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FEDERAL RESEARCH

SEMATECH's Efforts to Strengthen the U.S. Semiconductor Industry

GAO

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Resources, Community, and
Economic Development Division

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The Honorable Robert A. Roe,
Chairman
The Honorable Robert S. Walker,
Ranking Minority Member
Committee on Science, Space, and
Technology
House of Representatives

In response to your June 9, 1988, request that we annually assess certain aspects of SEMATECH's progress, this report discusses SEMATECH's efforts to strengthen U.S. suppliers of equipment and materials for the semiconductor manufacturing industry. Our review of SEMATECH's operations and technology transfer program, which your offices requested that we report on separately, is continuing, and the results of that work will be contained in a subsequent report.

As arranged with your offices, unless you publicly release its contents earlier, we plan no further distribution of this report until 30 days after the date of this letter. At that time, we will send copies to the Secretary of Defense; the Chief Operating Officer of SEMATECH; the President of SEMI/SEMATECH; and the Director, Office of Management and Budget. We also will make copies available to other interested parties upon request.

This report was prepared under the direction of John M. Ols, Jr., Director, Housing and Community Development Issues, (202) 275-5525. Other major contributors to this report are listed in appendix III.

J. Dexter Peach
Assistant Comptroller General

Executive Summary

Purpose

Semiconductors, devices that enable computers and other products to store and process information, are the foundation of the $550 billion worldwide electronics industry. In response to losing a significant share of the semiconductor market to Japanese companies in the 1980s, several U.S. semiconductor and computer manufacturers formed SEMATECH in 1987 to provide the U.S. semiconductor industry with the capability for world manufacturing leadership. Believing that participation in a government-industry consortium furthering semiconductor manufacturing technology was in the nation's economic and security interests, the Congress appropriated $100 million for SEMATECH's use in each of the past 3 fiscal years, matching funds provided by SEMATECH's 14 member companies.

The Chairman and Ranking Minority Member, House Committee on Science, Space, and Technology, requested that GAO annually review SEMATECH by assessing federal oversight of the program, SEMATECH's progress in meeting its objectives, SEMATECH's efforts to strengthen U.S. suppliers of semiconductor manufacturing equipment and materials, and SEMATECH's technology transfer program. A previous report focused on the SEMATECH consortium's start-up activities. This report specifically examines the equipment and materials supplier sector by assessing (1) the extent of and reasons for its decline and (2) SEMATECH's efforts to strengthen it. As part of this review, GAO surveyed senior executives from 31 of 142 companies affiliated with SEMI/SEMATECH, which represents equipment and materials suppliers participating in the SEMATECH program.

Background

Semiconductors are used in electronic products ranging from household appliances and computers to telecommunications systems and weapons systems. The performance of increasingly sophisticated electronic products is dependent on more powerful semiconductors that can store more information and process it faster, which in turn are dependent upon decreasing the diameter of semiconductors' integrated circuits. This miniaturization requires technological advances in making increasingly precise manufacturing equipment and purer materials, primarily chemicals and gases. While some U.S. semiconductor suppliers are large companies, most have annual sales of less than $20 million and produce equipment and materials for only at most a few of the more than 100 steps involved in the highly exacting process of manufacturing semiconductors.

SEMATECH established an overall objective of enabling U.S. semiconductor manufacturers to achieve parity with their Japanese counterparts by the end of 1991 and regain world manufacturing leadership by the middle of 1993. SEMATECH recognized the importance of strengthening U.S. semiconductor equipment and materials suppliers by elevating it to be a second overall objective in the consortium's latest operating plan.

Results in Brief

U.S. companies' share of world semiconductor equipment sales declined from 69 percent in 1983 to 51 percent in 1988, the latest year for which comparable data were available. In contrast, Japanese companies' market share increased from 25 percent in 1983 to about 40 percent in 1988. Similarly, U.S. companies' share of world semiconductor materials sales declined from 25 percent in 1984 to 17 percent in 1988. According to senior executives GAO surveyed from 31 equipment and materials suppliers, the high cost of capital, weak relationships between SEMATECH's 14 member companies and their suppliers, and other factors that led to the decline of the U.S. semiconductor supplier base still confront the industry and seriously constrain any efforts to strengthen it.

In response to the declining competitiveness of U.S. suppliers, SEMATECH is trying to improve working relationships between semiconductor manufacturers and their U.S. suppliers by, among other things, providing forums for companies' technical managers to interact and developing industrywide approaches for estimating costs and ensuring quality. SEMATECH also has increased the percentage of its annual budget for outside research from 20 percent to 50 percent, mainly for projects to develop new, or to improve existing, equipment and materials.

The executives GAO surveyed from 31 supplier companies generally support the SEMATECH program. However, executives from 16 of the companies were uncertain whether SEMATECH will significantly strengthen the U.S. supplier industry, in part because of SEMATECH's limited available resources, but, more basically, because of the need for a fundamental change in the relationship between semiconductor manufacturers and their suppliers. Many of the executives believe that each of SEMATECH's members must emulate SEMATECH's example by working more closely with and supporting their suppliers in order to strengthen the broader U.S. supplier base. In June 1990 SEMATECH's members agreed to participate in a program intended to establish closer working relationships with their key suppliers.

Principal Findings

Decline of the U.S. Semiconductor Equipment and Materials Industry

In 1979 the nine largest semiconductor equipment suppliers in world sales were U.S. companies. By 1989 Japanese firms had captured 4 of the top 5 positions, while only 4 U.S. companies were among the 10 largest suppliers. In particular, U.S. companies' share of world sales for the critical industry segment of lithography equipment, which is used to transfer integrated circuit patterns onto semiconductors, declined from 71 percent in 1983 to 29 percent in 1988. Similarly, U.S. companies' share of world sales for equipment that implants ions on semiconductor wafers—another important segment—dropped from 77 percent in 1983 to 51 percent in 1988. Further, a 1989 survey by SEMATECH of its 14 member companies indicated that they are increasingly using Japanese equipment in their most advanced fabricating facilities.

According to the executives GAO interviewed from 31 supplier companies, the problems that led to the competitive decline of U.S. suppliers generally are in areas in which Japanese competitors have distinct advantages. These problems include (1) the high cost of capital in the United States; (2) poor relations between U.S. semiconductor manufacturers and their suppliers; and (3) a low level of investment by U.S. suppliers in plant and equipment and in research and development, which is at least partially attributable to the high cost of capital. Further, according to the executives, the structure of the U.S. semiconductor equipment industry, which is composed of a large number of small companies, increases their difficulty in generating the resources to develop more technologically advanced equipment and in competing with larger and financially stronger Japanese firms.

SEMATECH's Efforts to Strengthen U.S. Suppliers

SEMATECH increased its efforts to assist U.S. semiconductor equipment and materials suppliers in response to their declining competitiveness. For example, it (1) established a Department of Supplier Relations to coordinate the consortium's activities involving SEMI/SEMATECH suppliers and (2) increased its planned funding for outside research in 1990 from $84 million to an estimated $137 million, mainly for projects to improve existing equipment and develop next-generation equipment. Because of insufficient resources to address the equipment and materials industry's problems, SEMATECH has focused its efforts on four segments of the industry, including the lithography equipment segment, on which it believed it could have the greatest impact.

Despite these efforts, however, the suppliers told GAO that a much broader range of initiatives, in addition to SEMATECH's program, is needed to significantly strengthen U.S. suppliers. For example, executives from 21 of the 31 suppliers surveyed said their companies' relationships with U.S. semiconductor manufacturers typically are based on short-term considerations, and 3 noted that their Japanese customers provide better feedback than their U.S. customers on how their equipment is performing. Many of these executives believe SEMATECH's ultimate success in strengthening the industry is contingent on the extent to which its 14 member companies establish closer long-term relationships with their U.S. suppliers. In particular, the executives cited the need for SEMATECH's members to involve U.S. suppliers in their planning process, share technical performance data for equipment with their suppliers, and assume some of the costs and risks associated with developing the next generations of semiconductor fabrication equipment and materials. Various economists and political scientists similarly have pointed out that Japanese suppliers have benefited from such close interactions with their customer firms.

In June 1990 SEMATECH's members endorsed a new partnering program in which they intend to work more closely with their key U.S. suppliers, in particular, by sharing (1) strategic goals and plans, (2) information about the technical performance of their suppliers' equipment, and (3) some of the costs of suppliers' product development work. This initiative, directed at one of the central needs that suppliers' executives highlighted for reasserting U.S. technological leadership, requires that SEMATECH's members change the way they have traditionally conducted business with their suppliers.

Matters for Congressional Consideration

Because SEMATECH's members will play a critical role in determining whether the U.S. semiconductor supplier base can be revitalized, the Congress may wish to closely monitor the commitment of SEMATECH's members to developing closer long-term working relationships with their suppliers and make further federal funding for SEMATECH contingent upon the members' following through with this commitment.

Agency Comments

GAO discussed the information in this report with officials of the Department of Defense, SEMATECH, and SEMI/SEMATECH, who agreed that the facts presented were accurate. However, at the Committee's request, GAO did not obtain official comments on a draft of this report.

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Abbreviations

DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
EIP	equipment improvement program
GAO	General Accounting Office
IBM	International Business Machines Corporation
JDP	joint development project
RCED	Resources, Community, and Economic Development Division
R&D	research and development
SEMATECH	SEmiconductor MAnufacturing TECHnology
SEMI	Semiconductor Equipment and Materials Institute

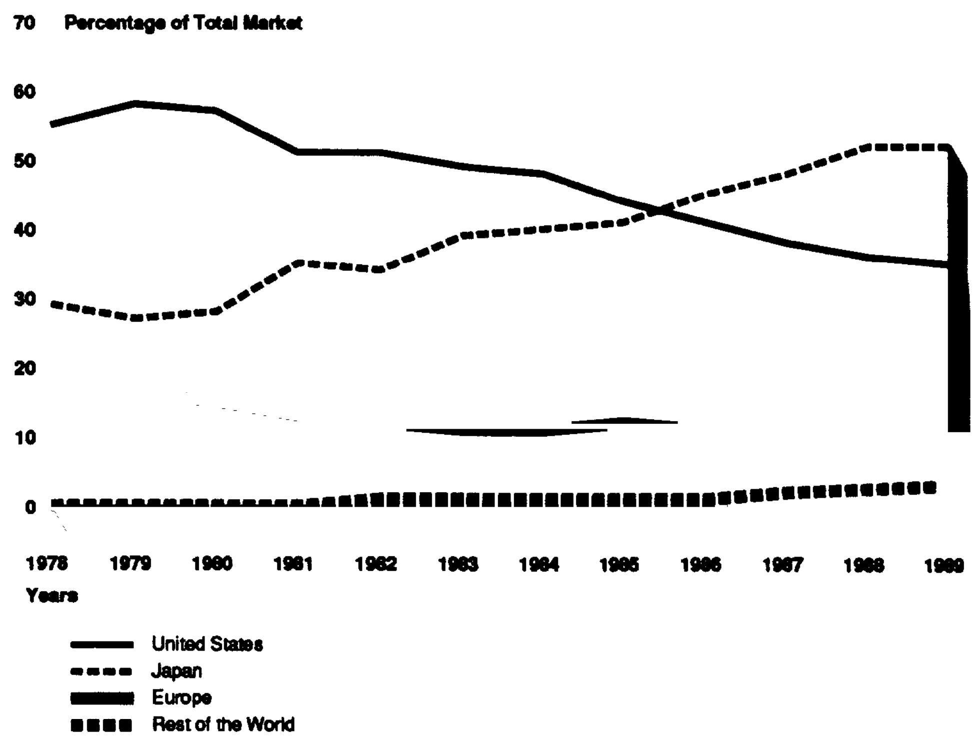
Chapter 1

Introduction

Semiconductors, devices that enable computers and other products to process and store information, are the foundation of the electronics industry, which had worldwide sales of about $550 billion in 1989 and is projected to have sales in excess of $800 billion by 1993. In 1989 $270 billion worth of electronic products were sold in the United States, and the U.S. electronics industry employed 2.6 million workers.

Until the early 1980s, the United States was the world leader in semiconductor production. However, U.S. companies have since lost a significant portion of their market share in the production of semiconductors and associated manufacturing equipment and materials to Japanese companies, which began a major program in 1975 to establish a strong semiconductor industry. (See fig. 1.1.)

Figure 1.1: Worldwide Market Share for Semiconductors



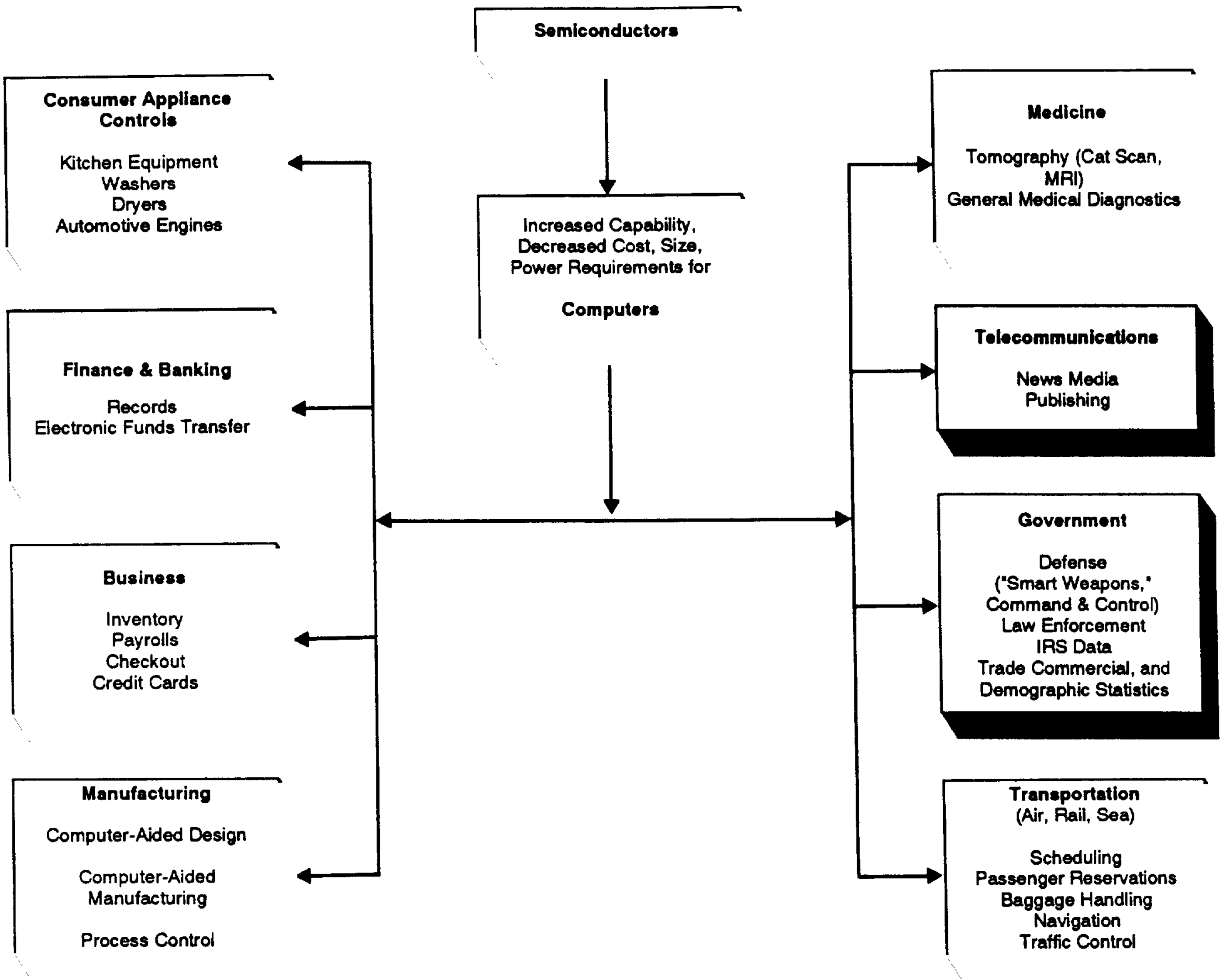
Source: Dataquest.

In response to the strong Japanese competition, several U.S. semiconductor and computer companies formed SEMATECH in 1987 as a research and development (R&D) consortium. Believing that participation in a government-industry consortium furthering semiconductor manufacturing technology was in the nation's economic and security interests, the Congress directed the Secretary of Defense to make grants to SEMATECH for R&D and has appropriated $100 million annually in the past 3 fiscal years, which matches contributions by SEMATECH's 14 member companies.

Importance of the Semiconductor Industry to the U.S. Economy

The ability to produce the most advanced semiconductors has enabled U.S. companies to be world leaders in computers, telecommunications equipment, defense weapons systems, and other sophisticated electronic products. (See fig. 1.2. for sectors of the economy that depend on semiconductor technology.) The performance of electronic products depends on the ability of semiconductors to process and store information. In turn, the capability to manufacture more powerful semiconductors depends on technological advances in semiconductor manufacturing equipment and materials.

Figure 1.2: The Contribution of Semiconductors to the Economy



In recent years several studies assessing the decline of the semiconductor industry have highlighted the critical interrelationships among the electronics industry, semiconductor manufacturers, and the suppliers of manufacturing equipment and materials. The studies have pointed out that the erosion of the U.S. semiconductor equipment and materials supplier base in turn reduces the competitiveness of the U.S. semiconductor industry and places U.S. electronics manufacturers at a competitive disadvantage. For example, a report on the semiconductor equipment and materials industry by the National Advisory Committee on Semiconductors[1] stated,

> It is essential that companies develop state-of-the-art technology in order to remain viable businesses. The continued success and health of the U.S. semiconductor and electronic industries rely heavily on viable semiconductor materials and equipment companies that can provide the most advanced equipment.

In addition, a report by the National Academy of Engineering[2] noted that if technological leadership in one area is lost, it is difficult to recapture and stated,

> . . . the loss of leadership in critical fields may have a cumulative effect that not only strips the United States of technological know-how in these areas but may seriously deplete the overall capability of the United States to compete in several related fields.

Establishment of SEMATECH

SEMATECH was incorporated in Delaware in August 1987 as a not-for-profit R&D corporation. To implement its overall objective of providing the U.S. semiconductor industry the capability for world leadership in manufacturing, SEMATECH has developed a three-phased, 5-year plan for achieving parity with Japan by the end of 1991 and regaining world leadership by the middle of 1993. SEMATECH elevated the importance of strengthening U.S. suppliers of semiconductor equipment and materials by making it a second overall objective in the consortium's 1991 operating plan. The following companies are members of SEMATECH:

Advanced Micro Devices, Inc.
American Telephone and Telegraph Company
Digital Equipment Corporation

[1] Preserving the Vital Base: America's Semiconductor Materials and Equipment Industry, National Advisory Committee on Semiconductors (July 1990).

[2] The Technological Dimensions of International Competitiveness, National Academy of Engineering (1988).

Harris Corporation
Hewlett-Packard Company
Intel Corporation
International Business Machines Corporation (IBM)
LSI Logic Corporation
Micron Technology, Inc.
Motorola, Inc.
National Semiconductor Corporation
NCR Corporation
Rockwell International
Texas Instruments, Inc.

Each member company is represented on SEMATECH's Board of Directors and Executive Technical Advisory Board.

SEMI/SEMATECH, Inc., was formed in September 1987 as an independent organization of U.S. semiconductor equipment and materials suppliers to link the suppliers and SEMATECH. SEMI/SEMATECH, which had 142 member companies as of January 30, 1990, is located along with SEMATECH in Austin, Texas.

Federal Participation in SEMATECH

In December 1985 the Department of Defense's (DOD) Deputy Under Secretary for Research and Engineering requested that the Defense Science Board establish a task force to assess the impact of trends in the semiconductor industry on DOD's weapons acquisition programs. The task force reported that for the 25 semiconductor products and processes examined, Japanese companies led in 12, U.S. companies led in 5, and relative parity existed in 8.[3] The report concluded that the erosion of U.S. technological leadership in semiconductor manufacturing had serious implications for the nation's economy and would seriously impair the nation's defense capabilities that rely upon technologically superior weapons. The report recommended that action be taken to retain a domestic strategic semiconductor base and maintain a strong base of expertise in associated technologies.

The National Defense Authorization Act for Fiscal Years 1988 and 1989 (P.L. 100-180) and the National Defense Authorization Act for Fiscal Years 1990 and 1991 (P.L. 101-189) have authorized the Secretary of Defense to make grants to SEMATECH to defray its R&D expenses, provided in part that available funds from federal, state, and local governments

[3]See Defense Semiconductor Dependency (Feb. 1987).

for any fiscal year may not exceed 50 percent of the total cost of R&D activities. In April 1988 the Secretary of Defense delegated responsibility for overseeing SEMATECH to the Defense Advanced Research Projects Agency (DARPA), which approves the consortium's annual operating plans. The Congress has appropriated $100 million annually for SEMATECH in fiscal years 1988 through 1990. DARPA's grant funds are matched by member companies' contributions to the program.

Semiconductor Manufacturing and the Role of Equipment and Materials Suppliers

Semiconductors, or "chips," regulate the flow of electricity in solid-state electronic goods. (See the glossary for definitions of semiconductor manufacturing terminology.) Most of these devices are made from silicon—essentially purified sand. When different individual components, such as diodes and transistors, are joined together within a single semiconductor, the device is called an integrated circuit. Semiconductors are fabricated in a "clean room" manufacturing area that needs to be scrupulously clean. A single speck of dust can be enough to contaminate the fabrication process and reduce the percentage (yield) of chips meeting specifications.

According to a SEMATECH pamphlet describing the integrated circuit manufacturing process, fabricating the most complex semiconductors today consists of more than 100 steps, during which hundreds of copies of an integrated circuit are formed on a single silicon wafer, mainly through chemical processes. Generally, the process involves creating 8 to 20 patterned layers on and into the substrate of the wafer, ultimately forming the complete integrated circuit.

In the first stage of the fabrication process, a silicon wafer is heated and exposed to ultrapure oxygen to form a silicon dioxide film of uniform thickness on the surface of the wafer. Next, in the photolithographic phase, a photoresist (light-sensitive film) is applied to the wafer, giving it characteristics similar to photographic paper. A wafer stepper aligns the wafer to a mask and then projects an intense light through the mask, exposing the photoresist with the mask pattern. In the etching stage, the exposed photoresist is removed, and the wafer is baked in a furnace to harden the remaining photoresist pattern. The wafer is then exposed to a chemical solution so that the areas not covered by the hardened photoresist are etched away. In the doping stage, atoms with one fewer and one more electron than silicon are implanted in the areas exposed by the etching process to alter the electrical characteristics of the silicon. These processes are repeated several times before active semiconductors are formed.

In the dielectric deposition and metallization stage, the individual devices are interconnected using a series of metal depositions and patterning steps, followed by the deposition and patterning of dielectric films for insulation. After the last metal layer is patterned, a final dielectric layer is deposited to protect the circuit from damage and contamination. Openings are etched in this film to allow access to the top layer of metal by electric probes and wire bonds. An automatic, computer-driven electric test system then checks the functionality of each chip on the wafer, rejecting any that fail the test. A diamond saw slices the wafer into single chips, and the good chips are assembled into a package that provides contact leads for them.

In the industry's beginning, semiconductor manufacturers designed and developed their own manufacturing equipment and materials. However, the demand for increasingly powerful semiconductors required integrated circuits with more components and smaller geometries and consequently has led to more stringent manufacturing processes. Techniques, equipment, and materials that were useful at larger geometries are no longer sufficiently precise, requiring the development of new equipment and processes for manufacturing the next generation of semiconductors.

While some U.S. semiconductor equipment suppliers are large companies, most have annual sales of less than $20 million and produce equipment used in only at most a few steps in the fabrication process. In many cases, engineers left established companies to form companies that manufacture more sophisticated and specialized equipment. These start-up companies have been the source of many of the industry's technological innovations. However, manufacturing each new generation of semiconductors requires more advanced and usually more expensive equipment than manufacturing the previous generation did, which in turn requires a greater investment in R&D by the equipment suppliers.

Objectives, Scope, and Methodology

In a letter dated June 9, 1988, the Chairman and Ranking Minority Member, House Committee on Science, Space, and Technology, asked that we annually assess SEMATECH's activities for the duration that it receives federal funding. Specifically, the Committee asked us to address 21 issues regarding (1) federal oversight of the consortium; (2) SEMATECH's technological progress, including its objectives, milestones, and accomplishments; (3) SEMATECH's efforts to transfer technology; and (4) the participation by suppliers of semiconductor manufacturing equipment and materials in the consortium. Our first report in response to this request examined the federal role, SEMATECH's approach and organization for achieving its overall objectives, and SEMATECH's initial technology transfer efforts.[4]

This report examines the U.S. semiconductor equipment and materials industry by assessing (1) the extent of and reasons for its decline and (2) SEMATECH's efforts to strengthen its members. To perform this work, we did the following:

- We reviewed recent reports on the semiconductor equipment and materials industry as well as trade publications.
- We assessed semiconductor industry market trends by examining world sales data from Dataquest, Inc., for semiconductors; VLSI Research, Inc., for semiconductor manufacturing equipment; and Rose Associates for semiconductor materials.
- We interviewed responsible SEMATECH and SEMI/SEMATECH officials and reviewed pertinent documents.
- We surveyed senior executives of 31 of SEMI/SEMATECH's member companies to obtain their views on the extent of and reasons for the U.S. industry's decline and the effectiveness of SEMATECH's response.

Appendix I lists the 31 semiconductor equipment and materials suppliers we surveyed, which comprised 22 percent of SEMI/SEMATECH's 142 member companies as of January 30, 1990. We mainly selected companies located in "Silicon Valley," in northern California, and around Boston, Massachusetts, because suppliers are clustered in these regions, enabling us to meet with almost all of the suppliers' executives. The suppliers we surveyed make equipment or materials for each of the product lines defined by SEMI/SEMATECH (see table 1.1). Of the 31 suppliers, 8 had 1989 annual sales of less than $10 million; 13 had sales between $10.1 million and $100 million; and 10 had sales exceeding $100 million. Thirteen of the 31 companies had received one or more SEMATECH contracts to improve existing or develop new equipment.

[4] Federal Research: The SEMATECH Consortium's Start-up Activities (GAO/RCED-90-37, Nov. 3, 1989).

Table 1.1: Product Lines of the 31 SEMI/SEMATECH Companies GAO Surveyed

Product line	Number of companies
Hot processing, ion implantation	8
Sputtering, chemical vapor deposition	8
Photolithography	8
Measurement, metrology	6
Systems	4
Defects	6
Assembly, testing	1
Materials	4
Etching	5
Other	7

We discussed the information in this report with officials of DARPA, SEMATECH, and SEMI/SEMATECH, who agreed that the facts presented are accurate. However, at the Committee's request, we did not obtain official comments on a draft of this report. Our review was conducted between January and June 1990 in accordance with generally accepted government auditing standards.

The Decline of and Problems Confronting the U.S. Semiconductor Equipment and Materials Industry

During the 1980s, the competitive position of U.S. suppliers of semiconductor equipment and materials steadily declined. In particular, the world market share of U.S. semiconductor manufacturing equipment suppliers declined from 69 percent in 1983 to 51 percent in 1988. Similarly, the world market share of U.S. semiconductor materials suppliers declined from 25 percent in 1984 to 17 percent in 1988. In contrast, Japanese suppliers of semiconductor equipment and materials have steadily increased their market share, and Japanese companies have become the technological leaders in two of the most critical equipment industry segments—those supplying equipment for lithography and ion implantation. In addition, SEMATECH's survey of its 14 members indicated that they are relying increasingly on Japanese equipment for their most advanced semiconductor fabricating facilities.

According to the senior executives of suppliers we surveyed, the major factors that led to the decline of U.S. semiconductor equipment and materials suppliers still confront the industry and seriously constrain any efforts to strengthen it. Further, these problems are in areas in which Japanese competitors appear to have distinct advantages, including the availability and cost of capital, working relationships between semiconductor manufacturers and their suppliers, the level of investment in plant and equipment and in R&D, and the size and financial strength of the suppliers.

Decline of U.S. Suppliers

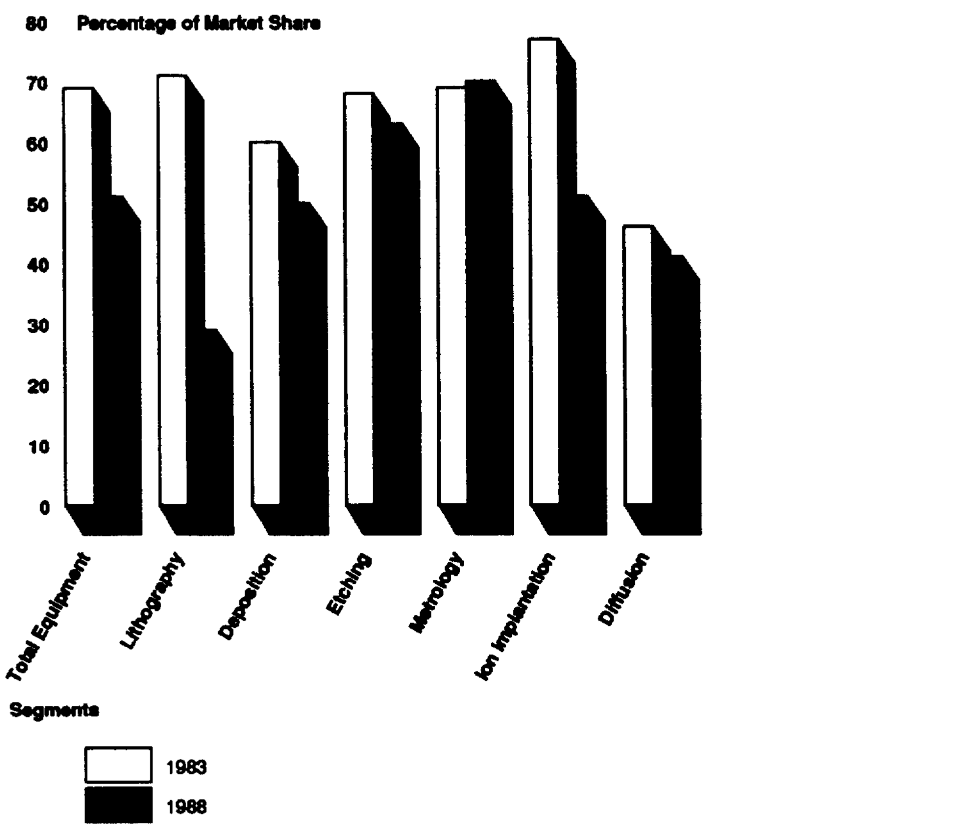
The July 1990 report of the National Advisory Committee on Semiconductors provided statistics highlighting the declining market share held by U.S. suppliers of semiconductor equipment and materials. Market share, the report noted, is a critical indicator of the long-term business prospects of suppliers because of their need to reinvest a substantial portion of their profits—on average, a new generation of equipment must be produced every 3 years. The report concluded,

> The semiconductor materials and equipment industry in this Nation is headed for trouble. This equipment-and-materials sector of the U.S. semiconductor industry has declined dramatically over the past decade and shows every sign of continuing its decline, while the Japanese and, to a lesser extent, the European semiconductor materials and equipment industries are growing.

Semiconductor Fabrication Equipment

The National Advisory Committee on Semiconductors stated that U.S. suppliers' share of the world market was in serious decline for three of the six semiconductor fabrication equipment industry segments—those supplying equipment for lithography, ion implantation, and diffusion. From 1983 to 1988, the latest year for which comparable data were available, U.S. companies' market share for lithography equipment dropped from 71 percent to 29 percent; for ion implantation equipment, from 77 percent to 51 percent; and for diffusion equipment, from 46 percent to 41 percent. (See fig. 2.1.) Although U.S. companies have retained a relatively significant market share in the deposition, etching, and metrology, equipment segments, SEMATECH's 1991 strategic operating plan noted that Japanese companies have captured large market shares in supplying particular pieces of equipment in the segments.

Figure 2.1: U.S. Semiconductor Equipment Suppliers' Market Share by Segment in 1983 and 1988



Source: VLSI Research, Inc.

Japanese suppliers also have become the largest companies in the semiconductor equipment industry (see table 2.1). In 1979, 9 of the top 10 semiconductor equipment suppliers in world sales were U.S. companies.

However, in 1989 only 4 U.S. companies were ranked in the top 10, while Japanese firms captured 4 of the top 5 positions.

Table 2.1: Top 10 Semiconductor Equipment Suppliers by Sales in 1979 and 1989

Dollars in millions

1979		1989	
Company	**Sales**	**Company**	**Sales**
Fairchild Test Systems	$111.4	Tokyo Electron Ltd.[a]	$633.9
Perkin-Elmer	101.2	Nikon[a]	582.2
Applied Materials	54.1	Applied Materials	523.3
GCA	54.1	Advantest[a]	398.8
Teradyne	53.4	Canon[a]	383.6
Varian	50.8	General Signal	353.7
Tektronix	39.2	Varian	335.0
Eaton	37.7	Hitachi[a]	210.0
Kulicke & Soffa	37.0	Teradyne	199.9
Balzers, A.G.[b]	33.7	ASM International[b]	186.8

[a]Japanese company.

[b]European company.

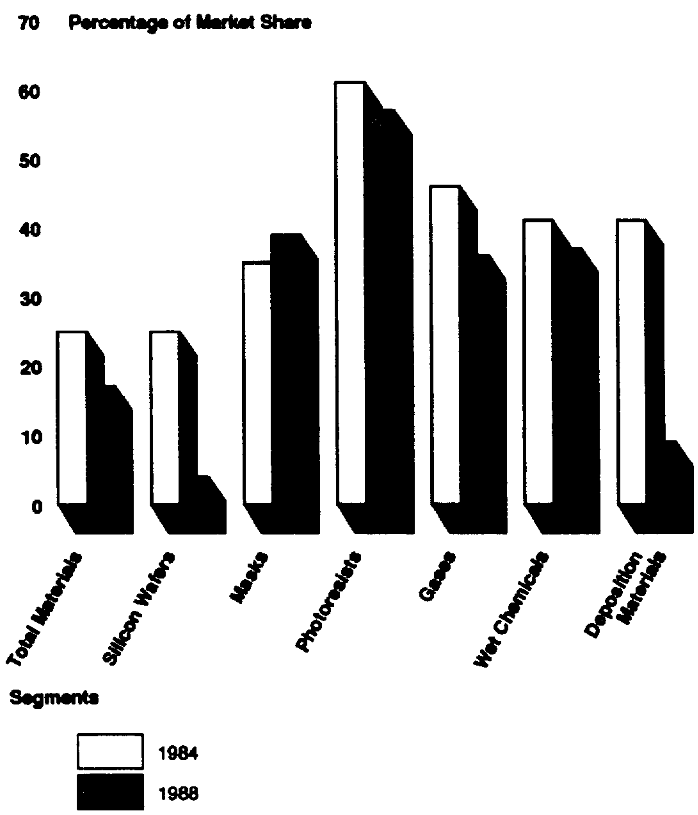
Source: VLSI Research, Inc.

Many U.S. semiconductor equipment suppliers are faced with a declining market share and the need to reinvest at a high rate to remain technologically competitive. For example, Perkin-Elmer Corporation in recent years lost leadership in photolithography equipment to Nikon Corporation and Canon, Inc. In response, Perkin-Elmer invested a reported $100 million to recapture the technological lead in photolithography. After reportedly being the target of a takeover by Nikon, Perkin-Elmer sold majority interest in its electronic beam technology division in March 1990 to a coalition of U.S. companies, including IBM and Dupont Company, and in its optical lithography division in May 1990 to the Silicon Valley Group, Inc. As part of the sale of the optical lithography division, in which the Silicon Valley Group obtained a 67-percent interest, IBM agreed to provide financial support to develop an advanced photolithography stepper and to make substantial purchases of the stepper. SEMATECH also awarded a joint development contract to the new company to support development of the new stepper.

Semiconductor Fabrication Materials

Overall, U.S. materials suppliers' market share declined from 25 percent in 1984 to 17 percent in 1988, although U.S. materials suppliers have remained strong in segments in which local or regional suppliers traditionally have provided the materials, such as bulk chemicals and gases. (See fig. 2.2.) The National Advisory Committee on Semiconductors found that the U.S. suppliers' share of the fabrication materials market is declining rapidly, citing in particular a decline in the share of the most profitable market segments. Similarly, SEMATECH's 1991 operating plan stated that of six materials segments surveyed, U.S. suppliers dominate only in photoresists.

Figure 2.2: U.S. Semiconductor Materials Suppliers' Market Share by Segment in 1984 and 1988



Source: Rose Associates.

One reason for the loss of market share by U.S. semiconductor materials suppliers is the acquisition of several U.S. suppliers by foreign companies in recent years. (Table 2.2 shows U.S. suppliers acquired by foreign companies in 1989.) One of these suppliers—Monsanto Electronic

Materials Corporation—was the last major U.S. manufacturer and seller of silicon wafers. In April 1990 Hercules Corporation announced an agreement to sell its Semi-Gas Systems subsidiary to Nippon Sanso, a Japanese company. Semi-Gas, which is the leading maker of gas containment systems for semiconductor fabrication facilities, helped develop the gas distribution system for SEMATECH's fabrication facility and has a joint development contract with the consortium. SEMATECH's Chief Administrative Officer stated that as a result of the joint development project (JDP), Semi-Gas has been able to improve the purity levels of its gas containment system by tenfold, giving the company a world leadership position that is probably at least 2 years ahead of any other company's technology in the world.

Table 2.2: U.S. Semiconductor Materials Suppliers Acquired by Foreign Companies in 1989

Dollars in millions

U.S. company	Product	Foreign investor	Acquisition price
Monsanto Electronic Materials	Silicon wafers	Huels AG[a]	$250
Cincinnati Semiconductor	Epitaxy wafers	Osaka Titanium[b]	50
Cominco Electronic Materials	Gallium arsenide wafers, targets, wires	Johnson Matthey[a]	40
Matheson Gas Products	Specialty gases	Nippon Sanso[b]	30
General Ceramic	Hermetic packages	Tokuyama Soda[b]	35
Micro Mask	Photomasks	Hoya[b]	25
Materials Research Corp.	Targets	Sony[b]	50
Total acquisition price			**$480**

[a]European company.

[b]Japanese company.

Source: Rose Associates.

Problems Confronting U.S. Suppliers

According to senior executives we surveyed from 31 of the 142 suppliers participating in SEMI/SEMATECH, the problems that led to the competitive decline of the U.S. suppliers of semiconductor equipment and materials are in areas where their Japanese competitors have distinct advantages. Table 2.3 shows how the executives ranked each factor on a scale of 1 to 10, with 10 indicating the greatest contribution to the U.S. industry's competitive decline.

Table 2.3: Perceptions of Suppliers' Executives About Factors Contributing to the Decline of Their Industry

Factors	Ranking (Scale of 1-10)
High cost of capital in the United States	7.9
Poor relations between U.S. semiconductor manufacturers and their suppliers in comparison with relations between Japanese manufacturers and their suppliers	7.4
Low levels of investment in plant and equipment by U.S. semiconductor equipment and materials suppliers in comparison with investment levels by Japanese suppliers	5.9
Structure of the U.S. semiconductor equipment and materials industry (the industry is composed of a large number of small companies)	5.8
Cyclical changes in the semiconductor market	5.6
Low levels of expenditures on R&D by U.S. semiconductor equipment and materials suppliers in comparison with levels by Japanese suppliers[a]	5.4
Trade barriers imposed by Japan and other foreign countries	5.1
Unfair pricing strategies by foreign competitors	4.2

[a]U.S. semiconductor equipment suppliers, on average, spend close to 16 percent of sales on R&D, in comparison with the U.S. industrial average of about 3 percent of sales.

Some of these factors are interrelated. For example, the high cost of capital—ranked first—would account to some extent for the low levels of investment in plant and equipment and in R&D. In addition, U.S. suppliers face difficulties selling to Japanese semiconductor manufacturers, which account for a significant portion of the world market for semiconductor equipment and materials, because U.S. suppliers (1) typically are small and lack the financial resources to establish sales and service units overseas and (2) face Japanese trade and/or cultural barriers.

A September 1989 study by the Congressional Research Service identified many of the issues raised by suppliers' executives in our survey. Among the factors it identified as contributing to the increasing strength of Japanese suppliers were (1) the rapid expansion of the production capacity of Japanese manufacturers for certain advanced large-volume semiconductors since the mid-1970s, (2) the advantage of a growing domestic market, (3) close working relationships between Japanese semiconductor manufacturers and their suppliers, (4) direct support from the Japanese government through cooperative research in microelectronics, (5) the availability and lower cost of capital in Japan, and (6) greater diversity in the revenue base of Japanese suppliers compared to that of their U.S. competitors.

Cost and Availability of Capital

Senior executives from the 31 companies we surveyed ranked the high cost of capital in the United States as the most significant factor diminishing the competitiveness of U.S. suppliers. Executives from 26 companies stated that difficulties in obtaining capital have put either their companies or their industry segments at a competitive disadvantage. Executives from two companies told us that many in the U.S. financial community have "written off" the U.S. semiconductor industry. Another executive said that the major problem for small companies is not the lack of start-up capital; rather, the problem is finding investors patient enough to enable small companies to reinvest profits and grow sufficiently so they can compete successfully in the international market.

Because of the high cost of capital in the United States, many U.S. suppliers—especially smaller companies—have difficulty raising sufficient funds for needed R&D, which for suppliers to remain competitive, one executive explained, may require expenditures of up to 15 percent of the revenue from sales. The President of SEMI/SEMATECH told us that many U.S. suppliers have turned to Japanese companies for investment capital because of the lack of capital in the United States. SEMI/SEMATECH data show that Japanese companies either acquired or invested in 10 SEMI/SEMATECH companies between 1987 and May 1990.

Relations Between Semiconductor Manufacturers and Their Suppliers

Executives from the 31 SEMI/SEMATECH suppliers rated ineffective working relationships between semiconductor manufacturers and their suppliers closely behind the cost of capital as the most significant factor contributing to the declining competitiveness of U.S. suppliers. When asked about the most significant problems suppliers face regarding their relations with U.S. semiconductor manufacturers, executives from

- 25 of the 31 suppliers stated that manufacturers provide little financial support to their suppliers,
- 23 suppliers said that manufacturers do not involve their suppliers in their planning,
- 21 suppliers mentioned that relationships are based purely on short-term considerations,
- 21 suppliers noted that manufacturers do not share technical data on the performance of equipment with suppliers, and
- 15 suppliers considered their relations with manufacturers too adversarial and competitive.

The executives believe close relationships between U.S. semiconductor manufacturers and their U.S. suppliers are critical because suppliers, which currently must bear the high risks and high costs of developing new generations of equipment and materials, need help from manufacturers. Executives from seven suppliers particularly noted that to make continuing improvements and innovations, they need data from semiconductor manufacturers about the performance of suppliers' products in a real manufacturing environment and the manufacturers' future needs for equipment and materials. In comparison with U.S. semiconductor manufacturers, executives from three suppliers stated that Japanese manufacturers provide better equipment performance data and planning information, while executives from nine suppliers said Japanese manufacturers typically are the first to purchase their most advanced equipment.

These assertions are echoed by many economists and political scientists, who have pointed out that in the automotive industry, for example, Japanese parts and materials suppliers have benefited from close interaction with Japanese car manufacturers. In contrast to U.S. companies, Japanese manufacturers are believed to provide their suppliers more technical assistance and longer-term contracts. Some analysts believe that these close working relationships have been at least partially responsible for Japan's high rates of growth in productivity and of product innovation in the automotive and other industries.

Access to the Japanese Market

According to executives of 16 companies, to be competitive internationally, U.S. suppliers must sell in Japan, which represents a significant portion of the world market for semiconductor manufacturing equipment and materials. Several executives noted that success in Japan requires overcoming Japanese trade and/or cultural barriers; providing substantial resources to establish a sales network in Japan; and offering technologically superior products, which may be copied by competitors.

SEMATECH's Efforts to Strengthen the U.S. Semiconductor Equipment and Materials Industry

In response to the declining competitiveness of U.S. suppliers of semiconductor manufacturing equipment and materials, SEMATECH has devoted increased resources to strengthening the members of SEMI/SEMATECH. SEMATECH's efforts include (1) spending more of its annual budget on projects to improve and develop equipment and (2) working to improve the working relationships between semiconductor manufacturers and their suppliers by providing forums for companies' technical managers to interact, encouraging semiconductor manufacturers to establish long-term partnerships with their U.S. suppliers, and developing industrywide approaches for estimating costs and ensuring quality.

Senior executives from 28 of the 31 SEMI/SEMATECH suppliers we surveyed support SEMATECH's efforts to address their needs. However, executives of 16 of the 31 companies were uncertain whether SEMATECH will significantly strengthen the U.S. supplier industry, in part because of limited available resources, but, more basically, because of the need for a fundamental change in the relationship between semiconductor manufacturers and their suppliers. Many executives we interviewed believe the success of SEMATECH's initiatives is contingent on the extent that the consortium's 14 member companies establish closer long-term working relationships with their U.S. suppliers. In particular, the executives cited the need for SEMATECH's members to (1) involve U.S. suppliers in their planning process, (2) share technical performance data for equipment with these suppliers, and (3) assume some of the costs and risks associated with developing the next generations of semiconductor fabrication equipment and materials.

In June 1990 SEMATECH's members agreed to participate in a new Partnering for Total Quality program in which they intend to work more closely with their key U.S. suppliers by sharing (1) strategic goals and plans, (2) information about the technical performance of the suppliers' equipment, (3) competitive analysis information, and (4) some of the costs of suppliers' product development work.

SEMATECH's Efforts to Strengthen the U.S. Supplier Base

During the 3 years since its inception in 1987, SEMATECH has given increasing emphasis to assisting equipment and materials suppliers. For instance, SEMATECH's members agreed in April 1988 that 20 percent of SEMATECH's budget could be committed to outside projects, after initially proposing to DARPA that more than 80 percent of the consortium's R&D activities would be performed in-house. SEMATECH currently plans to spend about 50 percent of its budget on outside projects, particularly on

R&D contracts with SEMI/SEMATECH suppliers to improve existing equipment or develop the next generations of equipment. In addition, in July 1989 SEMATECH established a Department of Supplier Relations to coordinate its programs involving SEMI/SEMATECH suppliers, and its 1991 operating plan acknowledged the importance of strengthening U.S. suppliers by elevating it as a second overall objective.

SEMATECH's Equipment Improvement and Development Programs

During 1990 SEMATECH has increased its planned funding of outside R&D—particularly of projects to improve existing equipment and develop next-generation equipment—from $84 million to $137 million. Its 1991 operating plan established the following four major areas (termed "thrust areas") for its R&D program.

SEMATECH's Thrust Areas for R&D

Lithography	Multilevel metals	Furnaces and implantation	Manufacturing methods
Steppers	Etching	Furnaces	Modeling
Photoresists	Planarization	Implantation	Process integration
Tracks	Deposition		Manufacturing systems
Mask making			
Metrology			
X-ray			

These thrust areas focus on equipment because SEMATECH has insufficient resources to address both the equipment and materials segments of the industry and because SEMATECH believes, on the basis of information provided by member companies and its competitive analysis group, that it can have the greatest impact by strengthening key equipment suppliers.

As of June 30, 1990, SEMATECH had awarded 22 JDP contracts to develop next-generation semiconductor tools, equipment, and materials, and it had awarded 13 equipment improvement program (EIP) contracts. (See app. II.) SEMATECH's goal is to contribute 30 percent of the total cost of the JDPs and 10 percent of the total cost of the EIPs, with the participating supplier paying the remaining cost.

Two EIP contracts signed in 1990 involve the installation of equipment in the fabrication facilities of five of SEMATECH's members. As part of

SEMATECH's most expensive project, to improve the performance and reliability of GCA's optical stepper, 14 of the devices are being placed in the facilities of four member companies to generate equipment operation data in diverse manufacturing environments. SEMATECH has provided the funds to purchase the steppers, and the four member companies are providing facilities, personnel, and other resources needed to support the project. Another member of SEMATECH also has agreed to operate chemical vapor deposition equipment manufactured by Applied Materials, Inc., in its fabrication facility as part of a separate EIP project.

Some SEMI/SEMATECH suppliers also are working on individual projects with the National Institute of Standards and Technology, Sandia National Laboratories, or Oak Ridge National Laboratory. In addition, suppliers have access to Sandia's Semiconductor Equipment Technology Center and SEMATECH's 11 university-based centers of excellence.

Forums to Stimulate Communication

SEMATECH fosters technical information exchanges among its member companies, SEMI/SEMATECH suppliers, and national laboratory and university researchers through several forums, including one-on-one management meetings, semiannual meetings of suppliers' representatives with SEMATECH's technical advisory boards, semiannual conferences for senior executives (called "Presidents' day" conferences), and reviews of its centers of excellence research program.

In SEMATECH's one-on-one management meetings, suppliers' senior executives meet with senior SEMATECH and SEMI/SEMATECH officials to discuss the suppliers' products and strategic business plans. SEMATECH and SEMI/SEMATECH officials also provide information on their activities. As of July 12, 1990, executives from 63 SEMI/SEMATECH companies had attended one-on-one management meetings.

SEMATECH and SEMI/SEMATECH have established seven supplier technical advisory boards to act as forums for suppliers' representatives to exchange technical information with members of SEMATECH's technical advisory boards, who are senior technical managers from SEMATECH's member companies. Starting with the June 1990 meeting, SEMATECH decided to (1) convene the supplier boards in conjunction with the semiannual Presidents' day conferences to increase its member companies' involvement in the Presidents' day activities and (2) reduce the number of supplier board meetings from four in 1989 to two in 1990 to ease the burden on attendees. As of July 12, 1990, 229 SEMI/SEMATECH company representatives had participated in the supplier technical advisory board meetings.

Presidents and other senior executives from SEMI/SEMATECH's member companies are invited to attend SEMATECH's semiannual Presidents' day conferences. While senior executives from SEMATECH's member companies are invited, several members of SEMI/SEMATECH complained at the December 1989 conference about the absence of representatives of SEMATECH's members. According to SEMATECH's Vice President for Supplier Relations, the consortium has been working to increase member companies' participation. Eighty SEMI/SEMATECH companies participated in the June 1990 conference, which included presentations on partnerships between semiconductor manufacturers and their suppliers and technical workshops on SEMATECH's activities.

Participation by SEMI/SEMATECH's members in SEMATECH's annual reviews of the consortium's 11 centers of excellence is intended to increase the interaction between suppliers and university researchers. During the fall of 1989, SEMATECH, SEMI/SEMATECH, and the Semiconductor Research Corporation—which manages SEMATECH's centers of excellence program—signed an agreement giving SEMI/SEMATECH's members access to the centers' research. Representatives from 21 SEMI/SEMATECH suppliers attended the first joint review of the centers of excellence program in March 1990.

Initiatives to Improve Relations Between Manufacturers and Their Suppliers

In July 1989 SEMATECH established a Department of Supplier Relations to develop a comprehensive strategy for improving relations between semiconductor manufacturers and their equipment and materials suppliers. According to SEMATECH's Vice President for Supplier Relations, SEMATECH could not effectively develop a comprehensive strategy to improve relations between manufacturers and suppliers prior to the department's creation because the various SEMATECH groups dealing with suppliers were spread over a number of different departments.

In June 1990 SEMATECH's member companies approved Partnering for Total Quality guidelines for improving manufacturer-supplier relations. The guidelines, which were developed by two task forces of managers from SEMATECH members and SEMI/SEMATECH suppliers, highlight the elements necessary for long-term cooperative relationships and generally call for semiconductor manufacturers to work more closely with their key U.S. suppliers by (1) sharing strategic goals and plans; (2) giving them greater access to information about the long-term performance of their equipment in a fabrication facility, including the equipment's reliability and any recurring problems; (3) providing them with competitive analysis information; and (4) supporting their product development work. Each of SEMATECH's member companies agreed to have a high-level executive responsible for implementing the partnering guidelines. According to SEMATECH's Vice President for Supplier Relations, SEMATECH's Supplier Relations Action Council—which is composed of senior purchasing executives from the consortium's 14 members—will periodically review each company's progress in implementing the partnering guidelines.

The guidelines also provide (1) standards that both manufacturers and suppliers can use to continually improve the quality of products and services and (2) a total cost of ownership model for procuring equipment and materials that includes factors in addition to the purchase price, such as customer service, equipment failures, and factory yields. The cost model is intended to reduce uncertainties that result from manufacturers' emphasizing different factors in their procurement decisions.

Views of Senior Executives of Equipment and Materials Suppliers on SEMATECH's Initiatives

Executives from 28 of the 31 SEMI/SEMATECH suppliers we surveyed generally support SEMATECH's program and favor the expansion of one or more of SEMATECH's initiatives. However, while executives from 18 companies stated they have received good or excellent benefits by participating in SEMATECH, executives from 13 companies rated their benefits as fair or poor. Of 13 suppliers that were receiving financial and technical assistance from SEMATECH through one or more JDP and/or EIP contracts, 11 told us that they had received good or excellent benefits while 2 stated that they had received fair or poor benefits.

Executives from 16 of the 31 SEMI/SEMATECH suppliers either are uncertain whether SEMATECH's programs will significantly strengthen the U.S. semiconductor equipment and materials supplier base or believe the programs will not significantly strengthen it. In particular, executives from 12 companies stated that the success of SEMATECH's efforts to strengthen suppliers is contingent on the consortium's 14 member companies' taking a more active role in strengthening suppliers. Similarly, executives from seven companies stated that a much broader range of initiatives in addition to SEMATECH's program will be needed to strengthen the U.S. supplier base significantly. Executives from six companies stated that SEMATECH's initiatives will benefit only the suppliers that have a JDP and/or an EIP contract with SEMATECH, without providing much assistance to other suppliers.

Views on SEMATECH's External R&D Programs

Executives from 10 of the 13 companies receiving financial and technical assistance from SEMATECH through JDP or EIP contracts stated that SEMATECH's initiatives would significantly strengthen their companies' international competitiveness. Executives from the 13 companies cited one or more of the following benefits from their JDP and/or EIP contracts:

- 11 cited increased financial resources for R&D,
- 9 cited technical assistance from SEMATECH's personnel,
- 8 cited exchanges of technical information between their companies and semiconductor manufacturers and/or other suppliers, and
- 2 cited contributions of researchers from SEMATECH's centers of excellence and/or federal laboratories.

Executives from 9 of the 11 companies that have JDP contracts stated that the projects have allowed their companies to accelerate and/or increase the scale of their R&D activities. In one case, a JDP will enable the company to introduce a new product sooner, giving the company an important advantage over its foreign competitors. Similarly, executives we interviewed from all six companies with EIP contracts believe the projects will result in additional sales of their products. Even companies that do not have JDP and EIP contracts strongly support the programs. Executives from 24 of the 31 companies we surveyed believe the JDP and EIP funding should be expanded, allowing more suppliers to participate, if SEMATECH receives additional funding.

Thirteen of the 31 companies we surveyed have worked with or contacted federal laboratories involved in SEMATECH's program. Executives from 11 of these companies stated that SEMATECH has improved their access to federal laboratories' R&D results, and 2 executives cited specific benefits. In one case, a company working closely with Sandia National Laboratories obtained information for a total quality management program that it then implemented in several divisions. In the second case, the National Institute of Standards and Technology provided useful technical assistance for a company's R&D program.

Views on Initiatives to Improve Relations Between Manufacturers and Suppliers

Executives from 22 of the 31 suppliers we interviewed believe SEMATECH's initiatives to improve relations between manufacturers and their suppliers will succeed in improving their companies' relations with manufacturers, and executives from 25 companies support the expansion of these initiatives if SEMATECH receives additional funding. In fact, 7 of 20 executives who stated that their companies' relationships with

U.S. semiconductor manufacturers improved over the past year specifically credited SEMATECH's initiatives for this improvement. One executive mentioned that SEMATECH's uniform quality guidelines and standard total cost model will benefit many smaller suppliers that do not have the resources necessary to develop their own programs. However, another executive stated that SEMATECH's initiatives to improve manufacturer-supplier relations involve broad cultural changes within the semiconductor industry and will not be fully successful until SEMATECH's member companies make more of a commitment to changing their relationships with suppliers.

Views on the Forums for Communication

All of the executives we surveyed from the 31 SEMI/SEMATECH suppliers have participated in one or more of SEMATECH's forums to improve communication between semiconductor manufacturers and their suppliers. In general, the executives found one-on-one meetings with SEMI/SEMATECH's and SEMATECH's management, meetings with SEMATECH's supplier technical advisory boards, and technical workshops and conferences useful for developing contacts with executives and technical personnel from SEMATECH, other suppliers, and, to a lesser extent, manufacturers. According to one executive, prior to the existence of SEMATECH, most contacts between suppliers and manufacturers involved sales and marketing personnel, not high-ranking technical personnel. Another executive stated that his company has used information from a SEMATECH quality management workshop to develop a companywide total quality program.

However, several suppliers complained that only a few managers from semiconductor manufacturers attended the December 1989 Presidents' day conference, leading to changes and improved attendance at the June 1990 conference. In addition, several executives from small companies believe that SEMATECH's activities should be designed to facilitate participation by small companies. The executives explained that because small companies have only a few key personnel, they are less able to participate in SEMATECH's activities, such as technical workshops held in Austin, Texas.

Conclusions

SEMATECH is seeking to strengthen U.S. suppliers of semiconductor equipment and materials by (1) providing financial assistance to improve existing equipment and develop next-generation tools, equipment, and materials and (2) improving long-term working relationships between semiconductor manufacturers and their suppliers. Five members have agreed to operate suppliers' equipment in their fabrication facilities as part of two EIP projects.

Senior executives we surveyed from 31 SEMI/SEMATECH suppliers generally support SEMATECH's efforts. However, executives from 16 of the companies were uncertain whether SEMATECH will significantly strengthen the U.S. supplier industry because the consortium's efforts are limited by available resources. According to the executives, SEMATECH's success is contingent on the extent to which the 14 member companies will establish closer long-term working relationships with their U.S. suppliers.

In June 1990 SEMATECH's members agreed to participate in a new partnering program in which they intend to work more closely with their key U.S. suppliers by sharing (1) strategic goals and plans, (2) information about the technical performance of their equipment, (3) competitive analysis information, and (4) some of the costs of suppliers' product development work. This initiative, which is directed at one of the central issues that suppliers' executives highlighted for reasserting U.S. technological leadership, requires that SEMATECH's members change the way they have traditionally conducted business with their suppliers.

Matters for Congressional Consideration

Because SEMATECH's members will play a critical role in determining whether the U.S. semiconductor supplier base can be revitalized, the Congress may wish to closely monitor the commitment of SEMATECH's members to developing closer long-term working relationships with their suppliers and make further federal funding for SEMATECH contingent upon the members' following through with this commitment.

SEMI/SEMATECH Companies GAO Surveyed

Company	Location
ADE Corporation	Massachusetts
AG Associates	California
AMRAY, Inc.	Massachusetts
Applied Materials	California
Applied Science and Technology, Inc.	Massachusetts
Asyst Technologies, Inc.	California
ATEQ Corporation	Oregon
Bio-Rad Laboratories, Inc.	Massachusetts
Brooks Automation	Massachusetts
BTU Engineering Corporation	Massachusetts
Eaton Corporation	Massachusetts
GaSonics	California
GCA	Massachusetts
General Signal Corporation	California
Genus Incorporated	California
Hampshire Instruments, Inc.	Massachusetts
KLA Instruments	California
Lam Research Corporation	California
Lucas Laboratories, Ltd.	California
Novellus Systems, Inc.	California
Olin Corporation	Rhode Island
Optical Specialties, Inc.	California
ORASIS Corporation	California
Peak Systems, Inc.	California
Prometrix Corporation	California
Shipley Company	Massachusetts
Silicon Valley Group, Inc.	California
Thesis Group, Inc.	Texas
Ultratech Stepper	California
Varian Associates	California
Wilson Oxygen & Supply Company	Texas

SEMATECH's Joint Development and Equipment Improvement Projects Awarded as of June 30, 1990

Table II.1: Joint Development Projects

Supplier	Project
Advantage Production Technology	Wafer cleaning system
AMRAY, Inc.	High-resolution defect imaging and review tool
Applied Science and Technology, Inc.	Advanced plasma-etch technology
ATEQ Corporation	Advanced submicron reticle and mask exposure system
American Telephone & Telegraph Company	Deep ultraviolet resist technology
Drytek	Low-temperature plasma etching
Eaton Semiconductor Equipment Division	Advanced metal deposition system
Gas supplier team	Total systems approach to gas-related requirements
Union Carbide Industrial Gases, Inc.	
Semi-Gas Systems	
Wilson Oxygen and Supply Company	
GCA	Optical wafer stepper
Hampshire Instruments, Inc.	X-ray optics
Hewlett-Packard Company	Test chips and other devices for manufacturing demonstration
KLA Instruments	System to detect wafer defects
Lam Research Corporation	Technology for chemical vapor deposition
NCR Corporation	Isolation process technology
National Institute of Standards and Technology	Development of a metrology standard Parametric response surface control
ORASIS Corporation	System to detect wafer defects
Orchid One	Advanced electron beam microscope
Silicon Valley Group, Inc.	Advanced lithography processing systems
Silicon Valley Group Lithography Systems	Advanced lithography systems
University of Cinncinati	Research on advanced plasma-etch technology
Westech Systems, Inc.	Planarization equipment and processes

Table II.2: Equipment Improvement Projects

Supplier	Project
AMRAY, Inc.	AMRAY 1830 scanning electron microscope
Anatel, Inc./Particle Measuring Systems, Inc.	Point-of-use ultrapure water data
Angstrom Measurements, Inc.	Scanline II scanning electron microscope critical dimension measurement tool
Applied Materials, Inc	Precision 5000 chemical vapor deposition system Single wafer tungsten in Precision 5000 5500 cluster tool
Athens, Inc.	Hydrofluoric reprocessor Multielement analyzer
GCA	ALS 200 optical I-line stepper
Genus Incorporated	Genus 8720 chemical vapor deposition system for blanket and selective tungsten films
Insystems, Inc.	Holographic defect detection
Lam Research Corporation	Rainbow 4600 plasma metal etch system
Silicon Valley Group, Inc.	Vertical furnace technology

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Glossary

Chemical Vapor Deposition	A process in which insulating films and metals are deposited on a wafer using gases, elevated temperatures, and reduced pressure to obtain a chemical reaction.
Clean Room	A confined area in which the humidity, temperature, particulate matter, and contamination are precisely controlled within specified parameters. Federal Standard 209 defines the "class" of a clean room on the basis of the maximum number of particles of 0.5 micron size or larger that may exist in 1 cubic foot of air in the designated area.
Component	An individual electronic part, such as a transistor, diode, or capacitor, that is fabricated in a metal-oxide semiconductor or bipolar process.
Deposition	An operation in which a film is placed on a wafer without a chemical reaction with the underlying layer.
Dielectric	A material that does not conduct electricity, used as an insulating film in integrated circuits.
Diffusion	A process in which desired impurities are introduced into the silicon by baking the silicon wafers at high temperatures and pressures in chemically altered atmospheres. Diffusion is a less precise alternative to ion implantation.
Diode	A semiconductor component that allows electricity to flow only in one direction.
Doping	A process that deposits a chemical impurity onto a wafer surface to change its electrical properties.
Epitaxy	A silicon crystal layer grown on top of a silicon wafer exhibiting the same crystal structure orientation as the substrate wafer with a dissimilar doping type and/or concentration (examples:p/p+, n/n+, n/p, and n/n).

Etching	A process in which acid is used to remove previously defined portions of the silicon oxide layer covering the wafer to expose the silicon underneath. Removing the oxide layer permits introducing desired impurities into the exposed silicon through diffusion or ion implantation or the deposition of aluminum paths for electrical interconnection of circuit elements.
Gallium Arsenide	A compound semiconductor material that allows transistors and integrated circuits to operate much more rapidly than similar devices made of silicon.
Integrated Circuit	A complete electronic circuit composed of interconnected diodes and transistors and fabricated on a single semiconductor substrate, usually silicon.
Ion Implantation	A process in which the silicon is bombarded with high-voltage ions in order to implant them in specific locations and provide the appropriate electronic characteristics.
Lithography	A process in which the desired circuit pattern is projected onto a photoresist coating covering a silicon wafer. When developed, portions of the resist can be selectively removed with a solvent, exposing parts of the wafer for etching and diffusion.
Mask	A glass plate on which single integrated circuit layers are patterned. Typical integrated circuit fabrication requires 10-15 layers.
Metal Deposition	The use of sputtering or chemical vapor deposition to deposit conductive materials (i.e., aluminum, tungsten, or titanium) onto the wafer surface.
Metallization	A process in which a layer of metal, such as aluminum, is placed on the wafer to connect the transistors and diodes within an integrated circuit.

Metal-Oxide Semiconductor	One of two families of silicon transistors and integrated circuits (the other is bipolar) that is simpler to fabricate and hence is often used in manufacturing large, dense integrated circuits.
Metrology	The science of measuring and/or the ability to apply sensors and measurements to equipment and product.
Optical Lithography	The use of light waves to transfer integrated circuit patterns from a mask to photoresists on the wafer.
Photoresist	A photosensitive liquid plastic film applied to the surface of a wafer during lithography for micropatterning. (Also called resist.)
Planarization	A process in which a flat layer of glassy material is deposited over the lower layers of an integrated circuit. This step simultaneously creates a flat surface for further processing and isolates the lower layers.
Plasma	Ionized gas used to remove resist, etch, and deposit various layers onto a wafer.
Semiconductor	A material, typically silicon or germanium, that has four electrons in its outer ring and is a poor conductor of electricity. The term has come to refer to all devices made of semiconducting material, including integrated circuits, transistors, and diodes.
Silicon	One of the most common elements found in nature; the basic material used to make the majority of semiconductor wafers.
Solid-State Physics	The study of the properties, structure, or reactivity of solid materials, especially relating to the arrangement or behavior of ions, molecules, nucleons, electrons, and holes in the crystal of a substance, such as a semiconductor, or to the effect of crystal imperfections on the properties of a solid substance.

Solid-State Products	Products utilizing the electric, magnetic, or photic properties of solid materials, rather than electron tubes.
Sputtering	An operation in which a target material, such as gold or aluminum, is bombarded with argon ions. The displaced molecules of the target material are then deposited on the wafer surface.
Stepper	A sophisticated piece of equipment used to transfer an integrated circuit pattern from a mask onto a wafer.
Substrate	(1) The basic material upon which a device, circuit, or epitaxial layer is built; a wafer; (2) photoresist substrate—the material on which a photoresist coating is applied; (3) silicon substrate--the structure on which silicon epi is grown by the process of epitaxy.
Transistor	A three-terminal semiconductor device used mainly to amplify or switch.
Wafer	A thin disk, from 2 to 8 inches in diameter, cut from silicon or other semiconductor material. The wafer is the base material on which integrated circuits are fabricated.
X-Ray Lithography	The use of x-rays to transfer integrated circuit patterns from masks to resist-coated wafers.

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