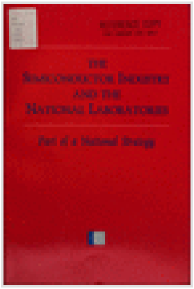
FROM THE ARCHIVES



The Semiconductor Industry and the National Laboratories: Part of a National Strategy (1987)

Pages
48

Size
5 x 8

ISBN
0309310830

Manufacturing Studies Board; National Materials Advisory Board; Commission on Engineering and Technical Systems; National Research Council

THE SEMICONDUCTOR INDUSTRY AND THE NATIONAL LABORATORIES

Part of a National Strategy

Report of a Workshop

Manufacturing Studies Board and
National Materials Advisory Board
Commission on Engineering and Technical Systems
National Research Council

National Academy Press
Washington, D.C. 1987

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This project was supported by the Academy Industry Program.

Available from:
The National Academy Press
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

STEERING GROUP FOR THE WORKSHOP ON THE SEMICONDUCTOR INDUSTRY AND THE NATIONAL LABORATORIES

LARRY W. SUMNEY (*Chairman*), President, Semiconductor Research Corporation
WILLIAM F. BRINKMAN, Executive Director, Research, Physics Division, AT&T Bell Laboratories
W. DALE COMPTON, Senior Fellow, National Academy of Engineering
BERNARD H. KEAR, State of New Jersey Professor of Materials Science and Technology, and Director, Center for Materials Synthesis, College of Engineering, Rutgers University
JAMES C. McGRODDY, Vice-president, Development and Manufacturing General Technology Division, IBM Corporation
MARTIN J. McHALE, Vice-president, Computer Applications Systems, Control Data Corporation

MANUFACTURING STUDIES BOARD

WICKHAM SKINNER (*Chairman*), Emeritus James E. Robison Professor of Business Administration, Harvard University
ANDERSON ASHBURN, Editor (retired), *American Machinist*
AVAK AVAKIAN, Vice-president, GTE Sylvania Systems Group
IRVING BLUESTONE, Professor of Labor Studies, Wayne State University
BARBARA A. BURNS, Manager, SYSTECON, Division of Coopers & Lybrand
CHARLES E. EBERLE, Vice-president (retired), Procter and Gamble
ELLIOTT M. ESTES, President (retired), General Motors Corporation
ROBERT S. KAPLAN, Arthur Lowes Dickinson Professor of Accounting, Graduate School of Business Administration, Harvard University
ROBERT B. KURTZ, Senior Vice-president (retired), General Electric Company
JAMES F. LARDNER, Vice-president, Component Group, Deere & Company
MARTIN J. McHALE, Vice-president, Computer Applications Systems, Control Data Corporation
THOMAS J. MURRIN, President, Energy and Advanced Technology, Westinghouse Electric Company
ROGER N. NAGEL, Director, Manufacturing Systems Engineering, Lehigh University
RICHARD R. NELSON, Henry C. Luce Professor of International Political Economy, School of International and Public Affairs, Columbia University
DAN L. SHUNK, Director, Center for Automated Engineering and Robotics, College of Engineering and Applied Sciences, Arizona State University
JEROME A. SMITH, Director of Operations, Martin Marietta Corporation
JOHN M. STEWART, Director, McKinsey & Company, Inc.
STEVEN C. WHEELWRIGHT, Kleiner Perkins Caulfield and Byers Professor of Management, Graduate School of Business Administration, Stanford University

JOHN A. WHITE, Regents' Professor, Industrial and Systems Engineering, and Director, Material Handling Research Center, Georgia Institute of Technology

EDWIN M. ZIMMERMAN, Member of the Bar, District of Columbia

NATIONAL MATERIALS ADVISORY BOARD

JOHN P. RIGGS, Executive Director of Technology, Celanese Research Corporation
WILLIAM P. SLICHTER, Executive Director (retired), Research Materials Science and Engineering Division, AT&T Bell Laboratories
JOHN E. TILTON, Coulter Professor, Department of Mineral Economics, Colorado School of Mines
JAMES C. WILLIAMS, Dean, Carnegie Institute of Technology, Carnegie Mellon University

Executive Summary

According to a recent report by the Defense Science Board, leadership in 19 of 25 key products and processes in the semiconductor industry has been lost to Japan and the relative position of U.S. producers is continuing to decline.[1] One response to this competitive challenge is to increase the U.S. semiconductor industry's efficiency through shared and collaborative research efforts. Existing industry cooperatives, such as the Semiconductor Research Corporation (SRC) and the Microelectronics and Computer Corporation (MCC), are proving the feasibility and effectiveness of collaborative research efforts. As an adjunct to industry collaboration, should other national resources, such as the national laboratories of the U.S. Department of Energy (DOE), be mobilized to leverage facilities, capabilities, and results on a national level?

To begin to answer this question and to determine the potential value, role, and contributions of the national laboratories in addressing the problems of the semiconductor industry, the National Research Council held a workshop on February 24, 1987. The workshop assembled representatives from the semiconductor industry, the national laboratories, federal agencies, and Congress to determine how cooperation between the laboratories and industry might take place within the context of a broader national action program.

A variety of issues related to the competitiveness of the semiconductor industry was discussed at the workshop. The participants agreed that the current problems of the semiconductor industry represent a national crisis that requires a coherent national action program in response. To summarize the discussion, workshop participants recognized that little progress is likely without a consensus on the short- and long-term competitive goals of the U.S. semiconductor industry.

Once these goals are identified, a national strategy to achieve them must be developed that would address issues such as the role of government, the extent of cooperation versus competition appropriate for a healthy industry in the future, appropriate research foci, effective use of resources outside of the industry, and mechanisms for achieving cooperation and synergism among participants in this national strategy. The workshop participants raised the idea that an organization or advisory committee with representatives from the semiconductor manufacturers, their suppliers and customers, government, and universities might be formed to provide the necessary leadership to build consensus and devise an effective national strategy.

In discussing the elements of an effective national strategy, the workshop participants agreed that it should combine and coordinate the resources of the semiconductor industry and the federal government in a cooperative effort to restore competitiveness. There was a consensus that the facilities and expertise available at the DOE's national laboratories are valuable resources that should be used to augment the research capabilities of industry and the universities.

To facilitate greater cooperation between the national laboratories and the semiconductor industry, several suggestions were made.

- A dialogue between the semiconductor industry and the national laboratories should be initiated and formalized to identify appropriate research projects and to negotiate pragmatic solutions to issues like data access, ownership and publication rights, cost sharing, scheduling, and technology transfer mechanisms. Existing collaborative research efforts could serve as models.
- A standing advisory council with representatives from industry and the various national laboratories could be formed to facilitate this dialogue and to serve as a forum for the discussion

of issues. Such a council could develop a broad agreement on the generic issues involved in cooperation and coordinate the overall cooperative effort, thereby facilitating agreements on specific research projects that are likely to be negotiated between individual laboratories and interested companies.

- There are opportunities for the national laboratories to continue existing projects and to initiate new research that would be beneficial to the industry. However, to maximize the effectiveness of this research, the mission of the laboratories needs to be expanded to include research in semiconductor-related science and technology. Additional funding will also be needed to provide the laboratories with sufficient resources to make an effective contribution to the long-term competitiveness of the semiconductor industry. The workshop attendees believed that these two issues—a broadened mission and increased funding—need to be addressed in DOE's budget process as quickly as possible.

There was broad agreement at the workshop that the federal government in general, and the national laboratories in particular, have a role to play in restoring U.S. competitiveness in semiconductors. If the industry can articulate specific areas of generic research that conform to the capabilities of the national laboratories, and the laboratories can adjust their operations and mobilize their resources to address those research areas, the potential contribution of the national laboratories for future industry competitiveness can be realized.

1
Background

STATE OF THE INDUSTRY

The rapid decline in competitiveness of the U.S. semiconductor industry is generating increasing alarm throughout the industry and government. Between 1980 and 1985, the U.S. share of the $26 billion world market for semiconductors dropped from 64 percent to 53 percent.[2] In the last four years alone (1983–1986), U.S. semiconductor companies have lost 20 percent of their market share.[3] In the key area of dynamic random-access memory (DRAM) chip production, where production technology is at the leading edge, the United States has fallen in a single decade from a position of total dominance to producing only about 10 percent of the devices sold.[4]

U.S. leadership in semiconductor production has been lost to Japan. A recent report of the Defense Science Board (DSB) declared that out of 25 semiconductor products or processes Japan now leads in 12 while the United States leads in 5, with parity in the other 8.[5] Furthermore, the report indicates that the U.S. position relative to Japan is continuing to decline in 19 of the 25 categories, including 4 of the 5 in which the United States now

TABLE 1 U.S. Losses in Semiconductor Technology Leadership

Technology Area	Japan Lead	U.S.-Japan Parity	U.S. Lead
Silicon products			
DRAMs[a]	<<<		
SRAMs[a]	<<<		
EPROMs[a]		<<<>>>	
Microprocessors			<<<
Custom, semicustom logic			<<<
Bipolar	<<<		
Nonsilicon products			
Memory	<<<		
Logic	<<<		
Linear			<<<>>>
Optoelectronics	<<<		
Heterostructures	<<<		
Materials			
Silicon	<<<		
Gallium arsenide	<<<		
Processing equipment			
Optical lithography		<<<	
E-beam lithography			<<<
X-ray lithography		<<<	
Ion implantation technology			<<<
Chemical vapor deposition		<<<>>>	
Deposition, diffusion, other		<<>>>	
energy-assisted processing	<<<		
Assembly		<<<>>>	
Packaging	<<<		
Test	<<<		
Computer-aided engineering		<<<>>>	
Computer-aided manufacturing		<<<	

KEY: >> = U.S. position improving; <<<>>> = U.S. position maintaining; <<< = U.S. position declining.

[a]DRAMs = dynamic random-access memory chips; SRAMs = static random-access memory chips; EPROMs = erasable, programmable, read-only memory.

SOURCE: Interagency Working Group on Semiconductor Technology.

leads. The United States is not gaining in any category. (Table 1 depicts these trends.)

A review of advanced processing of electronic materials conducted by the National Research Council in 1986 showed corresponding trends in this specific field. While the United States still holds the edge in three established areas, it lost control of a fourth (optical lithography) in 1986. In seven *emerging* areas having critical importance for future semiconductor processing, the Japanese have taken an early lead.[6]

This decline is of vital concern for several reasons. Not only is the worldwide semiconductor market substantial and likely to grow steadily, but also semiconductors are key to competitive production in many other large industries, such as computers, telecommunications, transportation, and medical equipment. Dependence on foreign sources for low-cost, high-quality chips can have pervasive downstream economic effects in terms of lost jobs, lost opportunities, and a worsening quality of life for Americans.

The potential impact on national security is also of concern. The U.S. Department of Defense (DOD) accounts for less than 10 percent of U.S. semiconductor sales, but these are often specialized devices. The DOD's ability to procure advanced semiconductors depends on the continued ability of the domestic commercial sector to produce leading-edge devices; reliance on second-rate or foreign products is considered unacceptable.[7]

Although many factors—technical, managerial, organizational, and economic—are contributing to the decline of the U.S. semiconductor industry, one primary reason is the decrease in long-range research and development (R&D) on the part of U.S. companies, especially in manufacturing process technologies. As manufacturing processes become increasingly complex and expensive, the ability of individual U.S. companies to afford the necessary research and subsequent implementation on an economic scale becomes more difficult. Japanese companies have the advantage of greater vertical integration allowing them to finance investments in process technology R&D with the profits from other businesses. Their dominance of the high-volume DRAM market provides valuable mass production experience and continued process refinement. Furthermore, intense competition between Japanese manufacturers provides strong incentives to make the necessary process refinements, while at the same time, the Ministry for International Trade and Industry (MITI) provides the leadership to focus and coordinate the overall Japanese effort.

EXISTING INITIATIVES

Over the past few years a number of proposals have been made by representatives of industry, government, and academe to address the declining competitiveness of the U.S. semiconductor industry. Two recent initiatives launched in parallel by the DOD and the Semiconductor Industry Association emphasize the development of advanced manufacturing technologies to restore competitive production capabilities.

A DSB Task Force on Semiconductor Dependency issued a report in February 1987 calling for the establishment of a Semiconductor Manufacturing Technology Institute.[8] This institute is envisioned as a consortium of private companies, capitalized with approximately $250 million and supported by $200 million per year in DOD contracts and industry funds.[9] Its purpose would be to develop, demonstrate, and advance the technology base by at least three generations for efficient, high-yield manufacture of advanced semiconductor devices and to provide the production facilities for special devices needed by DOD.[10]

The second initiative is being mounted by the Semiconductor Industries Association. Known as SEMATECH, for Semiconductor Manufacturing Technology, it is an industry consortium for both developing the manufacturing technologies that individual companies can no longer afford to develop and demonstrating those technologies by limited manufacture of advanced memory chips. The organizers project annual funding requirements to be $250 million, which is expected to come equally from the U.S. government and industry. A key element of SEMATECH will be its technology demonstration facility. The project will involve close collaboration among chip manufacturers, users, equipment producers, and the government.[11]

These two concepts, developed independently and almost simultaneously, arrived at a common focus. Both initiatives address semiconductor manufacturing technology as a central theme. Both envision DOD support for a collaborative industry effort, including production facilities. No fundamental differences exist in the two concepts at this time. Minor differences will be worked out sufficiently so that the two initiatives can form the core of a national effort to reverse the decline of U.S. competitiveness in semiconductors. However, it should be emphasized that the initiatives remain in the planning stage and no government money has yet been committed.

ROLE OF THE NATIONAL LABORATORIES

As these two initiatives illustrate, a potential response to the competitive challenge facing the U.S. semiconductor industry is to increase the industry's efficiency through shared and collaborative efforts. Ideally, such collaborative research would eliminate redundancy by performing generic R&D that participating companies could share for their mutual benefit. Existing industrial cooperatives, such as SRC and MCC in the semiconductor industry as well as the Electric Power Research Institute (EPRI) and the Gas Research Institute (GRI), have demonstrated that collaborative research is both feasible and successful.

Another response to the competitive challenge that could strengthen the value of collaborative research efforts is a coordinated mobilization of national resources capable of making a contribution to the semiconductor industry. For example, the national laboratories are a potentially important resource. Other federal laboratories, such as those within DOD and the National Bureau of Standards, also might have a role. Finally, the basic research agencies of the government, independent research organizations, universities, state-funded research initiatives, and the tool and material supplier base of the industry could be better mobilized to provide a coordinated national response to the semiconductor competitiveness problem.

For any of these organizations to be useful in responding to the competitive challenge in semiconductors, they must offer four basic attributes: (1) outstanding people capable of performing semiconductor research; (2) relevant technical experience, capabilities, and facilities; (3) an organizational environment that will support a productive response to critical needs in semiconductor technology; and (4) available mechanisms for transferring technology efficiently and effectively to potential users.

Government laboratories figure prominently among the organizations with these attributes. In his January 27, 1987, State of the Union Address, President Reagan broached the theme of industrial competitiveness, pledging his intention to see "that government does everything possible to promote America's ability to compete."[12] Apart from direct funding, the government laboratories represent an important resource at the disposal of the federal government for addressing the problems of competitiveness. In its report to the President's Science Adviser in 1983, a White House

Science Council panel chaired by David Packard recommended that "R&D interactions between federal laboratories and industry should be greatly increased by more exchange of knowledge and personnel, collaborative projects, and industry funding of laboratory work."[13]

In February 1987, the National Research Council held a workshop, "The Semiconductor Industry and the National Laboratories," to explore the potential value, roles, and contributions of the DOE-funded national laboratories in addressing the serious difficulties facing the U.S. semiconductor industry. Workshop participants attempted to determine how cooperation among the laboratories and industry might take place within the context of a broad national program of action. The remainder of the report will describe the themes that emerged from the workshop.

2
The DOE Laboratories: Capabilities and Potential Role

GENERAL CAPABILITIES

There are nine multiprogram national laboratories (Table 2). All were established under the Manhattan Project and the subsequent Atomic Energy Commission. They are government-owned, contractor-operated (GOCO) facilities that perform R&D for all major DOE programs and work for other federal agencies and the private sector on a cost-reimbursable basis.

The mission of the laboratories is threefold. They conduct: (1) basic research programs involving large multidisciplinary teams or capital-intensive experimental facilities; (2) basic and applied R&D programs in energy; and (3) R&D and production support for nuclear weapons and other defense-related activities. They also attempt to fulfill an educational role through linkages with universities and to provide for the transfer of technology to the public and private sectors.

Collectively, the national laboratories represent a considerable national resource. They house some of the most advanced and expensive research equipment found anywhere in the world: synchrotrons, supercomputers, particle accelerators, reactors, electron microscopes, and a multitude of other instruments, simulators, and specialized laboratory and test facilities. Over the years,

TABLE 2 The U.S. Department of Energy Multiprogram Laboratories

Laboratory	Year of Origin	Contractor	FY 1985 DOD Operating Budget[a]	FY 1985 Staffing
Argonne National	1946	University of Chicago	226	3,981
Brookhaven National	1947	Associated Universities, Inc.	203	3,263
Idaho National Engineering	1949	EG&G-Idaho, Inc. Westinghouse Nuclear	381	5,037
Lawrence Berkeley	1943	University of California	150	2,814
Lawrence Livermore	1952	University of California	150	7,876
Los Alamos National	1947	University of California	641	7,500
Oak Ridge National	1942	Martin-Marietta Energy Systems Inc.	370	4,771
Pacific Northwest	1956	Battelle Memorial Institute	142	1,982
Sandia National	1945	AT&T Technologies	930	8,400
Total			3,752	45,624

[a]Millions of dollars.

the laboratories have made enormous strides in fundamental and applied research in physics, chemistry, nuclear energy, defense materiel, medicine, electronics, computers, advanced materials, and other areas.

Technology transfer is taken seriously by the national laboratories. The Federal Technology Transfer Act of 1986 permits laboratory directors to enter into cooperative R&D agreements with private companies and to negotiate licensing agreements and contracts. All the DOE national laboratories have active joint ventures with individual firms and in some cases with consortia of firms. In 1985, the total number of joint projects was 125.

Exchange programs provide for the exchange of personnel between the laboratories and industry. The facilities are made available, under DOE's user facility policy, to qualified scientists and engineers from industry and academe for their research, including proprietary research. The DOE has issued class waivers granting patent rights in advance for work done by the laboratories for others, and for work done by others in the user facilities.

In fiscal year (FY) 1985, the DOE laboratories held 105 technology transfer workshops. Active consulting by laboratory staff is another medium for technology transfer.

CAPABILITIES OF SELECTED LABORATORIES

Presentations at the workshop by representatives of the DOE national laboratories described specialized facilities and expertise in place at the laboratories that are applicable to the semiconductor industry. At Brookhaven National Laboratory (BNL), for example, the National Synchrotron Light Source has given the staff experience in the design and use of storage rings and beam technologies. BNL sponsored a series of workshops in the summer of 1986 to generate concerted industry-government interest in the development of a synchrotron x-ray source for lithography of submicrometer features in semiconductors.

Sandia National Laboratories has a number of programs in integrated circuit technologies, processing science, materials, design, and diagnostics (Table 3). Sandia's microelectronics program emphasizes radiation-hardened chip technology for use in nuclear weapon systems and spacecraft. A new facility, known as the Radiation-hardened Integrated Circuit (RHIC-II) Laboratory, is under construction, including a Class One clean room. This facility is designed to support development and pilot production of ultra-large-scale integrated (ULSI) circuits at submicron dimensions in the 1990s.

Current programs at Oak Ridge National Laboratory (ORNL) relevant to the semiconductor industry range from fundamental materials characterization and solid-state theory to advanced manufacturing and specialized control technologies. There are specialized facilities for ion implantation and ion beam processing and deposition, pulsed laser annealing, laser photochemical vapor deposition, and neutron transmutation doping of silicon.

Lawrence Berkeley Laboratory, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Argonne National Laboratory also have some capabilities and facilities relevant to the semiconductor field.

THE SEMICONDUCTOR INDUSTRY'S NEEDS

Representatives from the semiconductor industry described

TABLE 3 Sandia Programs in Microelectronics Components Technologies, Processing, Science, Materials, and Diagnostics

Program Area	FY 1987 FTE[a]	Total Costs ($million)
Silicon integrated-circuit processing	66	13.0
Integrated-circuit design	50	8.0
Testing and assembly	40	6.0
Silicon technology	40	7.3
Integrated-circuit production operations (Allied Bendix)	209	17.0
Robotics and automation	15	2.8
Engineering modeling	5	0.8
Processing science and modeling	27	6.0
Diagnostics and materials	18	4.0
Compound semiconductor research	29	6.0
Total	499	70.9

[a]FTE = full-time equivalents.

their views on a national effort to strengthen semiconductor competitiveness. Their consensus was that the overriding objective of a national semiconductor strategy should be to strengthen the U.S. semiconductor technology base. That encompasses both merchant and "captive" chip producers, tool makers, and material suppliers as well as the resources in universities and government laboratories. In contrast to past tendencies, the focus today must be on the industrial commercial base, not on the expansion of fundamental knowledge.

The workshop participants recognized that it is probably unwise to characterize current industrial needs too narrowly; new breakthroughs and developments in both the technology and the market can readily alter detailed strategies. However, they were willing to set forth some broad directions.

To restore U.S. competitiveness in the international semiconductor market, the primary need is for improvements in semiconductor manufacturing processes. R&D is needed to advance chip fabrication and processing technology for better control, higher yields, and improved chip performance. The necessary research should include work on materials, wafer fabrication, material handling, processing equipment, design and manufacturing integration, and robotics. Assembly, packaging, testing, and inspection technologies, which account for 30 percent of total manufacturing costs, also deserve increased emphasis. The goal should be twofold: to develop electronic materials and new processing technologies for future devices and to refine and simplify existing processes to facilitate greater automation. The development of advanced equipment for characterization and diagnosis is a related area where more work is needed.

The second key area of need is advances in device technology. For example, DRAMs enter a new generation of devices every 2.5 years.[14] Present mass production capabilities offer 1-micron, 1-megabit (MBIT) chips. Nearing prototype production are 0.7-micron, 4-MBIT devices. U.S. industry should now be driving toward the second generation—0.35-micron, ULSI 64-MBIT advanced memory chips—and research efforts should be targeted at even smaller feature sizes of perhaps 0.25 micron with memories of 256 MBIT.

Various technologies are available to produce such ULSI chips. Excimer laser-based optical lithography with multilevel resists will probably be used down to minimum feature sizes of 0.5 to 0.3 microns. Sub-0.3 micron production could be based on electron beams, ion beams, or x rays using a synchrotron or plasma source. The ultimate choice will depend on both technical (e.g., alignment, depth of focus, and mask materials) and economic (e.g., capital cost and productivity) factors.

Researchers in both Japan and the Federal Republic of Germany are now working with government sponsorship to develop a commercially viable synchrotron x-ray source. Although the workshop participants emphasized the need to continue developing a variety of alternatives, they agreed that similar efforts are needed in the United States to demonstrate the merits of a synchrotron-based x-ray lithography system to produce 256-MBIT chips. Research should begin to address related technical areas such as x-ray masks, x-ray resists, alignment accuracy and control, magnet fabrication and flux control, and injector design.[15] Demonstration could be accomplished by linking this effort to a cooperative initiative such as SEMATECH.

To reiterate, the workshop participants emphasized that the urgent need is for R&D to support development and manufacture of advanced semiconductor devices. As the devices and processes become increasingly complex, the necessary R&D becomes too expensive for all but the largest individual companies to pursue effectively. A concerted national effort, mobilizing the resources of both the public and private sectors, is needed to achieve the breakthroughs that will be necessary for future competitive success.

AREAS OF OPPORTUNITY FOR THE NATIONAL LABORATORIES

Appendix A presents summaries of four proposals that were developed for the workshop by four of the DOE national laboratories. The proposals are for:

- the development of synchrotron x-ray lithography (Brookhaven);
- a Center for Silicon Process Integration (Sandia), including an automated pilot-production plant;
- an Advanced Processing Science Center Consortium (ORNL) for R&D in processing and new materials; and
- the establishment of a Process Analysis and Diagnostics Program (Lawrence Berkeley) focusing on materials and process characterization.

These proposals cover a wide range of subject matter. They also vary in terms of their degree of applicability to the industrial needs identified at the workshop. The evaluation of a working group of workshop participants is included at the end of each proposal summary in Appendix A.

The proposals presented at the workshop undoubtedly represent just some of the areas of opportunity that the national laboratories offer in support of the U.S. semiconductor industry. The workshop identified other areas in which individual companies have much to gain and little to lose by working together in collaboration with the laboratories. Design systems are a good example and others can be found in facility design, technical intelligence, and development of data bases. The laboratories' proposals are indicative of a relatively untapped resource that could be marshalled far more effectively than at present.

ISSUES AFFECTING INTERACTIONS WITH INDUSTRY

Although many U.S. semiconductor companies are already making use of the facilities and expertise of the national laboratories through bilateral collaborative efforts, several major concerns were raised at the workshop regarding future cooperation. Typically, current interactions are ad hoc, small in scope and scale, and are focused at fundamental rather than applied research. If the national laboratories are to provide beneficial support to the semiconductor industry in larger, more coordinated programs, supplying timely answers to industrial problems will be necessary. These programs would involve not only a change in the pace of research, but also the nature of the research to be pursued, the process of setting priorities, funding, and accountability. Efforts of the type described previously may require some change in operating style on the part of the laboratories.

Another major area of concern is the ability to define "U.S. industry" clearly enough, given the multinational nature of many U.S. electronics companies and the prevalence of institutional arrangements with foreign (e.g., Japanese) partners. To what extent should foreign participation or linkage be permitted in government-funded activities? Past programs at the national laboratories, such as the CAMDEC consortium in ceramics at Oak Ridge and the steel initiative at Argonne, have established rules regarding foreign participation. Some programs have completely precluded foreign participation through company ownership. Similar rules may be more difficult to define and apply in the semiconductor industry, but precedents have been, or are being, set.

Finally, the workshop attendees raised philosophical and practical concerns regarding the appropriate balance of federal research activities between the traditional emphasis on basic research and new initiatives in applied research designed to help meet the needs of commercial industry. The federal government has spurred technology development and implementation through regulation (e.g., pollution control), defense procurement needs, and mission-oriented programs such as the space program. Federal research activities have not been focused on commercial needs and, although substantial scientific and technological developments have been transferred from federal laboratories to private industry, such technology transfer has usually been unplanned.

Given this historical background, the ability of the federal government in general and the national laboratories in particular to make a beneficial contribution to the R&D needs of the semiconductor industry is not assured. Participants at the workshop agreed that a new structured program to focus some of the resources of the national laboratories on the commercial problems of the semiconductor industry will need careful planning and involvement with the industry to be successful. However, precedents exist that give cause for optimism.

3
Conclusions

A consensus emerged at the workshop that the decline in competitiveness of the U.S. semiconductor industry must be recognized as a crisis on a national level. The participants agreed that the first step in restoring the industry's competitiveness is to build a national consensus on the appropriate short- and long-term goals of the industry, including researchers, materials and equipment suppliers, chip manufacturers, and commercial and defense users. The workshop attendees recognized that building such a consensus and devising an effective national strategy for achieving it will require strong leadership that has traditionally been lacking in the industry. Substantial barriers exist, but the participants were optimistic that progress could be made.

In discussing the elements that would be needed to devise and implement an effective national strategy, the workshop participants raised a number of ideas that deserve further consideration.

NATIONAL AND INDUSTRY NEEDS

1. National leadership might be provided through the formation of an organization or advisory committee with representatives from the semiconductor manufacturers, their suppliers and major customers, government, and universities. The committee,

which could perhaps be called the National Advisory Committee on Semiconductors, would provide a focal point for devising and implementing an effective national strategy for semiconductors. The committee would stay abreast of the state of the semiconductor technology base, both in the United States and abroad, and recommend actions to recover and maintain leadership in this technology. Perhaps most important, such a committee would facilitate government-industry cooperation in semiconductors through structured communication channels and better coordination of research, investments, expectations, and policies.

The workshop participants believed that the need for such a national advisory committee is apparent given the importance of the semiconductor industry to national welfare, but they recognized that the concept needs to be developed further to determine whether or not it should be a government body and its appropriate membership, necessary funding levels, responsibility, and authority.

2. An effective national strategy for restoring the competitiveness of the U.S. semiconductor industry would need to identify sources of national expertise and appropriate participants, and to address issues such as the extent of cooperation and competition, appropriate research foci, and mechanisms for achieving the most efficient use of available national resources. Close scrutiny of federal policies and laws would also be an important aspect of a national strategy. Current legislation is useful, but may be inadequate in some areas. For example, tax provisions, antitrust restrictions, and export controls are all areas that deserve reexamination. The appropriate committees of Congress should examine the legislative requirements for an effective national effort.

3. The workshop attendees agreed that an effective national strategy would need to include a national research agenda for the semiconductor industry to define areas of generic research that are best conducted through joint efforts. This research agenda should focus on design and production technologies leading to effective, competitive mass production of advanced devices. Such research should not be limited to achieving further reductions in circuit dimensions. It should include work on materials, wafer fabrication, material handling, processing equipment, design and manufacturing integration, robotics, and assembly, packaging, testing, and inspection technologies.

The national advisory committee described in item 1 would probably be the appropriate body to develop such a research agenda and monitor its progress, although such an activity needs more definition than could be supplied in a single workshop.

ROLE OF THE NATIONAL LABORATORIES VIS-À-VIS INDUSTRY

In addressing the potential role of the DOE national laboratories, the workshop participants concluded that the facilities and expertise at the laboratories represent a valuable set of resources that should be utilized effectively to augment the research capabilities of industry and universities. Several suggestions were made at the workshop to facilitate greater cooperation.

4. A dialogue between the semiconductor industry and the national laboratories should be initiated and formalized to identify appropriate research projects and to negotiate pragmatic issues such as data access, ownership and publication rights, cost sharing, scheduling, and technology transfer mechanisms. Various collaborative research efforts, both with the semiconductor industry and other industries, have been undertaken in the past which could serve as models for such cooperation.

5. An effective mechanism is needed to facilitate this dialogue between the DOE laboratories and the semiconductor industry. One possibility raised at the workshop is to form a standing advisory council with representatives from the industry and the various national laboratories to serve as a forum for discussion of issues. Such a council could develop a broad agreement on the generic issues involved in cooperation, such as data access, publication rights, and technology transfer, thereby facilitating agreements on specific research projects that are likely to be negotiated between individual laboratories and interested companies. The council could also serve as a coordinating body to eliminate overlap and redundancy in research projects, to stimulate continued cooperation, and to facilitate effective technology transfer.

6. Although the workshop attendees expected that most of the cooperation between the semiconductor industry and the national laboratories would continue to be based on specific research projects performed jointly or on a contract basis, opportunities exist for the national laboratories to initiate research that would

be beneficial to the industry. Some existing research projects are relevant to the needs of the semiconductor industry, and future investments in facilities and equipment at the laboratories will broaden the scope of such activity. However, to maximize the effectiveness of this research, the mission of the laboratories should be expanded to include research in semiconductor-related science and technology. Additional funding will also be required to provide the resources for an effective contribution to the long-term competitiveness of the semiconductor industry. The need for both broadened mission and increased funding should be addressed in DOE's budget process as quickly as possible.

The simplest way to summarize these points from the workshop discussion is to describe the participants' concerns regarding the impediments to progress that exist in the current operating environments for both the private sector and the federal government. In general, the semiconductor industry has not been sufficiently coordinated or organized to articulate the nature of its problems. Furthermore, it is not clear that the primary sources of the industry's declining competitiveness are inadequate technology and insufficient research activity. Business, economic, and organizational factors may be equally important in explaining the industry's recent difficulties.

The national laboratories have been successful in cooperating with individual companies on relatively small projects that integrate well with their primary research efforts, but have not yet attempted large-scale cooperative research. The possibility for conflict between serving their primary government mission and providing meaningful support for private industry is great. Furthermore, research findings and technology developments at the national laboratories have been transferred successfully to many different industries. Too much focus on the semiconductor industry could conceivably be detrimental to the national laboratories' work with other industries.

Finally, policymakers in both the public and private sectors need to ensure that viable research plans and cooperative mechanisms are in place before major investments are made. Improvements in these environmental conditions, through pursuit of the elements described above, are a prerequisite for an effective national strategy for semiconductor competitiveness.

Notes

[1]Defense Science Board. Report of the Defense Science Board Task Force on Semiconductor Dependency. U.S. Government Printing Office, Washington, D.C., February 1987.

[2]Appleton, B. R. Advanced Processing of Electronic Materials: Government Perspective. Report of the Panel on Research Resources in Materials Science and Engineering, Materials Science and Engineering Study. Oak Ridge National Laboratory, October 17, 1986, p. 1.

[3]Pollack, A. U.S. sees peril in Japan's dominance in chips. *The New York Times,* Monday, January 5, 1987.

[4]Nordwall, B. D. Defense Science Board urges semiconductor consortium. *Aviation Week and Space Technology,* March 2, 1987, 126(9):94.

[5]Defense Science Board.

[6]National Research Council. Advanced Processing of Electronic Materials in the United States and Japan. Report of the Panel on Materials Science, National Materials Advisory Board, Commission on Engineering and Technical Systems. National Academy Press, Washington, D.C., 1986, p. 2.

[7]Defense Science Board.

[8]Ibid.

[9]Pollack.

[10]Nordwall.

[11]Auerbach, S. Chip makers seek funds for proving ground. *The Washington Post,* January 4, 1987, p. H-1.

[12]Reagan, R. Remarks by the President on the State of the Union. The Capitol, Washington, D.C., January 27, 1987, p. 5.

[13]Office of Science and Technology Policy. Report of the White House Science Council, Federal Laboratory Review Panel. Executive Office of the President, Washington, D.C., May 1983, p. x.

[14]Robertson, J. SIA, DOD agree on SEMATECH name for IC consortium. *Electronics News,* February 23, 1987.

[15]Letter from Hon. Don Fuqua and Bill Carney, members of Congress, to Dr. Alvin Trivelpiece, director of the Office of Energy Research, Department of Energy, Washington, D.C., October 6, 1986.

Appendix A
Four Proposed Collaborative Projects

SYNCHROTRON X-RAY LITHOGRAPHY

(Proposal by Brookhaven National Laboratory)

Background. Until the early 1980s, technologies permitting 1:1 projections of material were employed to deposit lines on substrates to form integrated circuits (ICs). Size reductions were greatly limited by these technologies. Currently, and through the early 1990s, various reduction steppers are being used to further reduce line sizes. (For example, deep ultraviolet stepper lithography is expected to permit resolutions as small as 0.3 micron in prototype chips by 1994.) However, for the 1992-2002 decade, synchrotron lithography in the x-ray range will be the technology of choice. Among its advantages are high throughput, greater linewidth control and uniformity, transparency of defects, large field size, and the fact that no focus is required. More particularly, it permits 0.25-micron resolution in the manufacture of ICs. Because it eliminates many of the processing steps required in optical or E-beam lithography, x-ray lithography should yield considerably lower cost per wafer.

Proposal. Brookhaven proposes to use its facilities (some existing and some to be developed for the purpose) and personnel to pursue the development of x-ray lithography as a tool for pursuing the next generation of integrated circuit. The goal would be to develop a manufacturable technology for the mid-1990s that would yield 0.25-micron linewidth ICs with a 64-megabit, dynamic random-access memory (DRAM).

The technology would employ Brookhaven's planned synchrotron facilities as the x-ray generator. The proposed effort would require several elements. (1) A formidable task would be the development of x-ray mask technology; this would include the materials required for the mask membrance and absorber, and the development of new tooling equipment for E-beam writing and other purposes. (2) Research and development (R&D) on the synchrotron exposure system would be another element, requiring the development and optimization of beamline components and the evaluation of the system (i.e., determination of its lithographic limits). (3) Demonstration of the 0.25-micron IC itself would entail evaluating the economic viability of the technology and comparing it with competing technologies. (4) Finally, an IC demonstration facility would be developed, with a mask-making capability and a 1,000 wafer-start per week process line.

Brookhaven officials project that application of synchrotron x-radiation would start midway through the third year of the program, with 0.25-micron technology first becoming available sometime around the end of the fourth year. Design and prototyping of a 0.25-micron, ultra-large-scale, 64-megabit DRAM chip would extend from the fifth through the sixth year.

Some of the key technical barriers and other considerations identified by Brookhaven are: mask stability, cleaning, contamination, and cost; E-beam writing of a 1:1 mask; ion beam repair; brief synchrotron up-time; manufacturing at the 0.25-micron size; IC radiation damage; and x-ray resists.

Working Group Comments. A working group of workshop participants held a divided opinion on the merits of the Brookhaven proposal. The group's industry participants expressed a noncommittal view of x-ray lithography in general. In question was not only the cost-effectiveness of the technology, but also whether lower-cost alternative technologies would be available by the time 0.25-micron technology is required by the competitive marketplace. In any case, the group felt that the Brookhaven proposal must be considered in the context of a broader national initiative.

Additionally, the group believed, any attempt to develop x-ray lithography must take into account the apparent willingness of IBM to share the results of its efforts.

CENTER FOR SILICON PROCESS INTEGRATION

(Proposal by Sandia National Laboratories)

Background. Sandia management and staff are aware that the U.S. semiconductor industry is in crisis. Recognizing that the laboratory possesses facilities and semiconductor processing skills of potential relevance to the needs of industry, they explored ways in which Sandia could help. In 1986 a team from the Semiconductor Research Corporation (SRC) visited Sandia to assess its potential contributions. This team identified the following areas in which Sandia support could most benefit the industry (in order): (1) refine new semiconductor equipment and materials, and distribute know-how; (2) develop a prototype automated process line; (3) develop a design/fabrication facility optimized for rapid product development through prototype parts; and (4) develop/qualify a submicron complementary metal oxide semiconductor (CMOS) process and transfer it to industry. The latter was identified as the area that would require the maximum additional effort from Sandia. From these considerations, Sandia developed a proposal for a Center for Silicon Process Integration (CSPI).

Proposal. The theme of CSPI activities would be to integrate and perfect silicon processes to improve the insertion of technology into manufacturing. The goals of the proposed center are: (1) to work with industry to develop key process equipment and stable, robust processes; (2) to integrate new equipment and processes in a pilot-production environment; (3) to create an environment that facilitates transfer of technology among industrial, university, and government personnel; and (4) to develop and integrate automation relevant to the semiconductor industry.

To achieve the first two of these goals, the proposed center would hope to establish, by 1991, an equipment set and the processes necessary to support development of 0.5-micron CMOS technology, with a 0.25-micron CMOS follow-on program. Production engineering on the 0.25-micron chip would begin in 1993. Achieving this objective would require that Sandia skip one generation of radiation-hardened technology (i.e., 1.0 micron) and merge two subsequent ones (0.7 and 0.5 microns)—a significant acceleration of its program.

A second feature of the proposed center would be to establish among the national labs, industry, and universities a number of joint programs addressing manufacturability. Joint working groups comprising researchers from the three sectors would utilize the facilities of the laboratory. Workshops, seminars, and other standard venues for technology transfer would be employed.

To achieve the fourth goal, the CSPI would establish a national automation and computer-integrated manufacturing (CIM) pilot program. Through work on CIM data-base structures and control functions, on application of mobile robots to wafer fabrication, and on hardware/software interfaces with robots and CIM, the center would pursue development of an integrated, flexible system that is facility-independent. The objective in this area would be to establish, by 1990, an automated wafer fabrication system that requires minimal human intervention or control. By 1992, the program would move to define and implement a second-generation, totally automated system.

According to the authors of the proposal, the work in the automation area would provide industry with a proven automation strategy and system hardware/software that could be transferred to other semiconductor facilities with minimal development costs. The facility would also function as a test-bed for new concepts and equipment, and would stimulate related cooperative R&D efforts in the nation's universities, industry, and national labs. The proposed center would differ from SEMATECH in that it would emphasize flexible (rather than high-volume) and preproduction (rather than commercial) technology, focusing just on wafer fabrication, automation, and CIM—whereas SEMATECH addresses all facets of semiconductor manufacturing.

The proposed center would aim for significant benefits to industry in three to five years, aided by its nonproprietary environment for cooperative efforts on problems of manufacturability. Estimated total annual cost is estimated at $35 million.

Working Group Comments. In the opinion of a working group of workshop participants, the Sandia proposal suffers from the laboratory's mission requirement that efforts be directed at radiation-hardened devices. That requirement limits the scope of the proposed activity in undesirable ways. Furthermore, the technology being pursued is not at the leading edge in performance (e.g., 0.7-micron device prototypes are virtually at hand). The fact that the proposal is endorsed by the SRC, however, carried some weight with working group participants.

ADVANCED PROCESSING SCIENCE CENTER CONSORTIUM

(Proposal by Oak Ridge National Laboratory)

Background. Although its primary mission is in energy technologies and basic physical and life sciences, the Oak Ridge National Laboratory (ORNL) has the largest materials R&D program among DOE laboratories. ORNL recognizes the fact that existing national laboratory/industry interactions in semiconductor processing lack several things, such as a focus on industry needs, commitment commensurate with the magnitude of the problems, and appropriate involvement of the semiconductor industry. There are already mechanisms in place at ORNL for interacting with industry on collaborative projects. The most notable are the Collaborative Research Centers (CRCs), which make selected facilities available to outside users. These are operated at no cost to users for nonproprietary research. (Proprietary research requires full-cost recovery.)

Of the CRCs, the most relevant to semiconductor research and technology is one operated in conjunction with the Surface Modification and Characterization (SMAC) Facility. The SMAC is a $10 million facility with capabilities for ion beam and laser processing, materials and surface characterization, and processing and new materials development. The SMAC CRC had approximately 90 collaborative users in FY 1985. To date, ORNL has conducted six projects in collaboration with the semiconductor industry. An example is a project on direct ion beam deposition, carried out jointly between IBM and Motorola, on the one hand, and two ORNL divisions on the other.

Proposal. The ORNL proposal is for the establishment of an Advanced Processing Science Center (APSC) consortium for semiconductor R&D. The proposed center would focus on (1) advanced processing technology and (2) new materials development. Development would occur in three phases. In the start-up phase, the APSC would share existing SMAC CRC space and facilities.

Approximately $2.5 million would be required from DOE for new equipment. The laboratory/industry consortium would be organized jointly by DOE and industry. Estimated additional funds needed to initiate the APSC and the collaborative R&D programs are $2 million.

Phase II, expected to extend from years 2–4, would be an evolutionary period during which separate space and facilities are to be developed at ORNL for the APSC, with continued access to SMAC and other ORNL facilities. Focused, collaborative R&D projects would be initiated at this stage. Phase III would be the stable state, with core support from ORNL and full-scale collaborative programs, also involving universities, in operation.

According to the authors of the proposal, among the advantages offered by the APSC arrangement (apart from the obvious leveraging of government funds and facilities for the benefit of industry) are the facts that it: (1) provides a multidisciplinary approach to a multidisciplinary problem; (2) expands the mission of the laboratory to an explicit focus on industrial competitiveness; (3) establishes a "MITI laboratory"-like entity (Japan's Ministry of International Trade and Industry) within the U.S. system; and (4) provides an educational center in this vital field.

Working Group Comments. A working group of workshop participants agreed that the processing and characterization expertise offered by ORNL would be very useful to industry. However, they considered it imperative that the knowledge generated by any such endeavor be embedded in manufacturing and characterization equipment. To that end, close collaboration with equipment vendors would be essential. The emphasis should be on manufacturing and characterization technology, they believe, rather than on new materials for future devices.

PROCESS ANALYSIS AND DIAGNOSTICS

(Proposal by Lawrence Berkeley Laboratory)

Background. The Lawrence Berkeley Laboratory (LBL) conducts a broad range of multidisciplinary research, with a heavy emphasis on particle and nuclear physics. There are current research activities relating to semiconductor devices in four of its divisions. Specialized facilities are available on site for structural and electrical characterization of materials. These include an atomic resolution microscope and an advanced light source now under construction. The latter is a 1–2 GeV synchrotron light source, due to be completed in 1992. It will be a user facility (i.e., available to outside users) with a significant capacity for dedicated beamlines. Potential semiconductor applications are said to include high-throughput x-ray lithography and a variety of analytical techniques such as x-ray microscopy for the detection of trace contaminants.

The largest element of LBL semiconductor-related work is found in its Center for Advanced Materials (CAM). An Electronic Materials Program within CAM is directed at research on III-V crystal growth, and at the development of relevant analytical techniques. Within that program, there are currently four projects (three in research and one in development) conducted jointly with industry.

Proposal. The proposal is to establish, within the CAM, a new program on Process Analysis and Diagnostics. The technical goals of this program would be in three areas: (1) microscopic understanding of the semiconductor fabrication process, (2) development of diagnostic tools, and (3) process equipment simulation. The proposed program would facilitate industry access to LBL facilities and encourage collaboration. The latter would build on an existing CAM Industrial Fellows Program. The proposal envisions some 10 full-time equivalent LBL scientists working with industry topical groups and liaison personnel and collaborating with research groups at the University of California, Berkeley.

Working Group Comments. The reactions of the working group to this proposal were similar to the reactions to the Oak Ridge proposal. They agreed that the characterization, diagnostic, and simulation expertise offered by LBL could be useful to industry. However, the knowledge generated by any such endeavor should be focused on solving applied engineering problems in the manufacturing process rather than on fundamental research. As with the Oak Ridge proposal, close collaboration with equipment vendors would be essential.

Appendix B
Workshop Participants

LARRY K. ANDERSON, Vice-president, Organization 2000 (Component, Development), Sandia National Laboratories

BILL R. APPLETON, Director, Solid State Division, Oak Ridge National Laboratory

SEYMOUR BARON, Associate Director, Brookhaven National Laboratory

MARTIN BLUME, Deputy Director, Brookhaven National Laboratory, Associated Universities, Inc.

JUDITH L. BOSTOCK, Budget Examiner, Nuclear Energy Branch, Office of Management and Budget

WILLIAM F. BRINKMAN, Executive Director, Research, Physics Division, AT&T Bell Laboratories

ROBERT A. BURMEISTER, Director, Materials Research Laboratory, Hewlett-Packard Company

W. DALE COMPTON, Senior Fellow, National Academy of Engineering

BENJAMIN S. COOPER, Professional Staff Member, Senate Committee on Energy and Natural Resources

JOHN DUGAN, JR., Staff Director, Subcommittee on Energy Research and Production, Committee on Science and Technology, U.S. House of Representatives

DEAN E. EASTMAN, Thomas Watson Research Center, IBM Corporation

FRANK FRADRIN, Director, Materials Sciences Division, Argonne National Laboratory

TOMMY GEORGE, Vice-president and Assistant General Manager, Motorola Semiconductor Products Sector

JULES GODEL, Associate Chairman, National Synchrotron Light Source Department, Brookhaven National Laboratory

BOB LEE GREGORY, Director of Microelectronics, Sandia National Laboratories

RICHARD HESSE, National Synchrotron Light Source Department, Brookhaven National Laboratory

WILLIAM C. HOLTON, Director, Microstructure Sciences, Semiconductor Research Corporation

PAUL G. HURAY, Senior Policy Analysis, Office of Science and Technology Policy

LOUIS C. IANNIELLO, Deputy Associate Director for Basic Energy Sciences, U.S. Department of Energy

ROBERT A. JACOBSEN, Manager, Advanced Products Development, Maxwell Laboratories

BOB JENKINS, Vice-president and Director for Technology Management, Motorola Semiconductor Products Sector

R. A. JOHNSON, Manager, Energy Programs, General Dynamics

ANTOINETTE GRAYSON JOSEPH, Director, Office of Field Operations Management, U.S. Department of Energy

SANFORD L. KANE, Vice-president, Industry Operations, IBM Corporation

GAYNOR N. KELLEY, President and Chief Operating Officer, The Perkin-Elmer Corporation

RONALD L. KERBER, Deputy Under Secretary for Research and Advanced Technology, U.S. Department of Defense

JACK S. KILBY, Consultant (Chairman, Advisory Group on Electronic Devices, U.S. Department of Defense)

E. R. KIMMY, Program Manager, Energy Programs, General Dyanmics

CAROLE E. KITTI, Economist, Special Studies Division, National Security and International Affairs, Executive Office of the President, Office of Management and Budget

MICHAEL L. KNOTEK, Chairman, National Synchrotron Light Source, Brookhaven National Laboratory

NORMAN KREISMAN, Industry Technology Competitiveness Adviser, Office of Laboratory Management, Office of Field Operations Management, U.S. Department of Energy
CHARLES F. KRUMM, Manager, Microelectronics Laboratory, Hughes Aircraft Company
ROSS A. LEMONS, Los Alamos National Laboratory
GORDON T. LONGERBEAM, Lawrence Livermore National Laboratory
MICHAEL B. MARKS, Assistant Director for Global Technology, Office of Science and Technology Policy
JOSEPH MATHIAS, Program Director, Cross-Disciplinary Research Division, Directorate for Engineering, National Science Foundation
E. D. (SUNNY) MAYNARD, JR., Director, Very High Speed Integrated Circuits/Electronic Devices, OUSDA (R&AT/CET), U.S. Department of Defense
JAMES C. McGRODDY, Vice-president, Development and Manufacturing, General Technology Division, IBM Corporation
MARTIN J. McHALE, Vice-president, Computer Applications Systems, Control Data Corporation
BRUCE M. McWILLIAMS, LP Program Leader, Lawrence Livermore National Laboratory
JIM NORLING, Vice-president and General Manager, Motorola Semiconductor Products Sector
WILLIAM T. OOSTERHUIS, Program Director, Instrumentation for Materials Research Program, Division of Materials Research, Directorate for Mathematical and Physical Sciences, National Science Foundation
D. O. PATTERSON, OUSDA (R&AT/CET), U.S. Department of Defense
HERMAN POSTMA, Director, Oak Ridge National Laboratory
FRANK PRESS, President, National Academy of Sciences
RICHARD A. REYNOLDS, Director, Defense Sciences Office, Defense Advanced Research Projects Agency, U.S. Department of Defense
PETER H. ROSE, President, Ion Beam Systems Division, Eaton Corporation
GERD M. ROSENBLATT, Lawrence Berkeley Laboratory
J. M. ROWELL, Solid State Science and Technology Research Laboratory, Bell Communications Research

N. P. SAMIOS, Director, Brookhaven National Laboratory
DAVID A. SHIRLEY, Director, Radiation Laboratory, Lawrence Berkeley Laboratory
L. DAVID SIKES, Vice-president, Technical Staff and Director, Semiconductor R&D Laboratories, Semiconductor Products Sector, Motorola Inc.
KERMITH SPEIERMAN, Chief Scientist, National Security Agency
HELMUTH SPIELER, Staff Scientist, Engineering Division, Lawrence Berkeley Laboratory
CHARLES E. SPORCK, President, National Semiconductor Corporation
EUGENE STARK, Chairman, Federal Laboratory Consortium for Technology Transfer, Los Alamos National Laboratory
DONALD K. STEVENS, Associate Director for Basic Energy Sciences, U.S. Department of Energy
ROBERT STRATTON, Vice-president, Corporate Staff and Director Central Research Laboratories, Texas Instruments Incorporated
LARRY W. SUMNEY, President, Semiconductor Research Corporation
MICHAEL J. THOMPSON, Executive Director, Integrated Circuit Design Division, AT&T Bell Laboratories
FREDERICK L. VOOK, Director, Organization 1100 (Solid State Sciences), Sandia National Laboratories
HARLAN WATSON, Subcommittee on Energy Research and Development, U.S. House of Representatives
PHILIP WEBRE, Principal Analyst, U.S. Congressional Budget Office
GWYN WILLIAMS, Physicist, Head, X-ray Lithography Steering Committee, National Synchrotron Light Source Department
A. W. YANOF, Supervisor, X-Ray Technology Group, AT&T Bell Laboratories
ALEXANDER ZUCKER, Associate Director, Oak Ridge National Laboratory

National Research Council Staff

DAVID L. BODDE, Director, Commission on Engineering and Technical Systems

ANNE G. KEATLEY, Director of the Academy Industry Program, National Academy of Sciences

GEORGE H. KUPER, Director, Manufacturing Studies Board, Commission on Engineering and Technical Systems

THOMAS C. MAHONEY, Staff Officer, Manufacturing Studies Board, Commission on Engineering and Technical Systems

MICHAEL A. McDERMOTT, Staff Officer, Manufacturing Studies Board, Commission on Engineering and Technical Systems

NORMAN METZGER, Deputy Director, Office of Government and Public Affairs

KERSTIN B. POLLACK, Director, Program Development, Manufacturing Studies Board, Commission on Engineering and Technical Systems

STEPHEN RATTIEN, Deputy Executive Director, Commission on Engineering and Technical Systems

DONALD C. SHAPERO, Staff Director, Board on Physics and Astronomy, Commission on Physical Sciences, Mathematics, and Resources

KLAUS M. ZWILSKY, Director, National Materials Advisory Board, Commission on Engineering and Technical Systems