ 36.8	$ 32.1
Drytek Dry Etch	$ 7.0	$ 15.0	$ 24.0	$ 23.0	$ 16.0
Total Dry Etch Mkt.	$93.2	$185.1	$314.3	$298.3	$236.1

Source: Dataquest
December 1987

International sales have assumed an increasing importance for Drytek since 1982. For dry strip and dry etch combined, international revenue as a percent of Drytek's total revenue rose from zero in 1982 to nearly 39 percent in 1986 (see Figure 6).

Figure 6

Drytek's International Sales
as Percent of Total Company Sales



Source: Dataquest
December 1987

Kayex

Kayex, which makes Hamco silicon-ingot-growing furnaces, ingot saws, and wafer grinders and polishers, reports to the president of Drytek.

Semiconductor Systems, Inc.

Semiconductor Systems, Inc. (SSI), produces track equipment (resist processing equipment and spin/bake systems). SSI has made dramatic gains in market share and sales since 1982, especially in the United States (see Table 8 and Figure 7). In 1982, SSI's total sales were $400,000 in a worldwide market of $76.5 million. By 1986, SSI's sales had risen to $8.8 million in a worldwide market of $143.5 million. SSI's share of the worldwide market in 1986 was 6 percent, and its share of the U.S. market was 13 percent. In 1986, only 10 percent of SSI's revenue came from outside the United States.

Table 8

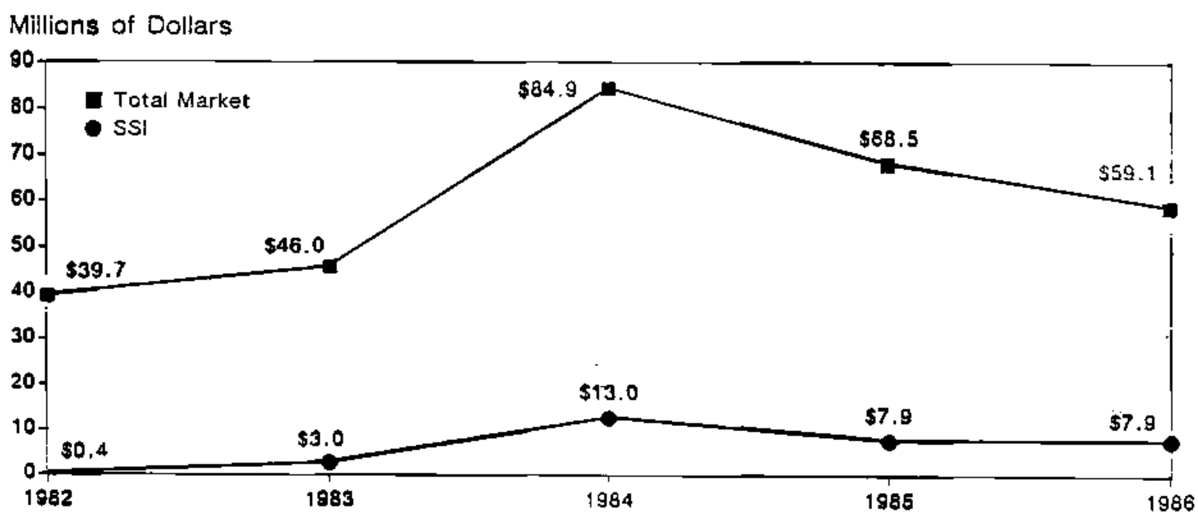
SSI'S Track Equipment Sales
(Millions of Dollars)

	1982	1983	1984	1985	1986
U.S. SSI Sales	$ 0.4	$ 3.0	$ 13.0	$ 7.9	$ 7.9
Total U.S. Track Mkt.	$39.7	$ 46.0	$ 84.9	$ 68.5	$ 59.1
Worldwide SSI Sales	$ 0.4	$ 3.0	$ 13.0	$ 8.8	$ 8.8
Total Worldwide Track Mkt.	$76.5	$100.4	$185.1	$165.7	$143.5

Source: Dataquest
December 1987

Figure 7

SSI U.S. and Total U.S. Track Equipment Sales
(Millions of Dollars)



Source: Dataquest
December 1987

Ultratech Equipment

Ultratech Equipment manufactures wafer and mask cleaning systems. In June 1987, Ultratech Equipment was combined with SSI to complement SSI's line of spin, bake, and develop equipment.

Ultratech Stepper

Ultratech Stepper offers a 1x stepper. It's strategy is to provide a cost-effective alternative to reduction steppers. Ultratech Stepper plans to do this by offering upgradable systems at a lower cost than reduction steppers. Each model of its stepper family can be retrofitted to state-of-the-art capability because the 1x lens can be changed or upgraded. Ultratech Stepper's most recent product offering, the UltraStep 1100 has submicron capability and, Ultratech Stepper believes, has sufficient pixel capability to fit a 16-megabit DRAM into a single exposure field.

Ultratech Stepper's product line is listed in Table 9.

Although Ultratech Stepper sales declined (along with the rest of the semiconductor capital equipment industry) from 1984 to 1986, its share of the worldwide stepper market increased from 11 percent to 12 percent (see Table 10 and Figure 8).

Table 9

Ultratech Stepper's Product Line

Model Number	Date Introduced	Capabilities
Model 900	1979	1x Lens
UltraStep 1000	1983	1x, 6-Inch Capable
UltraStep 1000	1984	1x, 6-Inch Capable, Wide Field Lens
UltraStep 1100	1986	Submicron Capability, Variable Numerical Aperture

Source: Ultratech
Dataquest
December 1987

Table 10

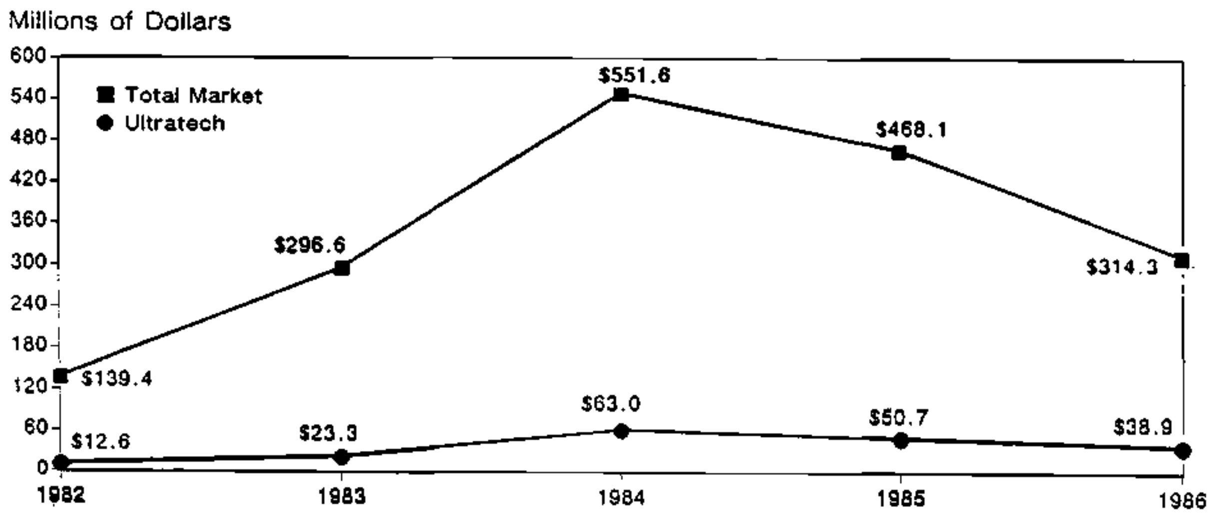
Ultratech Stepper's Stepper Revenue
(Millions of Dollars)

	1982	1983	1984	1985	1986
Ultratech Stepper U.S. Revenue	$ 12.3	$ 21.6	$ 53.1	$ 32.4	$ 27.4
Total U.S. Stepper Mkt.	$ 70.5	$121.8	$214.9	$137.5	$151.1
Ultratech Stepper Worldwide Revenue	$ 12.6	$ 23.3	$ 63.0	$ 50.7	$ 38.9
Total Worldwide Stepper Mkt.	$139.4	$296.6	$551.6	$468.1	$314.3

Source: Dataquest
December 1987

Figure 8

Ultratech Stepper and Total Stepper Worldwide Market Revenue



Source: Dataquest
December 1987

In 1982, almost 100 percent of Ultratech Stepper's sales were in the United States. By 1986, however, international sales had increased in importance to Ultratech Stepper and represented 30 percent of its sales.

Blue M

Blue M manufactures stringent environmental test equipment. Semiconductor devices are subjected to the stress of temperature, humidity, and thermal shock in environmental test chambers, clean room ovens, and burn-in chambers. Blue M's test chambers, ovens, baths, and furnaces also find application in the general laboratory environment.

Kinney Vacuum

Kinney Vacuum manufactures precision vacuum pumps that are required by several stages of semiconductor processing.

Lindberg

Lindberg manufactures heat-processing and induction heating equipment.

EXECUTIVE MANAGEMENT

The chief operating officers of SEG units are listed as follows:

- SEG—Jack Halter, senior vice president of General Signal and president of SEG
- Advanced Mechanization, Inc.—Paul Clugston, president
- Drytek—Arthur W. Zafiropoulo, president
    - Kayex—Elwyn Roberts, president
- General Signal Thinfilm—Ed Dohring, president of General Signal Thinfilm, formerly president of CPA
    - CPA—Randy W. Furr, vice president, finance and human resources, of General Signal Thinfilm and general manager of CPA
    - Ionscan—Dr. James A. Glaze, vice president, engineering and technology for General Signal Thinfilm and general manager of Ionscan

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   - Tempress—Russ Douglas, director of manufacturing for General Signal Thinfilm and general manager for Tempress, formerly director of operations at Tempress

   - Ultratech Photolytics—John Flaagan, general manager of Ultratech Photolytics, formerly vice president of Ultratech Equipment

   - SSI—Bill Currer, president

   - Ultratech Stepper—George Rutland, president

- Xynetics, Inc.—Neil Bonke, president of Xynetics, Inc., formerly president of Kayex

   - Electroglas—Bill Cornwell, general manager

   - Micro Automation—Neil Woodruff, general manager

   - Rucker & Kolls—Jim McMillen, general manager

   - Ultraglas—Leo DeVos, general manager

   - Ultratech Photomask, Inc.—Conor O'Mahony, vice president and general manager of Ultratech Photomask, Inc., formerly an engineering manager at Ultratech Stepper

The chief operating officers for General Signal's non-SEG semiconductor equipment companies are as follows:

- Blue M—J.A. Lawler, president

- Kinney Vacuum—Kurt Bramer, president

- Lindberg—S. Speltz, president

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KLA Instruments

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KLA Instruments

KLA Instruments
2501 Mission College Blvd.
P.O. Box 58016
Santa Clara, California 95052
Telephone: (408) 988-6100 Telex: 9103387357
(Thousands of Dollars Except Per Share Data)

Balance Sheet (June 30, 1986)

	1982	1983	1984	1985	1986
Current Assets	$15,977	$27,961	$51,959	$56,745	$73,331
Current Liabilities	$ 6,102	$ 9,555	$11,812	$16,509	$20,477
Current Ratio	2.62	2.93	4.40	3.44	3.58
Working Capital	$ 9,875	$18,406	$40,147	$40,236	$52,854
Long-Term Debt	$ 1,135	$ 313	$ 812	0	0
Debt/Equity	11%	1%	2%	0	0
Shareholder's Equity	$10,671	$24,811	$52,439	$62,641	$75,596
After-Tax Return on Average Equity	15.27%	16.50%	14.66%	15.30%	14.26%
Capital Expenditures	$ 742	$ 1,932	$ 4,547	$ 4,452	$ 2,999

Operating Performance (Fiscal Year Ending June 20, 1986)

	1982	1983	1984	1985	1986
Revenue	$16,162	$23,396	$42,873	$62,878	$82,526
Gross Margin	46%	51%	51%	54%	47%
Cost of Revenue	$ 8,800	$11,483	$20,818	$28,981	$44,008
RD&E Expense	$ 2,424	$ 3,067	$ 6,144	$10,734	$10,141
RDE/Revenue	15%	13%	14%	17%	12%
GA&S Expense	$ 3,227	$ 5,231	$ 8,161	$12,076	$14,001
G&A/Revenue	20%	22%	19%	19%	17%
Other Expenses (income)	($ 699)	($ 1,216)	($ 1,537)	($ 3,355)	($ 2,469)
Pretax Income	$ 2,410	$ 4,831	$ 9,287	$14,442	$16,845
Pretax Margin	14.91%	20.65%	21.66%	22.97%	20.41%
Effective Tax Rate	32.74%	40.55%	42.11%	42.61%	43.73%
Net Income	$ 1,510	$ 2,928	$ 5,664	$ 8,802	$ 9,854
Average Shares Outstanding (Thousands)	9,048	14,613	15,992	17,509	17,702
Per Share Earnings	$ 0.17	$ 0.20	$ 0.35	$ 0.50	$ 0.56
Total Employees	230	339	537	545	600

Source: KLA Instruments Corporation
Annual Reports and Forms 10-K
Dataquest
October 1986

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KLA Instruments

(The majority of this section is excerpted from the KLA Instruments Corporation Annual Report for the fiscal year ended June 30, 1986. For more detailed information and opinions about KLA Instruments, Dataquest clients are invited to use their inquiry privileges.)

THE COMPANY

Background

KLA is considered a pioneer in the automatic optical photomask inspection market. Established in 1976 specifically to design and manufacture photomask inspection systems, KLA introduced its first product in 1978. Today, KLA offers a broad line of automated photomask and reticle inspection systems and is one of the leaders in this area. In addition to becoming the leader in its original area of concentration and expertise, KLA has become the leading manufacturer of automatic wafer inspection equipment. It has recently begun to broaden its product base to include the assembly segment of the semiconductor equipment market, and reportedly also has plans to enter the market for automated inspection of printed circuit boards.

Its dominant position in its market segments is reflected in KLA's growth: the Company has grown from $3.2 million in sales in FY 1979 to $83 million in FY 1986. This represents a 59 percent compound annual growth rate (CAGR) over the last six years. The Company attributes its relative immunity to the downturn of 1985 to its strategy of developing systems that increase yield rather than capacity. KLA plans to continue to adhere to this strategy, and thus maintain its high growth rate, by continuing to develop systems that allow customers to achieve higher levels of design miniaturization and complexity.

KLA believes that over the next two decades, image processing technology will be essential to achieve these higher levels of miniaturization and complexity. The Company believes that image processing will have as large an effect on industrial manufacturing processes as data processing has had on the accounting industry. The field of image processing includes optical image transfer and pickup systems, high-speed image-processing computers, and proprietary image-processing software.

In keeping with this strategy of identifying tasks requiring human visual inspection, KLA today offers products in areas other than its traditional photomask and reticle inspection markets. It is now offering products in such areas as wafer inspection, solder mask inspection, IC device assembly, and device test, and it plans to enter the PCB board inspection market in 1987.

KLA Instruments

Operations

For the fiscal year ended June 30, 1986, KLA's sales increased 31 percent to $82.5 million. Net income increased 12 percent to $9.9 million. The Company reports that over the last five years, sales, net income, and earnings per share have grown at CAGRs of 50 percent, 60 percent, and 50 percent, respectively.

Gross margins declined in fiscal 1986 from 54 percent in fiscal 1985 to 47 percent. The Company reports that this change was the result of an increased percentage of sales of products manufactured by others and revenue from research and development contracts, which have lower margins. KLA reports that selling and general and administrative expenses were only 17 percent of sales in fiscal 1986, compared with 19 percent a year earlier.

KLA consists of four divisions and an Advanced Development Group. Its Reticle and Photomask Inspection Division designs and manufactures automated photomask inspection systems. The Wafer Inspection Division was formed in 1983 to develop a fully automated wafer inspection system. The Alignment, Inspection, and Measurement Division was recently established to deliver low-cost, modular image-processing systems to manufacturers of assembly equipment. The Automated Test Systems Division produces automated electrical test equipment using image-processing technology.

KLA also has minority ownership interest in Micrion, a Beverly, Massachusetts, company founded in 1983 to develop focused ion beam mask repair systems. KLA has exclusive marketing rights to Micrion's repair products for photomask and reticle applications.

International Operations

In June of this year, KLA appointed Dan Vilenski as Managing Director of a subsidiary being organized in Israel. The Company reported that KLA-Israel will develop and produce a proprietary optical instrument as part of an overall plan to establish operations in key international arenas.

KLA's gross profit margin on export sales is lower than that realized on domestic sales. Export sales are subject to certain export controls and restrictions; however, the company has not experienced any material difficulties because of these restrictions.

KLA Instruments

KLA's export sales to customers in Europe and the Far East have grown from 22 percent of total in fiscal year 1984 to 28 percent in fiscal 1985 and 32 percent in 1986. The Company credits these increases to its direct sales organization established in Europe in July 1984 and its Technology Center established in Japan in May 1985.

Marketing

KLA markets its systems in the United States and Canada through its own sales organization. In July 1984, the Company established a direct sales organization in Europe. In Japan, the Company's products are sold through an exclusive distributor. Marketing activities for the Company's products are supplemented through advertising in trade journals and exhibits at trade shows.

Research and Development

KLA is actively engaged in significant product improvement and new product development efforts. This research and development is funded in two different ways at KLA: internally and through research and development partnerships. Internally funded research and development expenses for fiscal years 1980 through 1986 are given in Table 1.

Table 1

KLA Instruments
INTERNALLY FUNDED RESEARCH AND DEVELOPMENT EXPENSES
(Thousands of Dollars)

Year	Amount	Percent of Net Sales
1980	$ 846	11.7%
1981	$ 1,656	12.6%
1982	$ 2,424	15.0%
1983	$ 3,067	13.1%
1984	$ 6,114	14.3%
1985	$10,734	17.1%
1986	$10,141	12.3%

Source: KLA Instruments Corporation Annual Reports

KLA Instruments

In addition to internally funded research and development, KLA has also entered into three research and development partnerships. These partnerships which are wholly owned subsidiaries of KLA. The subsidiaries are general partners in the partnerships and have exclusive management control of their businesses.

In 1981, KLA received $2 million through Partnership No. 1 to develop image processing equipment for assembly operations. This eventually led to the Alignment, Inspection, and Measurement Division. In 1982, the company received another $3.25 million through Partnership No. 2 to develop the KLA 2020 Wafer Inspection Division.

In February 1985, KLA received $5.8 million through Partnership No. 3 for an automated image analysis system for printed circuit board inspection. This new system will be KLA's next major product thrust. It is expected to be in production by early 1987.

In September 1985, the Company received a $710,000 addendum to a Department of the Army contract associated with the VHSIC program. The funding will be used for development and implementation of new image processing concepts to provide further improvement to the performance of KLA's High-Resolution Automatic Data Base Reticle Inspection System (HRADBRIS). The contract for this system now totals $2,460,000.

Approximately one out of every five KLA employees works in engineering, research, or development, and half of the technical staff has master's or doctor's degrees.

Company Structure

President and Chief Executive Officer of KLA is Kenneth Levy. Other officers include: Chairman of the Board, Robert E. Anderson; Senior Vice President, Robert J. Boehlke; Vice President of Advanced Development, Paul Sandland; Senior Vice President, Kenneth L. Schroeder; and Secretary, Paul Kreutz.

Mr. Levy was a cofounder of KLA in 1975. Prior to founding the Company, Mr. Levy was President of Cobilt, a manufacturer of automated semiconductor manufacturing equipment and a division of Computervision Corporation.

Mr. Anderson also cofounded the Company in 1975. After serving as a Senior Vice President and a director of the Company since its founding, he was elected Chairman in June 1985.

Mr. Boehlke joined the Company in April 1983 as Vice President and General Manager of the Reticle and Photomask Inspection Division. From August 1971 to April 1983, Mr. Boehlke was employed by Kidder Peabody & Co., a member of the New York Stock Exchange, and in his last position with that firm was a Vice President and stockholder.

Mr. Sandland joined the Company in April 1979 as Engineering Manager, and was elected Vice President of Engineering in July 1978 and Vice President of Advanced Development in January 1980.

Mr. Schroeder joined the Company in April 1979 as Vice President of Manufacturing, and became Vice President and General Manager of the Reticle and Photomask Inspection Division in July 1982. In April 1983, he became General Manager of the Wafer Inspection Division. From 1973 until March 1979, Mr. Schroeder was employed by Spectra-Physics, Inc., a laser systems manufacturer, where he was Division Manager of the Engineering Laser Systems Division and Manufacturing Manager.

Mr. Kreutz has been Secretary of the Company since December 1981, and has been a practicing attorney for more than five years. He is a member of Ware, Fletcher & Freidenrich, which is general counsel to the Company.

In April 1986, Robert J. Riopel was appointed Vice President of Finance and Administration, reporting to Mr. Levy. Also in April, Howard Gore was promoted to the newly created position of Corporate Controller and Raymond Werner was promoted to Assistant Treasurer. Both Mr. Gore and Mr. Werner will report to Mr. Riopel. The Company also announced in April that Robert Walsh resigned as Treasurer of the Company.

Also this year, Robert Heny was appointed to General Manager of the Wafer Inspection Division (WISARD) and Mike McCarver was appointed as Vice President of Sales for the Reticle and Photomask Inspection Division (RAPID).

Customer service is a vital part of KLA's strategy and structure. The customer support staff comprises more than 20 percent of the company's employees, and more than 95 percent of the customer support employees have technical degrees.

KLA considers its employee relations good. None of its approximately 600 employees are represented by labor unions.

OPERATING GROUPS OR DIVISIONS

The Reticle and Photomask Inspection Division

The Reticle and Photomask Inspection Division (RAPID) produces the KLA 200 Series of inspection systems, the KLA 228 Reticle Inspection System, the KLA/Micrion 808 Ion Beam Repair System, and the KLA 302 Solder Mask Inspection System. RAPID generates more revenue than any other of the Company's divisions, although, as the other divisions introduce new products, this share is declining (see Table 2).

Table 2

KLA Instruments
SALES BY DIVISION
(Millions of Dollars)

	1985		1986	
	Sales	Percent Share	Sales	Percent Share
RAPID Division	$46.6	74.1%	$43.5	52.7%
Wafer Inspection Division	4.7	7.5	19.5	23.6
AIM/ATS Divisions	5.2	8.3	9.5	11.5
Subtotal Systems Revenue	$56.5	89.8%	$72.5	87.9%
Service Revenue	6.0	9.5%	7.5	9.1%
Development Revenue	0.4	0.6%	2.5	3.0%
Total Revenue	$62.9		$82.5	

Note: Totals may not add due to rounding.

Source: Dataquest
October 1986

KLA Instruments

KLA believes that RAPID will continue to grow because of its large installed base in mask shops and IC manufacturing facilities and because of the growth in application-specific ICs (ASICs), which use three to five masks. The Company also expects RAPID to grow because of increased usage of its systems overseas. RAPID now has field support in 16 countries.

Table 3 lists the division's photomask and reticle inspection products. The KLA 100 was KLA's first product. It was introduced in 1978, and approximately 50 units were shipped before it was discontinued. All the other products listed in the table are currently in production.

Table 3

KLA Instruments
RETICLE AND PHOTOMASK INSPECTION DIVISION PRODUCTS

Model	Detection Resolution	ASP	Year Introduced
KLA 100	2 microns	$ 300,000	1978
KLA 101	0.9 micron	$ 300,000	1981
KLA 201	0.9 micron	$ 450,000	1982
KLA 208	0.5 micron	$ 700,000	1984
KLA 209	0.35 micron	$ 850,000	1984
KLA 218	0.5 micron	$ 668,000	1986
KLA 219	0.35 micron	$ 768,000	1986
KLA 221	0.9 micron	$ 718,000	1982
KLA 224	0.9 micron	$ 690,000	1983
KLA 228	0.5 micron	$1,000,000	1985
KLA 229	0.35 micron	$1,125,000	1986
KLA/Micrion 808	<1 micron	$1,000,000	1985
KLA 302		$ 40,000	1984

Source: Dataquest
October 1986

KLA Instruments

The KLA 100 Series used die-to-die comparison techniques to inspect photomasks and multidie reticles. The KLA Model 221 Inspection System (KLARIS) was the initial product in the KLA 200 Series, and added the capability of die-to-die data base comparison techniques. The first installation for KLARIS was made in early 1985.

The KLA 201 is a "stripped" version of the 221 and only has die-to-die capability, but can be upgraded in the field to add die-to-die data base comparison such that its performance is comparable to that of the 221. The KLA 224 is a dedicated, high-throughput reticle inspection system.

In October 1985, KLA announced the KLA 209, an advanced photomask and reticle inspection system. The 209 can detect defects of 0.35 micron on linewidths as small as 0.75 micron. The Company expects that the 209 will be used for reticle qualification as well as for photomask inspection.

In addition to the 209, the Company's RAPID division has shipped three other new products in fiscal 1986: the KLA 228 Reticle Inspection System, the KLA/Micrion 808 Ion Beam Repair System, and the KLA 229. The 228 is an image-to-data base system that uses proprietary image enhancement techniques to find defects as small as 0.5 micron. The average selling price (ASP) of the 228 is approximately $1 million.

The KLA/Micrion 808 also has an ASP of $1 million. The 808 will be the industry's first repair system to use ion beam technology for repairing submicron defects on photomasks and reticles. KLA has minority ownership in Micrion and exclusive marketing rights to the repair products for photomask and reticle applications.

In fiscal 1986, KLA introduced the third generation of KLARIS, the KLA 229, a die-to-die and die-to-data base reticle inspection system which validates the image of the integrated circuit on a photomask or reticle. The KLA 229 has the same optical resolution as the KLA 209.

In August, KLA introduced the first two models of its 210-Series High Speed Automatic Photomask Inspection Systems: the KLA 218 and KLA 219. The 218 and 219 can detect defect densities as small as the 208 and 209 (0.5 micron and 0.35 micron, respectively) but are twice as fast as the 208 and 209.

In August 1984, the division introduced the KLA 302 Solder Mask Inspection System to optically inspect the metal solder masks used in the IC bonding process. Solder masks that have defects can result in poor bonding and low yields. First shipments were made in 1984, and ASP is $40,000. The products of the Reticle and Photomask Inspection Division accounted for most of KLA's 1984 sales.

KLA Instruments

KLA claimed that it had installed approximately 300 photomask systems worldwide as of October 1985.

The Wafer Inspection Division

The Wafer Inspection Division was formed in 1983, and in 1984 it introduced the KLA 2020, the industry's first fully automated wafer inspection system. First shipments of this product were made in 1985. There are presently no competitors that can deliver completely automated wafer inspection systems.

In May 1985, the Company introduced a major enhancement to the 2020, the Design Reference Generator (DRG). The DRG allows the 2020 to compare a level on the silicon wafer with the design data base of the mask or reticle used to expose the wafer. The average selling price of the DRG is approximately $270,000. In May of this year, the Company introduced a computer subsystem, the KLAUT, which is used with the 2020 to format wafer inspection data into graphics displays for statistical analysis.

As of April 1986, KLA had received approximately 40 orders for the 2020 and had shipped 20. Approximately one-third of the 2020's installed base is reportedly being used for wafer stepper setup and reticle qualification. Another third is used for process control and full wafer inspection, and the remaining third is used for troubleshooting, yield control, and research and development. The Company is currently devoting one service engineer to every installed 2020. Average selling price of the 2020 is $1 million.

The Alignment, Inspection, and Measurement Division

The Alignment, Inspection, and Measurement (AIM) Division was established to develop products to automate assembly operations. The division's first product is the KLA Automatic System for Process Control (KLAASP). The KLAASP is an OEM product that provides cost-effective image processing to automate the alignment, measurement, and inspection tasks that occur during assembly and test operations. The KLAASP has an ASP of $15,000.

KLA has OEM contracts for its KLAASP image processing system with two Japanese equipment manufacturers.

KLA Instruments

The Automated Test Systems Division

The Automated Test Systems (ATS) Division was established to provide products to automate test operations. First shipments for the division's first product, the KLA 1007 Automated Wafer Prober, began in late 1984. The KLA 1007 combines state-of-the-art image processing technology with a proven precision wafer handling and positioning system supplied by a semiconductor equipment manufacturer. It is the first prober to combine electrical test with visual inspection.

Perkin-Elmer Corporation

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The Perkin-Elmer Corporation

Perkin-Elmer Corporation
Main Avenue
Norwalk, Connecticut 06856
Telephone: (202) 762-1000 Telex: 965-5954
(Millions of Dollars Except Per Share Data)

Balance Sheet (as of July 31)

	1981	1982	1983	1984	1985
Current Assets	$ 650	$ 657	$ 678	$ 761	$ 846
Current Liabilities	$ 251	$ 238	$ 270	$ 340	$ 389
Current Ratio	2.58	2.76	2.51	2.24	2.18
Working Capital	$ 398	$ 418	$ 405	$ 760	$ 846
Long-Term Debt*	$ 138	$ 144	$ 102	$ 122	$ 122
Debt/Equity	31.35%	29.89%	19.79%	21.76%	19.74%
Shareholders' Equity	$ 440	$ 483	$ 515	$ 563	$ 619
After-Tax Return on Average Equity	20.06%	13.59%	10.07%	12.26%	13.89%
Capital Expenditures	$ 52	$ 46	$ 47	$ 59	$ 68

Operating Performance (Fiscal Year Ending July 31)

	1981	1982	1983	1984	1985
Revenue	$1,116	$1,037	$1,015	$1,182	$1,305
Gross Margin	44%	43%	42%	42%	44%
Cost of Revenue	$ 623	$ 591	$ 587	$ 688	$ 733
RD&E Expense	$ 83	$ 81	$ 80	$ 92	$ 114
RD&E/Revenue	7%	8%	8%	8%	9%
SG&A Expense	$ 257	$ 262	$ 270	$ 305	$ 323
SG&A/Revenue	23%	25%	27%	26%	25%
Interest Expense**	$ 4	($ 4)	($ 10)	$ 5	($ 2)
Pretax Income	$ 149	$ 107	$ 88	$ 93	$ 136
Pretax Margin	13.34%	10.36%	8.63%	7.83%	10.42%
Effective Tax Rate	44.50%	41.65%	42.69%	28.65%	39.61%
Net Income	$ 83	$ 63	$ 50	$ 66	$ 82
Average Shares Outstanding (Thousands)	43,150	43,250	43,671	44,466	44,650
Per Share Earnings	$ 1.91	$ 1.45	$ 1.15	$ 1.49	$ 1.84
Total Employees	15,402	14,100	14,372	15,480	15,515

*Includes long-term debt and other long-term liabilities.
**Stated as a net figure including interest expense and income, also other income, patent infringement settlement, and provisions for restructuring.

Source: Perkin-Elmer, Annual Reports and Forms 10-K
DATAQUEST
January 1986

The Perkin-Elmer Corporation

(The majority of this section is excerpted from the Perkin-Elmer Report Form 10-K to the Securities and Exchange Commission and the Perkin-Elmer Annual Report for the fiscal year ending July 31, 1985. For more detailed information and opinions about Perkin-Elmer, DATAQUEST clients are invited to use their inquiry privileges.)

THE COMPANY

Background

The Perkin-Elmer Corporation was incorporated in 1939 under the laws of the state of New York. Perkin-Elmer develops, manufactures, and sells products in the following six industry segments: Analytical Instrumentation, Avionic Instrumentation, Electronic Data Systems, Electro-Optical Systems and Precision Optics, Semiconductor Production Equipment, and Thermal Spray Equipment and Supplies.

Perkin-Elmer consists of six operating groups: the Semiconductor Equipment Group, the Materials and Surface Technology Group, the Instrument Group, the Concurrent Computer Corporation, the Optical Group, and Bodenseewerk Geraetetechnik (BGT).

In May 1984, Perkin-Elmer's Semiconductor Production Equipment Group acquired Censor, a Liechtenstein producer of step-and-repeat alignment systems. The same month it also acquired Qualitron as a wholly owned subsidiary. Qualitron manufactures masks for the production of semiconductor devices. In July 1984, Qualitron's printed circuit division was sold to Hadco Corporation.

In September 1985, the Company combined the Physical Electronics Division of the Instruments Group and the METCO group to form the Materials and Surface Technology Group. In November 1985, the Company formed the Concurrent Computer Corporation from its Data Systems Group. By March 1986, 82 percent of Concurrent's equity was owned by Perkin-Elmer.

Fiscal 1985 operating profits increased 38 percent from 1984, while sales increased 10 percent. In a period of generally tight market conditions in the electronics industry, Perkin-Elmer's net sales for the first 6 months of fiscal 1986 (ending January 31) were up slightly from the same period in 1984, from $614.6 million to $620 million. Operating profits for the 6 months ending January 31, 1986 were stable at $268.9 million, compared to $266.1 million for the 6 months ending January 31, 1985.

The Perkin-Elmer Corporation

In fiscal 1985, Perkin-Elmer reduced the number of management levels in most of its operations and reduced the number of corporate officer positions. A total of 200 employees took a voluntary retirement in fiscal 1984 and fiscal 1985. This involved a substantial one-time cost of $11 million that was charged against income in fiscal 1984 and fiscal 1985. Annual direct savings from this action are calculated to be approximately $11 million.

OPERATIONS

The Semiconductor Equipment Group produces and sells capital goods for the semiconductor industry, specifically Micralign full-field scanning projection mask alignment lithography systems and Censor step-and-repeat alignment lithography systems; electron beam lithography systems (sold under the trademark MEBES); a direct-write electron beam system (AEBLE 150) sputtering equipment; and a plasma processing system sold under the trademark Omni-Etch. These markets traditionally have relatively few customers.

The Materials and Surface Technology Group was formed in September 1985 from Perkin-Elmer's METCO group and the Physical Electronics Division of the Instruments Group. This group will concentrate on materials science and surface technology markets.

The Instrument Group produces and sells analytical instruments that determine the composition and molecular structure of organic and inorganic chemical substances and measure the concentration of materials in a sample.

Concurrent Computer Corporation was formed on November 13, 1985. It assumed the activities and net assets of Perkin-Elmer's Data Systems Group which developed and produced 32-bit superminicomputers. Although the Data Systems Group was profitable, Perkin-Elmer felt that it did not always receive the attention it deserved. Concurrent was formed in response to this perceived lack of attention. It was hoped that as a separate corporation it would increase its visibility, achieve recognition from the financial community, and would be able to attract and maintain a strong management team. It is 82 percent-owned by Perkin-Elmer.

The Optical Group produces and sells electro-optical systems and precision optical components that are specially developed to meet the needs of the U.S. government's space and national security programs. The Optical Group also produces and sells commercial products, such as medical and industrial gas analyzers; microdesitometers; automatic document inspection systems; and ground-based astronomical telescopes and spectrographs.

Bodenseewerk Geraetetechnik (BGT) is a West German affiliate that produces and sells avionic instrumentation including flight guidance and control instruments for missiles and military and commercial aircraft. BGT's principal customer is West Germany's Federal Office of Military Technology and Procurement, which BGT serves both as a prime contractor and as a subcontractor.

Net sales for the year ending July 31, 1985, exceeded those of the previous fiscal year by 10 percent. Gross margin as a percent of sales for fiscal 1985 was up to 43.8 percent, from fiscal 1984's 41.8 percent. The Company attributes this to several causes. First, commercial business segments represented a growing share of its business, while the lower-margined government contracting segments represented a shrinking share. Second, the Company noted a growing acceptance of some of its newest, most advanced, and highest-margined products in the marketplace; this was especially evident in Concurrent Computer Corporation. Finally, the Company was able to raise prices on selected products, allowing it to offset the negative impact of the strong U.S. dollar.

Perkin-Elmer's strategy is to be technology-driven in order to respond to the changing needs of its markets. Horace C. McDonell, president and chief executive officer, wants to "maximize the Company's firepower at the front." To do this, Perkin-Elmer has been actively engaged in minimizing administration and overhead expenses, in improving productivity, while simultaneously increasing R&D expenses 24 percent in fiscal 1985.

INTERNATIONAL OPERATIONS

Perkin-Elmer's consolidated net sales abroad for the fiscal years ending July 31, 1983, 1984, and 1985 were approximately $463 million, $476 million, and $533 million or 46 percent, 40 percent, and 41 percent, respectively, of the Company's consolidated net sales. The profitability of such sales, which included products exported from the United States as well as those manufactured abroad, did not differ significantly from similar sales in the United States.

On January 10, 1986, Perkin-Elmer and Citizen Watch Company, Ltd. of Tokyo signed a final agreement, forming a joint venture company to manufacture the Company's products in Japan. Initial capitalization was $500,000. Perkin-Elmer will own 60 percent of the new company; Citizen Watch will own 40 percent.

Under the terms of the joint venture, Perkin-Elmer Japan will have worldwide sales and marketing responsibility for products manufactured in Japan. Initially, the joint venture will manufacture Perkin-Elmer's SRA series of steppers and its Omni-Etch line of dry processing systems.

Citizen's Precision Machinery Division in Japan will be responsible for the actual production of the Company's equipment. Perkin-Elmer Japan will initially perform final test on the products, then test and assembly, and finally complete manufacture.

MARKETING

In the United States, Perkin-Elmer markets most of its products directly through its own sales organizations, although some lower-priced instruments produced by the Instrument Group are marketed through independent distributors and sales representatives. Sales to major markets outside the United States are generally made by foreign sales subsidiaries, although some sales are made directly to the foreign customers. In countries where the sales potential does not warrant the establishment of a sales subsidiary, sales are made through various representative and distributorship arrangements.

Perkin-Elmer leases sales and service offices in principal industrial cities in the United States, and in foreign countries through its sales subsidiaries. None of Perkin-Elmer's products is distributed through retail outlets.

RESEARCH AND DEVELOPMENT

Perkin-Elmer's R&D spending for fiscal 1985 was 24 percent higher than the previous year. R&D was 8.8 percent of sales for the company as a whole. This was due, primarily, to continued heavy spending for new product development in the Semiconductor Equipment Group (such as for X-ray lithography) and in the Data Systems Group (now Concurrent Computers).

EMPLOYEES

As of July 31, 1985, Perkin-Elmer employed 15,480 persons, 10,679 in the United States. None of the Company's U.S. employees is subject to collective bargaining agreements.

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The Perkin-Elmer Corporation

SEMICONDUCTOR EQUIPMENT GROUP

Perkin-Elmer's Semiconductor Equipment Group is the world's largest producer of semiconductor processing equipment. It is committed to meeting the semiconductor industry's production requirements for the next generation of semiconductor devices with efficient and productive tools and effective customer support.

In fiscal 1985, the Semiconductor Equipment Group reported sales of $315.9 million (see Table 1), up 22 percent from 1984. The Company attributed this strong growth to the demand early in the fiscal year for its latest Micralign projection mask aligners and to continuing demand for its electron beam exposure systems. However, sales for the 6 months ending January 31 were hurt by the semiconductor recession of 1985. Sales for the first six months of FY1986 were $121.7 million, down 17 percent from the same period a year earlier (see Table 2). Orders were $114.8 million, down 34 percent from the period a year earlier (see Table 3). The Company notes optimistically that orders for the quarter ending January 31, 1986, were higher than in the previous three quarters.

Table 1

OPERATING GROUP FINANCIAL DATA
FISCAL YEAR ENDING JULY 31
(Millions of Dollars)

	1981	1982	1983	1984	1985
NET ORDERS					
Instrument Group	$ 327.7	$323.7	$ 306.4	$ 358.4	$ 390.7
Semiconductor Equipment Group	177.6	125.1	174.4	310.2	294.3
Data Systems Group	228.1	222.1	202.0	244.6	273.9
Optical Group	173.2	130.3	155.4	208.0	181.8
Bodenseewerk Geraetetechnik	189.5	93.6	112.5	119.7	100.1
Metco	100.8	92.9	78.9	83.4	88.6
Subtotal	$1,196.9	$987.7	$1,029.6	$1,324.3	$1,329.4
Intersegment	(5.4)	(4.7)	(11.8)	(18.5)	(15.8)
Total	$1,191.5	$983.0	$1,017.8	$1,305.8	$1,313.6

(Continued)

Table 1 (Continued)

OPERATING GROUP FINANCIAL DATA
FISCAL YEAR ENDING JULY 31
(Millions of Dollars)

NET SALES					
Instrument Group	$ 328.7	$ 323.8	$ 311.5	$ 342.5	$ 371.0
Semiconductor Equipment Group	193.8	165.0	170.0	257.8	315.9
Data Systems Group	225.3	210.6	214.0	233.1	259.2
Optical Group	162.3	144.8	145.4	183.3	190.6
Bodenseewerk Geraetetechnik	111.5	111.7	107.0	100.3	96.0
Metco	100.9	86.7	78.1	81.4	88.2
Subtotal	$1,122.5	$1,042.6	$1,026.0	$1,198.4	$1,320.9
Intersegment	(6.7)	(5.8)	(10.6)	(16.1)	(16.3)
Total	$1,115.8	$1,036.8	$1,015.4	$1,182.3	$1,304.6
INCOME BEFORE TAXES					
Operating Profit					
Instrument Group	$ 49.2	$ 43.9	$ 32.8	$ 31.5	$ 46.3
Semiconductor Equipment Group	47.5	20.9	19.1	34.7	47.1
Data Systems Group	20.8	19.0	15.1	15.6	24.4
Optical Group	17.6	13.5	13.1	17.7	18.3
Bodenseewerk Geraetetechnik	11.7	12.5	13.8	14.7	15.0
Metco	19.4	11.2	7.9	9.4	8.9
Subtotal	$166.2	$121.0	$101.8	$123.6	$160.0
Intersegment	-	(0.2)	(0.2)	(0.7)	(1.1)
Total	$166.2	$120.8	$101.6	$122.9	$158.9
Interest Income (Expense) Net	(0.8)	4.1	3.4	0.3	(3.4)
General Corporate Expenses	(16.6)	(17.5)	(17.3)	(30.6)	(19.5)
	$148.8	$107.4	$87.7	$92.6	$136.0

Source: Perkin-Elmer, Annual Reports and Forms 10-K

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Table 2

SALES BY BUSINESS SEGMENT
UNAUDITED
(Millions of Dollars)

	6 Months Ending January 31	
	1985	1986
Instrument Group	$146.2*	$163.4
Semiconductor Equipment Group	146.2	121.7
Concurrent Computer Corporation	127.1**	132.2**
Optical Group	97.4	92.2
Materials and Surface Technology Group	63.4	70.4
Bodenseewerk Geraetetechnik	44.0	54.8
Subtotal	$624.3	$634.7
Intersegment	(9.7)**	(14.7)**
Total	$614.6	$620.0

*Restated to reflect the transfer of Physical Electronics Division from Materials and Surface Technology Group which was established in fiscal 1986. This group also reflects the previous reported results of Metco.
**Amounts for the first quarter have been restated to reflect the formation of Concurrent Computer Corporation on November 13, 1985.

Source: Perkin-Elmer, Second-Quarter and Six-Month Report

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Table 3

ORDERS BY BUSINESS SEGMENT
UNAUDITED
(Millions of Dollars)

	6 Months Ending January 31	
	1985	1986
Instrument Group	$157.6*	$170.5
Semiconductor Equipment Group	172.9	114.8
Concurrent Computer Corporation	137.8	144.9**
Optical Group	103.1	95.4
Materials and Surface Technology Group	63.4*	69.9
Bodenseewerk Geraetetechnik	40.6	25.4
Subtotal	$675.4	$620.9
Intersegment	(8.4)	(15.1)**
Total	$667.0	$605.8

*Restated to reflect the transfer of Physical Electronics Division from Materials and Surface Technology Group which was established in fiscal 1986. This group also reflects the previous reported results of Metco.
**Amounts for the first quarter have been restated to reflect the formation of Concurrent Computer Corporation on November 13, 1985.

Source: Perkin-Elmer, Second-Quarter and Six-Month Report

In fiscal 1985, the Group increased its capital spending to $20 million (see Table 4), an increase of 104 percent from 1984. Capital spending in 1985 was slightly over 6 percent of the Group's sales.

The Semiconductor Equipment Group offers a broad range of semiconductor equipment; especially equipment that serves the industry's most advanced technologies, such as submicron geometries. It also offers a full line of lithography products, including the MEBES III, an E-beam exposure system used in maskmaking. DATAQUEST estimates that Perkin-Elmer has shipped 95 MEBES systems from its introduction in 1977 through 1985, giving it the world's largest installed base of maskmaking equipment.

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The Perkin-Elmer Corporation

Table 4

SEMICONDUCTOR EQUIPMENT GROUP FINANCIAL DATA
FISCAL YEAR ENDING JULY 31
(Millions of Dollars)

	1981	1982	1983	1984	1985
Net Orders	$177.6	$125.1	$174.4	$310.2	$294.3
Net Sales	$193.8	$165.0	$170.0	$257.8	$315.9
Income before Taxes	$ 47.5	$ 20.9	$ 19.1	$ 34.7	$47.1
Capital Spending	$ 9.3	$ 8.2	$ 12.3	$ 9.8	$20.0

Source: Perkin-Elmer, Annual Reports and Forms 10-K

In the lithography field, the Company also manufacturers and markets the AEBLE 150, a direct-write E-beam system; the SRA 9000 stepper system; and the Micralign aligners.

The Micralign product line of projection mask aligners includes the Micralign 660 HT system, which is capable of processing six-inch wafers at a very high throughput of 120 wafers per hour.

The AEBLE 150, one of Perkin-Elmer's leading products in submicron lithography, can direct-write features on wafers of sizes down to one-half micron. AEBLE 150 is a commercial version of a prototype developed in conjunction with the Department of Defense's VHSIC program.

The Semiconductor Equipment Group believes that it is well positioned in plasma systems technology to offer submicron etching with its Omni-Etch 10000 and 20000 dry processing systems.

It has also added the Model 4480 to its sputter deposition systems, which, along with the Omni-Etch 20000, offer plasma processing of six-inch wafers at high throughput rates.

Average selling prices for the group's semiconductor equipment are shown in Table 5.

Table 5

AVERAGE SELLING PRICES
(Thousands of Dollars)

Product	Average Selling Price
AEBLE 150	$3,500
MEBES III	$2,700
MICRALIGN 600 (6" capability)	$ 800
OMNI-ETCH	$ 475
SRA 9000	$ 900

Source: DATAQUEST
April 1986

MATERIALS AND SURFACE TECHNOLOGY GROUP

The Materials and Surface Technology Group was formed in September 1985 from the slow-growing METCO (the world leader in thermal spray products) and the Physical Electronics Division of the Company's Instrument Group. The Company estimates the market for surface and materials technology to be $1 billion.

Both sales and orders for the six-month period ending January 31, 1986, were up from the period a year earlier; sales were up 11 percent to $70.4 million, and orders were up 10 percent (see Tables 2 & 3).

Products offered by the Materials Group to the semiconductor industry include a molecular beam epitaxy system (MBE) used in the fabrication of gallium arsenide wafers, sputtering equipment, CVD equipment, and auger microprobes.

INSTRUMENT GROUP

Perkin-Elmer is the world's largest manufacturer of chemical and materials research and analytical instruments. Its instruments are used in almost every type of industry, as well as in education and the government.

The Perkin-Elmer Corporation

The Instrument Group was a pioneer in the development of Computer Aided Chemistry. This is a major concept to computerize laboratories by integrating analytical instruments with computers through specially developed software. The group has recently introduced robotics systems.

The Instrument Group boasted of a 1985 growth in sales of 8 percent, to $371 million (see Table 1), and a growth in orders of 9 percent, to $391 million.

For the six months that ended January 31, 1986, the Instruments Group's orders were $170.5 million (see Table 3), up 8 percent from the same six-month period the previous year. Sales for the six months that ended January 31, 1986, were $163.4 million, up 12 percent from a year earlier.

Because of its focus on specific growth markets, and because of increased expenditures on research and development, the Company believes that the rest of 1986 will see continued growth.

In January 1986, the Company announced the formation of a partnership with Cetus Corporation to develop instrument systems and related reagents for use by industries engaged in biotechnology research and development. Perkin-Elmer will have a 51 percent ownership in the partnership.

In September of 1985, the Physical Electronic Division of the Instruments Group has been transferred to the newly formed Materials and Surface Technology Group.

CONCURRENT COMPUTER CORPORATION

Although it had been profitable in recent years, Perkin-Elmer's computer group did not receive the attention, recognition, and credibility that the Company believed it deserved from the financial community, the computer industry, and its own markets. Consequently, the Company formed tne Concurrent Computer Corporation in November 1985 from its Data Systems Group. Over the counter trading officially began on January 24, 1986. In March 1986, 82 percent of Concurrent was owned by Perkin-Elmer.

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OPTICAL GROUP

Perkin-Elmer's Optical Group is a leader in the production of advanced electro-optical systems and precision optics for use in a wide range of high-technology programs, such as space science, astronomy, remote sensing, laser defense, and atmospheric and hazardous gas monitoring.

The Optical Group recently finished building the Optical Telescope Assembly for NASA's Hubble Space Telescope. The Optical Group is now increasingly involved in military programs, including the Strategic Defense Initiative (SDI).

Fiscal 1985 sales increased by 4 percent, from $183 million in 1984 to $191 million in 1985 (see Table 1). Orders, however, declined 13 percent from $208 million to $182 million. For the six months that ended January 31, 1986, both orders and sales had declined from the same period a year earlier; orders had declined 7 percent, from $103.1 million to $95.4 million; sales had declined 5 percent, from $97.4 million to $92.2 million. The Company believes that these declines represented the completion of major portions of the Hubble Space Contract, and it had expected that contracts for SDI, Advanced Short-Range Air-to-Air Missiles (ASRAAM), and the Solar Optical Telescope (SOT) would take up the slack. However, in March 1986 the Group announced a 75-person layoff due to substantially reduced activity in the SOT program and reduced NASA business in general.

BODENSEEWERK GERAETETECHNIK (BGT)

BGT has an excellent reputation in Europe for its work in the development and production of avionic instrumentation and missile systems. It is known as a strong systems company for air-to-air missiles and has an excellent technological background in advanced seeker heads and in control and navigation systems. It participates in such programs as the Tornado multirole combat aircraft, the European Airbus commercial wide-body jet aircraft, the AIM 9L air-to-air missile and, most recently, the ASRAAM (Advanced Short Range Air-to-Air Missile).

Sales declined slightly for BGT in 1984 to $100 million (see Table 1), 6 percent less than the previous year. Orders, however, grew by 7 percent, to $120 million. For fiscal 1985, sales declined again, by 4 percent, to $96 million. Orders declined by 17 percent, to $100 million. Because of the strength of the West German mark, however, sales were up by 9 percent. For the six months ending January 31, 1986, the Group's sales increased 25 percent from the same six-month period a year earlier, to $54.8 million. At the same time, however, orders declined 60 percent, to $25.4 million.

Silicon Valley Group

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Silicon Valley Group

Silicon Valley Group, Inc.
541 East Trimble Road
San Jose, California 95131
Telephone: (408) 945-9300
(Thousands of Dollars Except Per Share Data)

Balance Sheet (September 30)

	1982	1983	1984	1985	1986
Current Assets	$ 5,887	$24,647	$30,882	$36,699	$38,678
Current Liabilities	$ 1,490	$ 2,674	$ 3,736	$ 3,938	$ 4,319
Current Ratio	3.95	9.22	8.27	9.32	8.96
Working Capital	$ 4,397	$21,973	$27,146	$32,761	$34,359
Long-Term Debt	$ 60	$ 234	$ 300	$ 364	$ 408
Debt/Equity	0.01	0.01	0.01	0.01	0.01
Shareholders' Equity	$ 4,620	$22,694	$28,429	$34,380	$37,385
After-Tax Return on Average Equity (%)	51%	22%	21%	18%	7%
Capital Expenditures	$ 126	$ 570	$ 824	$ 849	$ 1,914

Operating Performance (Fiscal Year Ending September 30)

	1982	1983	1984	1985	1986
Revenue	$12,095	$16,958	$30,463	$36,864	$27,842
Gross Margin	62%	62%	60%	59%	56%
Cost of Revenue	$ 4,595	$ 6,493	$12,039	$15,130	$12,378
R&D Expense	$ 1,061	$ 1,569	$ 2,906	$ 4,660	$ 4,686
R&D/Revenue	9%	9%	10%	13%	17%
SG&A Expense	$ 3,141	$ 4,148	$ 6,586	$ 7,946	$ 8,036
SG&A/Revenue	26%	24%	22%	22%	29%
Interest Income	$ 135	$ 926	$ 1,521	$ 1,695	$ 1,997
Pretax Income	$ 3,433	$ 5,674	$10,453	$10,823	$ 4,739
Pretax Margin (%)	28%	33%	34%	29%	17%
Effective Tax Rate (%)	45%	46%	48%	47%	44%
Provision for Income Taxes	$ 1,545	$ 2,611	$ 4,997	$ 5,090	$ 2,093
Net Income	$ 1,888	$ 3,063	$ 5,456	$ 5,733	$ 2,646
Average Shares Outstanding (Thousands)	3,392	4,014	4,360	4,382	4,438
Earnings per Share	$ 0.56	$ 0.76	$ 1.25	$ 1.31	$ 0.60
Dividends per Share	$ 0.00	$ 0.00	$ 0.00	$ 0.00	$ 0.00
Total Employees	128	188	317	297	268

Source: Silicon Valley Group Annual Reports and 10-K Reports
Dataquest
May 1987

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Silicon Valley Group

(Material in this section has been excerpted from the following sources: 1986 Silicon Valley Group, Inc., Annual Report, product literature, Prudential-Bache, and the business press. For more detailed information and opinions on Silicon Valley Group, Dataquest clients are invited to use their inquiry privileges.)

THE COMPANY

Background

Silicon Valley Group, Inc., (SVG) develops, manufactures, and markets automated wafer-handling and production-processing equipment primarily for the semiconductor industry. Typically referred to as wafer track equipment, SVG's various systems perform wafer clean, photoresist coat, and bake before the wafers are exposed during the photolithographic process. The Company also offers automated interface systems between its track equipment and photolithography equipment, including aligners and all major stepper products.

SVG has recently expanded into a new product area, offering a vertical thermal reactor for chemical vapor deposition (CVD). The Company's equipment also aids the manufacture of thin-film recording heads used in disk drives for the computer industry and the processing of silicon wafers into solar cells. Table 1 is a list of SVG's product line.

SVG has shown steadily increasing sales over the past five years. Revenue of $5.8 million in 1982 has increased at a cumulative annual growth rate (CAGR) of 60.1 percent to reach $38.7 million in 1986. The majority of revenue through 1986 can be attributed to track equipment.

Silicon Valley Group

Table 1

Silicon Valley Group
PRODUCT LINE

Product Family	Product Name	Date of Introduction	Features/ Description	Maximum Wafer Size
Automatic Photoresist Equipment	SVG-G8126PC		In-line system; coat	5 inches
	SVG-8128PD		In-line system; develop	5 inches
	SVG-8132CTD		In-line system; develop	5 inches
	SVG-8136HPO		In-line system; hot plate bake	5 inches
	SVG-8138VP		In-line; prime; hot plate bake	5 inches
	SVG-8120SSC		In-line; brush and jet scrub; single-sided	5 inches
	SVG-8818 DWC	1986	Double-sided wader cleaner; automated vertical handling	8 inches
	SVG-8620SSC		In-line; brush and jet scrub	6 inches
	SVG-8626PC		In-line; coat	6 inches
	SVG-8632CTD		In-line; develop	6 inches
	SVG-8636HPO		In-line; hot plate bake	6 inches
	SVG-8638VP		In-line; prime; hot plate bake	6 inches
	SVG-8640MHP	1986	In-line; hot plate bake; long bake times possible; programmable; vacuum wafer transfer; oven priority baking	6 inches
	SVG-8642SOG		Spin-on-glass coater; bowl wash feature	6 inches
Deposition	SVG-6000VTR	1986	Vertical thermal reacter; low-pressure CVD; automatic wafer	6 inches
	SVG-6301SN		Handling and loading; throughput 160 wafers per hour	
Edge Grinder	SVG-146		Grinds silicon and 666; contour edge including flat; rims and dry; fully automated; throughput 300 wafers per hour	5 inches
Wafer Inspection	SVG-8024WV System/80		12 inspection programs stored in memory; accommodates H-type and box-type cassettes; variable chuck rotation; six possible sort cassettes	5 inches
	Wafer Abrader SVG-16 WATH		N/A	
	SVG-2215 Index Station		N/A	

N/A = Not Available

Source: Silicon Valley Group Company Literature

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Silicon Valley Group

Operations

The 1986 downturn in the semiconductor production equipment industry moved the Company to strengthen its competitiveness through increased customer involvement. SVG is focusing its engineering efforts to adapt equipment to individual customer needs. A sizable share of its products shipped during fiscal 1986 was customized, and some modifications have been integrated into SVG's standard equipment. The Company has also expanded its international network of field representatives and increased process support.

SVG began a program of development for stepper interfaces during 1985, and during fiscal 1986 followed the effort through, developing and installing interfaces for all the major steppers and aligners.

The Company entered a new product area with the development of a vertical thermal reactor (VTR), targeting the CVD market. It also developed CVD application processes including silicon nitride and flat-temperature poly-silicon deposition. The Company has restructured, establishing the SVG Track Division to ensure that efforts in its more established product lines are not diluted.

The Company purchased Anicon, Inc., a major competitor in the CVD product segment, in January 1987. It is believed that Anicon can add important process technology to SVG's own deposition effort. Anicon has an installed base of over 120 systems whose major users include Seiko, Siemens, and Texas Instruments.

SVG confirmed that it had received a large order from Sandia Labs, the government-sponsored research facility in New Mexico, signaling early success for the VTR. Japanese interest was also reported to be high.

Strategy and International Competitiveness

SVG equipment is now operating in semiconductor production lines in more than twenty countries. Its products are sold through a worldwide network of sales offices, independent sales representatives, and distributor organizations. Service is provided by Company employees based in several countries. The Company is strengthening its international marketing and sales organization in order to service and support the growing base of equipment delivered worldwide.

The Company reported that 24 percent of its 1984 revenue was from exports. In 1986 this figure increased to 35 percent. Table 2 shows SVG's sales figures by region.

Silicon Valley Group

Table 2

ESTIMATED REGIONAL SALES
(Thousands of Dollars)

	1984	1985	1986
United States	$23,171	$25,874	$18,148
Export	7,292	10,990	9,694
Total	**$30,463**	**$36,864**	**$27,842**

(Percent of Total)

	1984	1985	1986
United States	76.1%	70.2%	65.2%
Export	23.9	29.8	34.8
Total	100.0%	100.0%	100.0%
Total	200.0%	200.0%	200.0%

Source: Silicon Valley Group,
1986 Annual Report
Dataquest
May 1987

SVG's share of the Japanese track market has traditionally been low, although the Company has done well in other Far Eastern markets. The Japanese track equipment market tends to be dominated by large local manufacturers, such as Dai Nippon Screen.

As mentioned above, Japanese interest in SVG's new VTR is high.

To expand its resources and representation in the Japanese market, SVG formed a wholly owned subsidiary in Japan, and formalized a distribution agreement with a Japanese representative.

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Silicon Valley Group

Research and Development

SVG has continuously expanded and improved its product line to remain competitive and to hold market share. The Company's track equipment offers a full range of automation, including diagnostics and cassette-to-cassette configurations for both standalone units and in-line systems.

In an effort started in 1975, SVG has been working with photolithographic equipment manufacturers to develop interfaces between SVG wafer track equipment and wafer steppers. It has also developed and shipped interfaces for all the major steppers and aligners, as well as an etcher interface.

As mentioned previously, the Company has developed not only a VTR, but also process designs, including silicon nitride and flat-temperature polysilicon deposition.

Research and development as a percentage of revenue has steadily risen from 10 percent in FY 1984 to 17 percent in FY 1986.

Company Management

SVG's President is Papken Der Totsian. Other officers include Senior Vice President of Marketing, Kenn Giles; Vice President of Finance, Tony Muller; Manager of Purchasing, Will Starek; Vice President of Manufacturing, Arthur Silver; and Vice President of Technology, Johan Tam.

Solitec, Inc.

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Solitec, Inc.

Solitec, Inc., and Subsidiary Companies
1715 Wyatt Drive
Santa Clara, California 95054
Telephone: (408) 980-1355 Telex: 371-7520
(Thousands of Dollars except Per Share Data)

Balance Sheet (September 30)	1984	1985	1986	Q1 87	Q2 87
Current Assets:					
Cash and Cash Equivalents	N/A	$1,799	$ 463	$ 470	$ 404
Restricted Cash Collateralized for Certain Short-Term Indebtedness	N/A	0	$ 2,500	$ 2,500	$ 2,147
Accounts Receivable (Net of Allowance for Doubtful Accounts of $218 in 1986 and $57 in 1985)	N/A	$1,212	$ 2,780	$ 3,571	$ 2,165
Refundable Income Taxes	N/A	$ 203	$ 576	$ 786	$ 141
Inventories	N/A	$1,216	$ 2,467	$ 1,992	$ 1,930
Prepaid Expenses	N/A	$ 54	$ 32	$ 18	$ 19
Total Current Assets	N/A	$4,484	$ 8,818	$ 9,337	$ 6,806
Property and Equipment, Net	N/A	$ 564	$ 1,505	$ 1,294	$ 1,113
Investment in Affiliate	N/A	$ 10	$ 574	$ 601	$ 319
Cost in Excess of Net Assets of Acquired Businesses, Net	N/A	$2,498	$ 3,075	$ 3,151	$ 3,131
Other Assets, Principally Intangible Assets	N/A	$1,082	$ 165	$ 156	$ 363
	N/A	$8,638	$14,137	$14,539	$11,732
Liabilities and Shareholders' Equity					
Current Liabilities:					
Notes Payable	N/A	N/A	N/A	$ 3,658	N/A
Banks	N/A	N/A	$ 2,875	N/A	$ 2,848
Other	N/A	0	$ 356	N/A	N/A
Accounts Payable	N/A	$ 211	$ 2,041	$ 1,506	$ 1,183
Accrued Liabilities	N/A	$ 567	$ 1,517	$ 1,435	$ 949
Contract Advance Payment	N/A	$ 0	$ 2,721	$ 2,792	$ 2,147
Income Taxes Payable	N/A	N/A	N/A	$ 328	$ 224
Long-Term Debt Due within One Year	N/A	$ 147	$ 644	$ 613	$ 892
Total Current Liabilities	N/A	$ 925	$10,154	$10,332	$ 8,243
Long-Term Debt Due after One Year	N/A	$1,889	$ 3,768	$ 3,826	$3,314
Deferred Income Taxes	N/A	N/A	N/A	N/A	$ 298

(Continued)

Solitec, Inc.

Solitec, Inc., and Subsidiary Companies
1715 Wyatt Drive
Santa Clara, California 95054
Telephone: (408) 980-1355 Telex: 371-7520
(Thousands of Dollars except Per Share Data)
(Continued)

Balance Sheet (September 30)	1984	1985	1986	Q1 87	Q2 87
Shareholders' Equity					
Common Stock	N/A	$4,021	$ 4,897	$ 5,397	$ 5,397
Notes Receivable from Officer	N/A	N/A	N/A	($ 500)	($ 500)
Retained Earnings (Deficit)	N/A	$1,803	($ 4,682)	($ 4,516)	($ 4,500)
Total Shareholders' Equity	N/A	$5,824	$ 215	$ 381	$ 397
Total Liabilities and Shareholders' Equity	N/A	$8,638	$14,137	$14,539	$12,252
Working Capital	N/A	$3,559	($ 1,336)	($ 995)	($ 1,437)
After-Tax Return on Average Equity (%)	N/A	4	(3,016)	N/A	N/A
Operating Performance (Fiscal Year Ending September 30)					
Revenue	$4,202	$7,457	$13,237	$ 4,540	$ 2,283
Cost of Revenue	$1,338	$3,600	$ 9,079	$ 2,651	$ 1,499
R&D Expense	$ 408	$ 880	$ 1,542	$ 235	$ 113
G&A Expense	$ 976	$2,403	$ 5,078	$ 1,347	$ 864
Other Expense (Income)	($ 188)	$ 31	($ 192)	$ 20	($ 35)
Writeoff of Intangible Assets	N/A	N/A	$ 5,005	N/A	N/A
Pretax Income	$1,668	$ 543	($ 7,275)	$ 287	($ 158)
Gross Margin (%)	68	52	31	42	34
Pretax Margin (%)	40	7	(55)	6	(7)
R&D/Revenue (%)	10	12	12	5	5
Income Taxes (Credits)	$ 796	$ 289	($ 790)	$ 168	($ 46)
Net Income before Extraordinary Items	$ 872	$ 254	($ 6,485)	$ 119	($ 112)
Income Tax Reduction from Utilization of Loss Carry Forwards	N/A	N/A	N/A	($ 47)	$ 51
Gain on Debt Restructuring					$ 77
Net Income (Loss)	$ 872	$ 254	($ 6,485)	$ 72	$ 16
Common Shares Outstanding	1,957	2,309	2,680	3,004	3,177
Per Share					
Earnings	$ 0.45	$ 0.11	($ 2.42)	$ 0.04	($ 0.04)
Book Value	N/A	$ 2.52	$ 0.08	$ 0.13	$ 0.12

N/A = Not Available

Source: Solitec Annual Report and Forms 10-Q
Dataquest
June 1987

Solitec, Inc.

THE COMPANY

Background

Solitec, Inc., (formerly Reid-Ashman, Inc.) was formed in January 1980. The Company's initial products were proprietary accessories to assist in the testing of semiconductor IC testers. Solitec completed its initial public offering in January 1984. In 1985, the Company began an aggressive diversification program and has since divested itself of its original tester accessory business. In December 1985, Prudential Bache funded Solitec with $5.3 million for R&D.

Solitec does business under four names in four separate semiconductor markets, as shown in Table 1.

Table 1

SOLITEC'S PRODUCT LINES

Brand Name	Markets
Advanced Crystal Sciences	CVD, diffusion furnaces
Hybrid Technology Group (HTG)	Mask aligners, DUV exposures equipment
Solitec	Track equipment
Advent Systems	Quartz cleaning equipment

Source: Solitec Company Literature
Dataquest
June 1987

Solitec owns about 35 percent of DSP Technology, Inc., of Fremont, California. DSP is a electronic instrumentation manufacturer with revenue of about $5.5 million. (This revenue is not included in the Solitec financial statement.) DSP also markets burn-in systems for the semiconductor industry under the brand name Life Test Systems.

Solitec also owns approximately 86 percent of Laser Dynamics, Inc. Laser Dynamics is seeking to develop a new family of data storage products that, through proprietary techniques, will allow mass storage peripherals to operate at substantially greater speeds.

A history of the Company's acquisitions is shown in Table 2.

Table 2

SOLITEC'S ACQUISITIONS

Date	Company Acquired
January 1985	Solitec, Inc.
October 1985	Rome-Union Corp. Paolo S. DiCicco, Inc. dba Advent Systems
March 28, 1986	Hybrid Technology Group, Inc.
April 28, 1986	Advanced Crystal Sciences, Inc.

Source: Reid-Ashman, Inc., Forms 10-K

Operations

Due to significant losses in 1986 and to market uncertainties, Solitec elected to write off a significant amount of the good will that accompanied its 1985 and 1986 acquisitions. A loss of $6.5 million after provision for an income tax credit of $790,000 was recorded for 1986, $5.0 million of which was the result of its write-off of intangible assets, including good will. During 1986, the Company believes that it made significant progress in consolidating the operations of the acquired companies, even though losses were still reported in each quarter of fiscal 1986. The Company reports, however, that it was able to lower its break-even point to $4.2 million per quarter.

In 1985 and 1986, net sales increased 77 percent and 78 percent, respectively. The Company reports that these increases were due entirely to the inclusion of sales from the companies it acquired during those years.

Cost of sales in 1986 increased to 69 percent of net sales, from 48 percent in 1985 and 32 percent in 1984. The increased cost of sales, the Company believes, was a result of sharply lower sales without a corresponding reduction in fixed cost of the acquired companies, a shift in the sales mix to lower-margin products, and higher sales discounts.

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Marketing, general, and administrative expenses increased from 23 percent of net sales in 1984 to 32 percent in 1985 and 38 percent in 1986. The Company attributes this rise in expenses to sales decline and constant fixed-overhead expenses.

In 1986, Solitec received a qualified auditor's opinion stating, among other things, that "the Company's continuation as a going concern is dependent upon achieving and maintaining profitable results of operations and maintaining adequate sources of financing." The Company points out the opinion says "maintain" adequate financing, not "obtain" adequate financing.

The Company reports that it achieved a profit in Q1 and Q2, ending in December 1986 and March 1987.

Strategy

Solitec's corporate objective is to supply process, not equipment; the Company believes that equipment is only a means to deliver the process. Solitec has identified photolithography and CVD as its two main areas of process strength.

Its goal in photolithography processing is to have the most advanced track systems in the market. Solitec's strategy for its aligners, formerly manufactured under the HTG name, is to target the low end of the market. Its target markets for aligners are university R&D centers, Korea, and the People's Republic of China.

In CVD, its strategy is to extend the life of the horizontal tube by delivering uniformities of plus or minus 3 percent from run to run.

Solitec's ultimate goal is to merge track and CVD technology.

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R&D

Solitec-sponsored R&D expenses are shown in Table 3.

Table 3

R&D EXPENSES
(Thousands of Dollars)

Year	Amount	Percent of Sales
1984	$ 408	10%
1985	$ 880	12%
1986	$1,542	12%

Source: Solitec, Forms 10-K

In December 1985, Solitec entered into an agreement with PruTech under which the Company is developing new semiconductor products in the areas of photolithography and CVD equipment. Under the contract, Solitec will receive $5.3 million.

In addition to providing the most advanced photolithographic track systems on the market with these R&D funds, Solitec hopes to extend the life of the horizontal diffusion/deposition tube and ultimately, Solitec wants to merge track and CVD technology.

Solitec is looking forward to meaningful results in 1987 from its product development efforts at its Laser Dynamics subsidiary.

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Solitec, Inc.

PRODUCTS

Table 4 lists the products that Solitec currently markets.

Table 4

LIST OF PRODUCTS

Product Type	Name	Description	Year Introduced
Track	820	Coat/bake with Auto-Coat	1987
	820	Develop/bake with Optimist (positive resist)	1987
	820	Negative developer	1983
	820	Positive developer (pressurized)	1984
	820	Scrubber	1984
	820	Hot plate bake	1986
	840	Vapor prime/cost/bake	1984
	840	Post exposure bake/develop	1986
Manual Spinners	5000 Series	Coat, develop (positive & negative, scrub, jet clean)	1970s
	3000 Series	E-Beam mask developer	1980
	7000 Series	Large substrate coat, develop, scrub, jet clean	1984
Contact/ Proximity Aligners	3A	Mask aligner (hybrids)	1980-1985
	3HR	Mask aligner (high resolution)	1980-1985
	3HRIR	Infalign (IR high resolution)	1980-1985
UV/DUV Exposure Systems	System 5 Series	Flood exposure systems	1984
		crosslink 5000 stabilization UV/DUV light sources	1985

Source: Solitec Product Literature

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Regional Sales History

Solitec's sales by region are given in Table 5.

Table 5

REGIONAL SALES FOR CVD AND TRACK EQUIPMENT
(Millions of Dollars)

	1981	1982	1983	1984	1985	1986
North America	$1.5	$6.8	$10.6	$13.5	$15.7	$10.6
Europe	0	0.5	0.6	0.8	1.5	0.8
ROW	0	0.1	0.2	0.2	0.7	0.7
Total	$1.5	$7.4	$11.4	$14.5	$17.9	$12.1

Source: Dataquest
June 1987

Sales History by Product

Solitec's sales by product line are given in Table 6.

Table 6

SALES BY PRODUCT LINE--TRACK, CVD, AND DIFFUSION
(Millions of Dollars)

	1981	1982	1983	1984	1985	1986
Track	$1.5	$1.5	$ 2.7	$ 4.5	$ 5.0	$ 6.5
CVD	0	5.5	8.1	9.4	12.9	5.3
Diffusion	0	0.4	0.6	0.6	0	0.3
Total	$1.5	$7.4	$11.4	$14.5	$17.9	$12.1

Source: Dataquest
June 1987

Solitec, Inc.

EXECUTIVE MANAGEMENT

Solitec's chairman, director, and president is Joseph J. McDowell. Mr. McDowell is one of the founders of Monolithic Memories. He was formerly chairman, president, chief executive officer, and chief financial officer of E-H International, a manufacturer of automated test equipment; and general manager of the Microprocessor and Memory Division of American Microsystems, Inc. Mr. McDowell has been with Solitec since 1983.

J. Scott Kamsler is Solitec's vice president and chief financial officer. He was formerly vice president and chief financial officer of E-H International. Prior to that, Mr. Kamsler held various financial positions at Intel Corporation. Mr. Kamsler has been with Solitec since 1984.

Victor Monia is a director at Solitec. He is also a cofounder and vice president of Visa Technologies, Inc., a company that develops and markets polyethylene-coated packaging materials. Mr. Monia has been with Solitec since 1983.

John Sullivan, a director at Solitec, was previously vice president of finance at Interdyne Company, a manufacturer of electromechanical magnetic tape products. Prior to Interdyne, he served as vice president of finance at Standard Engineering Corporation. Mr. Sullivan has been with Solitec since 1983.

Varian Associates

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Varian Associates

Varian Associates
611 Hansen Way
P.O. Box 10800
Palo Alto, California 94303
Telephone: (415) 493-4000 Telex: 348746
(Millions of Dollars Except Per Share Data)

Balance Sheet (September 28)

	1980	1981	1982	1983	1984	1985
Current Assets	$393.8	$ 362.7	$379.1	$446.0	$514.3	$473.8
Current Liabilities	$188.8	$ 177.4	$161.9	$182.4	$231.3	$247.1
Current Ratio	2.09	2.04	2.34	2.45	2.22	1.92
Working Capital	$205.0	$ 185.3	$217.2	$263.6	$283.0	$226.7
Long-Term Debt	$114.4	$ 109.8	$ 76.4	$ 42.3	$ 43.0	$ 46.2
Debt/Equity (%)	59	57	28	12	10	11
Shareholders' Equity	$195.2	$ 192.1	$274.7	$362.5	$426.9	$429.2
After-Tax Return on Average Equity (%)	0.03	(1.86)	11.35	14.09	15.17	6.10
Capital Expenditures	$ 33.0	$ 39.0	$ 30.0	$ 34.0	$ 61.0	$ 94.0

Operating Performance (Fiscal Year Ending September 28)

	1980	1981	1982	1983	1984	1985
Revenue	$554.3	$ 638.4	$691.2	$755.9	$927.8	$972.5
Gross Revenue (%)	27	31	33	35	36	31
Cost of Revenue	$406.4	$ 438.9	$460.6	$493.7	$595.8	$669.5
R&D Expense	$ 40.3	$ 38.6	$ 41.3	$ 47.5	$ 59.1	$ 73.3
R&D/Rev (%)	7	6	6	6	6	8
GA&S Expense	$ 42.0	$ 123.3	$136.1	$141.5	$160.1	$172.4
G&A/Rev (%)	8	19	20	19	17	18
Other Expense (Income)	$ 31.8	$ 38.7	$ 12.3	($ 4.5)	($ 4.1)	$ 0.6
Pretax Income	$ 33.8	($ 1.1)	$ 40.8	$ 77.7	$116.9	$ 56.8
Pretax Margin (%)	6.10	(0.17)	5.91	10.28	12.60	5.84
Effective Tax Rate (%)	34.62	(227.27)	35.11	42.46	48.77	54.03
Net Income	$ 22.1	($ 3.6)	$ 26.5	$ 44.9	$ 59.9	$ 26.1
Average Shares Outstanding (Millions)	15.60	16.00	19.50	21.40	21.80	21.30
Per Share Earnings	$ 1.3	($ 0.2)	$ 1.3	$ 2.1	$ 2.7	$ 1.2
Total Employees	12,900	12,800	12,600	13,600	15,900	13,600

Source: Varian Associates 1985 Annual Report and Form 10-K

Varian Associates

FINANCIAL SUMMARY
TOTAL COMPANY
FIRST NINE MONTHS ENDED JULY 4, 1985 AND 1986
(Millions of Dollars)

	1985	1986	Percent Change
Orders	$ 700	$ 664	(5.2%)
Sales	$ 733	$ 676	(7.8%)
Backlog	$ 590	$ 593	0.6%
Net Income	$15.1	($ 3.5)	
Net Per Share	$0.68	($0.24)	

Source: Varian Associates
Quarterly Financial Data

Varian Associates

THE COMPANY

Background

Varian Associates, founded 37 years ago, engages in the research, development, manufacture, and marketing of various products and services for the fields of communications, defense, industrial production, scientific and industrial research, and health care. Varian's principal lines of business are electron devices, analytical instruments, semiconductor equipment, and medical and industrial products.

Fiscal 1985 was a difficult and disappointing year for Varian, as financial performance fell well below expectations. A combination of internal and external factors were responsible for the lower results. Internally, Varian suffered from high costs and delays in product development and abnormally high manufacturing start-up costs in the Electron Device Group. Externally, the sharp decline in the semiconductor industry and slowdown in computer markets had a heavy impact on Varian's related businesses. The strength of the U.S. dollar through most of 1985 also had a depressing effect on Varian's results. Thus, during fiscal 1985, Varian's sales increased only 4.8 percent over the previous year, as compared to sales growth of 22 percent for 1984 over 1983. Gross profit as a percent of sales was 5.8 percent in fiscal 1985, down from 12.5 percent in fiscal 1984 and 10.2 percent in fiscal 1983.

Reorganization and Cost Reduction

During the second quarter of 1985, Varian discontinued operations of its Lithography Products Division. This action was taken to refocus Varian's resources on its strengths, which the Company believes are in sputter deposition systems and ion implantation. The action resulted in charges of $13.7 million or $0.62 per share in 1985, $9.8 million or $0.44 per share in 1984, and $2.8 million or $0.14 per share in 1983.

Another aspect of its refocusing program was the acquisition of Torrex, a young company that designs chemical vapor deposition (CVD) systems. This acquisition has produced two CVD systems and will allow for research and development of metal and insulator deposition systems for the next generation of semiconductor devices.

As part of its refocusing program, Varian has also sold its interest in Anelva, its Japanese affiliate.

At the beginning of 1985, a program that eliminated nearly 3,000 positions from Varian's 16,000-person work force by June 1986 was implemented. These reductions were achieved through a combination of attrition, job eliminations, and selective layoffs.

Varian Associates

During July 1986, Thomas D. Sege resumed operating control of Varian with the resignation of President Jerome J. Meyer. Mr. Sege has implemented another work force and cost reduction plan that left Varian with a little more than 12,000 employees at the end of September 1986. Other cost saving moves included a hiring freeze, voluntary salary cuts for approximately 57 top level executives, sharp reductions in the use of consultants and overtime, trimming down on travel, and temporary shutdowns at facilities where conditions permitted them. The Company expects these actions to reduce Varian's annual costs by $20 million to $30 million.

The Semiconductor Equipment Group (SEG) was reorganized during December 1986 to form a new Varian Fremont division. This division was created by combining the Zylin plasma etch division and the Torrex chemical vapor deposition unit. Steve Jensen, named general manager of the new Fremont division, reports directly to Tony Jurvenson, SEG vice president of operations.

Current Financial Information

Sales for the first nine months of fiscal 1986 were down 7.8 percent from the same period in fiscal 1985 to $676 million. Year-to-date orders of $664 million dropped 5.2 percent from the $700 million level of the prior year. The order backlog of $593 million was $3 million higher than at the same point in 1985. For the first nine months of fiscal 1986 Varian had a net loss from continuing operations of $3.5 million, or $0.24 per share. During the first nine months of fiscal 1985 the Company produced a net income of $15 million, or $0.68 per share.

For the third quarter of 1986, Varian posted a loss of $5.2 million. Chairman Thomas D. Sege attributed the loss to a combination of factors, primarily continuing losses in the semiconductor equipment area and lower-than-anticipated profit performances by the Electron Device and Instrument Groups. Two corporate manufacturing feeder plants, one of which is now being shut down, also incurred higher-than-planned expenses.

Operations

The Electron Device Group is the leading manufacturer of microwave, power, and special-purpose electron tubes. It also produces solid-state microwave devices and components, and integrated subsystems. More than half of its sales are for defense applications, including electronic countermeasures, radar, and missile guidance. About one-third of its sales are for communications applications, including radio and television broadcasting and satellite communications. The group also serves the industrial and medical markets, with its X-ray generation and imaging techniques. Replacements and spares represent more than one-half of the group's tube sales volume.

The Instrument Group manufactures, sells, and services a wide variety of analytical instruments that analyze the chemical structure and composition of substances and the concentration of material in a sample. Products include liquid and gas chromatographs, spectrometers, and spectrophotometers. Major markets served are petrochemical, environmental, pharmaceutical, and life science in industry, government, and academic laboratories. Typical applications include traditional chemical analyses, biochemical research, industrial hygiene, and process information for increased energy efficiency and quality control. Large and growing markets for the Company's analytical instruments are the development of standards for the presence of dangerous chemicals, the monitoring and controlling of these substances, and the field of genetic research.

The SEG manufactures process equipment used to make semiconductor devices. The group's two most important product lines are ion implantation and sputter deposition systems. The Company is a leader in the development, manufacture, and application of equipment that performs ion implantation and sputter coating in semiconductor wafer processing. Varian's new equipment places heavy emphasis on microprocessor control and automation. The group also produces high-purity metals for thin-film coating (sputtering and evaporation) of materials in a vacuum deposition process.

The Medical and Industrial Products Group manufactures linear accelerators, vacuum equipment and supplies, and electrical components. Its linear accelerators are used in cancer therapy and for industrial radiographic applications. The Company's leading CLINAC series of accelerators, marketed to hospitals and clinics worldwide, generate therapeutic X rays and electron beams for cancer treatment. LINATRON linear accelerators are used in industrial applications for X-ray examinations of heavy metallic structures for quality control. The vacuum equipment is used to produce, contain, measure, and control a vacuum environment for industrial and scientific purposes. The group's electrical components are low-priced devices used primarily in the telecommunications and computer industries.

International Operations

In fiscal 1985, international sales accounted for 22 percent of Varian's total sales. To increase its overseas competitiveness, Varian is expanding its purchases from overseas vendors and increasing the output of its offshore production facilities.

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Marketing

Varian markets its products throughout most of the world, with 65 field sales offices in the United States and 35 offices in other countries. In general, the Company's markets are quite competitive, characterized by the application of advanced technology and by the development of new products and applications.

Research and Development

In 1982 Varian formed its Office of Technology to focus its technological strength. It has substantially increased the level of investment in both product and manufacturing technology. Using CAE, CAD, and CAM, Varian is aiming at long-term cost reductions through the automation of labor-intensive manufacturing processes.

During 1985, Varian and Nippon Telegraph and Telephone Corporation (NTT) signed an agreement to cooperate in the development of new sputtering systems for planarization processes. These processes will be used for deposition of aluminum thin films on silicon wafers. Under the agreement between Varian and NTT, work in both countries will further develop and refine the processes. Varian will incorporate the findings from both parties' efforts into its sputtering systems.

An active research and development program develops new products such as the gyrotron, which generates very high power and is now used in fusion energy research, and gallium arsenide (GaAs), which is used in the design and manufacture of monolithic microwave integrated circuits (MMICs) and many other new devices now being deployed.

During 1985, Varian's capital spending was $94.1 million, up from the $60.6 million 1984 figure. Its 1985 R&D spending was $73.3 million, up 24 percent from 1984. The Company expects 1986 R&D to show 24 percent growth over 1985. Varian's future research activities will include gallium arsenide technology with emphasis on materials, discrete devices, and integrated circuits.

SEMICONDUCTOR EQUIPMENT GROUP (SEG)

Orders, sales, and backlog for the SEG were all down to approximately one-half or less for the first nine months of fiscal 1986 as compared to 1985. Sales dropped from $171 million to $82 million for the first nine months of 1985 and 1986. Orders dropped from $140 million to $67 million for the same time period. The SEG backlog for the third quarter of 1986 is down to $42 million from $79 million a year ago.

Mr. Sege said the weak market and high research and development expenses associated with a record number of new products led to a substantial loss for the group. He said the group should return to profitability well before the end of 1987.

Financial information is given in Tables 1 through 5.

Table 1

FINANCIAL SUMMARY
SEMICONDUCTOR EQUIPMENT GROUP
FIRST NINE MONTHS ENDED JULY 4, 1985 AND 1986

	1985	1986	Percent Change
Orders	$140	$67	(52.0%)
Sales	$171	$82	(52.0%)
Backlog	$ 79	$42	(47.2%)

Table 2

FINANCIAL SUMMARY
ELECTRON DEVICE GROUP
FIRST NINE MONTHS ENDED JULY 4, 1985 AND 1986

	1985	1986	Percent Change
Orders	$299	$292	(2.3%)
Sales	$294	$313	6.4%
Backlog	$372	$376	1.2%

Source: Varian Associates
Quarterly Financial Data

Table 3

FINANCIAL SUMMARY
INSTRUMENT GROUP
FIRST NINE MONTHS ENDED JULY 4, 1985 AND 1986

	1985	1986	Percent Change
Orders	$123	$131	6.4%
Sales	$117	$126	7.7%
Backlog	$ 37	$ 45	21.5%

Table 4

FINANCIAL SUMMARY
MEDICAL AND INDUSTRIAL PRODUCTS GROUP
FIRST NINE MONTHS ENDED JULY 4, 1985 AND 1986

	1985	1986	Percent Change
Orders	$150	$181	20.8%
Sales	$162	$164	1.0%
Backlog	$109	$132	21.3%

Source: Varian Associates
Quarterly Financial Data

Table 5

SEMICONDUCTOR EQUIPMENT GROUP
FINANCIAL SUMMARY
(Millions of Dollars)

	1983	1984	1985
Orders	$144	$238	$160
Sales	$113	$189	$212
Pretax Operating Profit	$ 13	$ 37	$ 23
As % of Sales	12%	20%	11%
Backlog	$ 60	$113	$ 57
Capital Expenditures	$ 2	$ 5	$ 18

Source: Varian Associates
1985 Annual Report

The SEG has four separate operational divisions: the Extrion Division located in Gloucester, Woburn, and New Bedford, Massachusetts; the Thin Film Division in Palo Alto, California; the Varian Fremont Division in Fremont, California; and the Specialty Metals Division in Grove City, Ohio. The Extrion Division's principal products are ion implantation equipment and rapid thermal processing equipment. The Thin Film Technology Division's principal products are sputtering systems and molecular beam epitaxy (MBE) systems. Those of the Varian Fremont Division are plasma etching equipment and CVD equipment.

New Product Introductions

During 1986, Varian continued its strong R&D commitment with a $30 million R&D investment within the SEG. High investment levels during 1985 and 1986 resulted in the unveiling of nine new systems by Varian at SEMICON/West 1986. Varian's 1986 equipment introductions are summarized below.

With the acquisition of Torrex, now part of the Varian Fremont Division, Varian introduced two new automated CVD systems, Models 5101 and 5150. These were the first systems to offer cassette-to-cassette handling of wafers up to 8 inches in diameter. The two new systems also feature computer control and self-cleaning. Model 5101 is a cold-wall design that performs both thermal and plasma-enhanced processing. Model 5150 is a hot-wall system for depositing films such as low-temperature oxides, nitrides, and polysilicon. The 5150 has a vertical configuration that saves space in the clean room.

Zylin, also part of the Varian Fremont division, has developed the Model 100 plasma etch system. This system can be equipped with up to five work chambers for multistep processes and parallel processing of individual wafers. The machine handles wafers from 3 to 8 inches in diameter and features an advanced automatic control system that is compatible with robotic cassette systems. It is housed in a stainless steel cabinet.

Model 3290 is Varian's fourth generation of the 3180 sputtering system. The 3290 is a cassette-to-cassette, vertical, single-wafer processing system. It is designed to handle 5- or 6-inch wafers at a throughput of 45 wafers per hour. Now equipped with three targets, the 3290 allows for 50 percent more uptime between target changes. ViaFil, a new processing technique that has been developed for the 3290, produces planarized aluminum silicon films for the enhanced step coverage needed for the production of submicron, complex devices.

The Model XM-8 sputtering system, which is based on the recently acquired GARTEK system, is designed primarily for gallium arsenide processing and backside metalization. The system is capable of sequential deposition of up to four materials with no cross-talk. It features a gentle wafer-handling system especially designed for deposition on fragile materials such as gallium arsenide or backlapped substrates.

The new RTP 8000 is a fully automated rapid thermal-processing system for wafers up to 8 inches in diameter. It has an operating range from 400 to 1,400 C with high-temperature uniformity. The system's cassette-to-cassette wafer-handling system, which has two robotic arms, processes 300 wafers per hour. This system is also available as a semiautomatic model, the RTP 800. Both systems offer significant advantages over diffusion furnaces for annealing implants of dopants, forming silicides, regrowing polysilicon, and rapid oxidation of silicon.

Varian has recently introduced four new Rapid Thermal Processing systems: Models 200 III-V, 400 XP, 160 XP, and 300 XP. These systems were designed for processing megabit devices, gallium arsenide, and advanced materials.

Models 200 III-V and 400 XP handle low- and high-energy implants, respectively. Both models can be used for production and research work with gallium arsenide.

For high dose applications, Model 160 XP is a high-current batch processing machine with flexible dual chambers. It is designed to handle wafers up to 8 inches. In the medium-current area, Model 300 XP offers the highest dose uniformity and reproduction across a broad operating range.

A modular design MBE system is now available along with the Model 360 GEN II for gallium arsenide work. The new modular system has increased throughput and can be expanded to meet changing needs.

ELECTRON DEVICE GROUP

Sales for this group rose 6.4 percent for the first nine months of fiscal 1986, to $313 million as compared to $294 million for the same period in 1985. Orders and backlog had almost no change at $292 million and $376 million, respectively. Year-to-date operating margins improved over 1985, but weak demand in some markets held the gains below what was anticipated.

Financial information is given in Tables 2 through 6.

Thomas D. Sege, Varian's chairman, said the third-quarter orders were disappointing. He also anticipates the fourth-quarter order levels to be significantly higher due to the traditional pickup in government buying toward the end of the fiscal year. He noted that stronger demand for the group's equipment and gallium arsenide-based night-vision and solid-state products should contribute to the improvement.

Table 6

ELECTRON DEVICE GROUP
FINANCIAL SUMMARY
(Millions of Dollars)

	1983	1984	1985
Orders	$401	$434	$425
Sales	$364	$403	$395
Pretax Operating Profit	$ 59	$ 59	$ 25
As % of Sales	16%	15%	6%
Backlog	$304	$331	$397
Capital Expenditures	$ 20	$ 31	$ 25

Source: Varian Associates
1985 Annual Report

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INSTRUMENT GROUP

Sales for the nine months of 1986 were ahead of 1985 by 7.7 percent to $126 million. Orders for the same period were up 6.4 percent to $131 million while backlog jumped 21.5 percent to $45 million. Mr. Sege said the group's progress in improving margins was interrupted by high costs associated with the introduction of new nuclear magnetic resonance products. As a result, the group had a small loss for the third quarter.

Financial information is given in Tables 3 through 7.

Table 7

INSTRUMENT GROUP
FINANCIAL SUMMARY
(Millions of Dollars)

	1983	1984	1985
Orders	$133	$147	$169
Sales	$124	$145	$159
Pretax Operating Profit	$ 3	$ 7	$ 5
As % of Sales	2%	5%	$ 3%
Backlog	$ 29	$ 31	$ 42
Capital Expenditures	$ 6	$ 3	$ 4

Source: Varian Associates 1985 Annual Report

MEDICAL AND INDUSTRIAL PRODUCTS GROUP

Nine-month sales for the group were nearly flat at $164 million. Orders, however, leaped 21.8 percent to $181 million, and backlog leaped 21.3 percent to $132 million. Year-to-date orders, sales, and earnings for Varian's cancer therapy equipment were very strong. The industrial sector of the group, however, was much weaker.

Financial information is given in Tables 4 through 8.

Table 8

MEDICAL AND INDUSTRIAL PRODUCTS GROUP
FINANCIAL SUMMARY
(Millions of Dollars)

	1983	1984	1985
Orders	$182	$249	$213
Sales	$159	$209	$219
Pretax Operating Profit	$ 13	$ 28	$ 15
As % of Sales	8%	13%	7%
Backlog	$ 82	$122	$115
Capital Expenditures	$ 3	$ 8	$ 10

Source: Varian Associates
1985 Annual Report

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Dataquest ALERT

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Wafer Fab Equipment Forecast—Putting Recent Events into Perspective: a "Square U" or a "V"?

Dataquest is currently in the process of updating the wafer fab equipment forecast, due to be released in the first week of January. Recent positive events in the market include the semiconductor book-to-bill exceeding 1.0, Intel's current stronger business outlook, Applied Material's optimistic earnings conference call, and their news release of a $117 million order from Hyundai. Also released this past week was the equipment book-to-bill at 0.75 with monthly bookings continuing a downward trend.

The popular question is — have we hit bottom in the equipment market, or when will we? But we believe the most pertinent question is — what is the nature and speed of the recovery? We feel it is important to share with our clients our current thinking in this uncertain market.

One thing is true: current sentiment is polarized. Depending on who you talk with, either we have bottomed and in a recovery is in progress in equipment, or the bottom is ahead of us and the sluggish market conditions could extend into 1998. So now we will analyze what the "shape" of the recovery will look like.

Summary of Event Details

First, the recent semiconductor book-to-bill exceeded unity in October for the first time this year as the market for PCs remain strong and as suppliers gear up for the holiday season. Spot prices of DRAM ticked up slightly, but have since settled back down as suppliers quickly responded with inventory releases of packaged products and die inventory in wafer form.

Second, Intel recently made positive comments about fourth quarter demand for MPUs and have recently increased spending plans for 1997. In mid-year, we were estimating Intel would spend $3.9 billion for production capacity in 1996. This figure has since been reduced to $3.4 billion and we now estimate they will spend over $4 billion in 1997.

Third, Applied Materials released fiscal quarter results ending October, 1996 in line with expectations. Orders were $683 million, down significantly from the $1.3 billion level experienced in the first part of the year. Sales were $861 million in the fourth quarter, down from $1.1 billion in the prior quarter. However, this was not the significant news. Comments made in the conference call after market close on November 21 were much more positive than negative. While management did indicate that they expected the slowdown in the equipment market to continue into 1997, they did give guidance that orders in the next quarter would be in the $725-750 million range and sales would be approximately $800 million. The primary focus

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being placed on the call by the investment community is the fact that orders are up sequentially from the previous quarter: a rally cry has ensued. Fourth, Applied announced a $117 million dollar order from Hyundai for their DRAM fab in Oregon. This represents the first order over $100 million Applied has received in over six months, and has been interpreted by some that the rebound is underway.

Fifth, SEMI released equipment book-to-bill for October at 0.75. While this ratio is up modestly from the 0.70 reported for September, the bookings continued to decline in October.

Initial Thoughts and Some Background Facts on the Events

We are viewing the semiconductor book-to-bill improvement as one primarily driven by the Christmas seasonal buying of components for the PC market. It remains to be seen what the end-use demand will actually be and the effect on the channel flow of orders for components come January. Our PC group believes that there is less "over-buying" occurring this year than last, yet we remain cautious thinking that order rate will soften again early next year as DRAM prices continue to decline.

The positive comments and recent investment increase made by Intel reflect their unique position in the market, and the strong unit growth of PCs in the fourth quarter. While their increase in spending will stabilize the market in the U.S. in 1997, capital spending in MPU only represents perhaps 10-12 percent of the market on average. There is no fundamental reason why this short term trend would transfer to other areas of spending in present conditions.

Applied Materials is a very well run company with seasoned management that has seen many downturns. They took quick action to position the company to weather the storm. For this reason, Applied should be considered to perform slightly better than the market. It should also be noted that their backlog level at the beginning of the year was about 6 months, is currently 5 months and declining. We would expect them to consume and manage their backlog to about the 4 month level at the minimum. Not all equipment companies will be so well positioned.

However, an order rate increase from $683 million to $725-750 million is NOISE LEVEL movement in this industry, and caution should be placed on reading too much into this increase. Further, the $117 million order from Hyundai does NOT reflect a return to capacity buys in our opinion. In a recent set of visits to companies, the consensus was that any orders received today are "strategic" buys. In the case of Hyundai, Samsung, and TSMC orders for equipment for U.S. production are seen as strategic for the company's long term success in the market. This kind of sustained investment is normal in the earlier stages of a downturn, and likely represents only a portion of the planned investment to position. There is a recent announcement by Samsung that capital spending will decline 17 percent in 1997 overall, meaning that spending in Korea is being cut deeper than that.

The SEMI equipment book-to-bill reflects continued order weakness. While the ratio will likely strengthen in the coming months, being very heavily influenced by Applied Materials, we would expect order rates to remain somewhat flat with some fluctuations throughout most of 1997. This is a very volatile indicator as the equipment business is much more "lumpy" than the chip market. Consensus from most companies we speak with see ORDER rates bottoming in the second quarter next year.

Some Fundamental Analysis—Numbers Don't Sum to Recovery Now

The capital spending market for 1996 splits roughly: 30 percent foundry/logic, 50 percent memory, 10 percent MPU, and 10 percent other (mixed signal, analog, discrete, etc.) Let us look at each capacity area separately.

Foundry/Logic

Foundry factory utilization rates are falling, and wafer prices have collapsed according to a recent pricing survey completed. Investments will continue in the foundry area since many projects have joint venture and partnership commitments, but initial ramp rates are likely to be cut back. Current projections are that excess capacity may last through all of 1998 in this area as a result. With cheap foundry capacity available, this will likely subdue large capacity outlays for non-foundry logic. While there is a stability in the investment picture here, there is also not a big driver for growth until 1999.

Memory/DRAM

DRAM capacity is in over-supply today. As we have noted several times, since the industry is in a transition from the 4 Mbit to the 16 Mbit DRAM, and since die sizes continue to shrink and yields ramp up, high bit demand does not necessarily translate to a similar higher requirement for silicon capacity. Table 1 below shows the result of fundamental capacity analysis.

Table 1
Fundamental silicon Capacity Analysis for DRAMs in 1996 and 1997

	1996	1997	Comments
Bit Demand Growth (percent)	73	70-75	1997 growth is industry consensus, Dataquest forecast is about 60 percent
Growth Silicon Area Required to Meet Bit Demand (percent)	12	12-15	Average die size, yields, and product mix for 4 and 16 Mbit DRAM included
Growth in DRAM Silicon Area Capacity (percent)	23	21	1997 growth factors in capital spending decline as currently forecast, and slow ramp in new DRAM fabs
Oversupply percentage in capacity	9	14-17	Assumes baseline is a balanced market at the end of 1995

Source: Dataquest (November 1996)

This fundamental analysis indicates that the "strategic investments" being made by DRAM suppliers will actually delay the timing of when demand catches supply. Current factory utilization rates for DRAM fabs are running around 70 percent, and we would expect utilization to continue falling in 1997 perhaps to the low 60s. According to this fundamental analysis, capacity spending in DRAM is not expected to return until late in 1998. An obvious question from this analysis is: what does bit demand have to be in 1997 to create a balanced

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market at the end of 1997? The answer is about 100-110 percent, meaning the average PC would have to ship with more than 32 Mbytes of memory in next year. While higher bit demand than the above shown is possible, creating a balanced market in 1997 is highly unlikely, so we would expect DRAM prices to remain under pressure through all of 1997.

MPU and Other Areas

We do expect these areas to be the first to recover and be tightly coupled with unit demand from the various product area. But since this represents a smaller percentage of spending, the result will only create some stability in the market short term and not be a fuel for growth.

Where Are We Likely to Take our Forecast?

We would not expect large changes in our thesis and forecast outlook. Here is a short summary of any adjustments being considered.

- Our July forecast placed growth in wafer fab equipment for 1996 at about 17 percent. The third quarter results were significantly weaker than anticipated, and when carried forward should lower the actual growth for 1996 in the 11-14 percent range.
- Our outlook for 1997 should not change appreciably. We are getting indications that the absolute levels will be adjusted down slightly, but with a weaker 1996 the market should be close to our 16 percent decline forecast of July, in a range of down 15-20 percent.
- Our biggest challenge is to forecast the 1998 market. In July we were cautious on growth prospects, as we believed the fundamentals for supply/demand dynamics would continue to be weak at the beginning of the year. Given the analysis in this Alert, we would continue to be cautious on 1998, and will likely be in a 3-7 percent growth range.
- At this point, we would maintain the stronger growth forecasts for 1999 and beyond, as our outlook for semiconductor growth in the longer term remains good, but this will come under review as we progress through our forecast process currently underway.

There are some who would like to believe that this recovery will be shaped like a "V" and that we are at the bottom now. While we are likely close to a bottom, we believe that the recovery in equipment spending growth will depend on fundamentals of supply/demand dynamics. Large capacity spending growth will likely not return until well into 1998, and the industry is likely to experience several quarters of "skirting along the bottom," making the likely shape of the recovery a "square U."

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