COOPERATIVE RESEARCH

Member Companies

Advanced Micro Devices, Incorporated
Burroughs Corporation
Control Data Corporation
Digital Equipment Corporation
E. I. du Pont de Nemours & Company
Eaton Corporation
E-Systems, Incorporated
General Electric Company
General Instrument Corporation
Goodyear Aerospace Corporation
Harris Corporation
Hewlett-Packard Company
Honeywell, Incorporated
IBM Corporation
Intel Corporation
LSI Logic Corporation
Monolithic Memories, Incorporated
Monsanto Company
Motorola, Incorporated
National Semiconductor Corporation
The Perkin-Elmer Corporation
RCA Corporation
Rockwell International Corporation
SEMI, Chapter*
Silicon Systems, Incorporated
Union Carbide Corporation
Varian Associates, Incorporated
Westinghouse Electric Corporation
Xerox Corporation

The following companies are included in the Semiconductor Equipment and Materials Institute, Inc., CHAPTER: Micro Mask, Inc.; Pacific Western Systems, Inc.; Probe-Rite, Inc.; Pure Aire Corporation.

COOPERATIVE
RESEARCH

In February of 1982, articles were filed incorporating the SRC as a nonprofit organization to "conduct research which will include scientific study and experimentation directed toward increasing knowledge and understanding in the fields of engineering and physical sciences related to the semiconductor field." The SRC has evolved more precisely to assess industry needs for research, develop strategies for meeting these needs, and fund research that is consistent with the developed strategy. Although not required, research up to now has been largely confined to universities in order to increase the number of graduate students receiving training in semiconductor-related fields. The result is a major, focused, generic research program that is supportive of the needs of the semiconductor industry involving the research efforts of over 300 faculty members and students in university laboratories.

The goals of the research are to provide a scientific and technical information base for future industry development efforts and, in the course of this: (1) to provide a clearer view of limits, directions, opportunities, and problems in semiconductor technology; (2) to decrease the fragmentation and redundancy in U.S. semiconductor research; (3) to establish above-threshold research efforts for critical areas that require resources beyond those of many individual companies; (4) to enhance the image of the semiconductor industry; and (5) to strengthen university-industry ties. Beyond these research goals, the SRC has a major concern with transferring the research results to the U.S. industrial base and in helping the United States maintain a lead in information technology.

The SRC is also a staff of 17 people working with representatives of 32 companies plus faculty and students from 35 universities to plan, manage, and carry out the research program. Since each of these participants provides significant inputs and insights to the research, a high degree of cooperation is required in order to assimilate and gain from the various collaborators. Two special advisory groups provide guidance to the SRC. The Technical Advisory Board includes R&D executives from each SRC member company and provides the Executive Director with detailed advice on the research agenda and its implementation. The University Advisory Committee is an independent group of university faculty members with semiconductor interests that advises the SRC on its research program, on university relationships, and on policy in response to requests from the Executive Director or the Board of Directors of the SRC.

It is notable that the SRC research agenda does not, at present, address all aspects of the semiconductor field but is limited to integrated circuits thus excluding discrete semiconductor devices. However, in another measure, the agenda is broadened to include research relating to manufacturing and to product design, as well as to include the more traditional research areas associated with materials, devices, and phenomena.

Chairman's Statement

The concept of cooperative support of semiconductor research by U.S. industry as implemented in the Semiconductor Research Corporation can now, two years after its start, be declared a success.

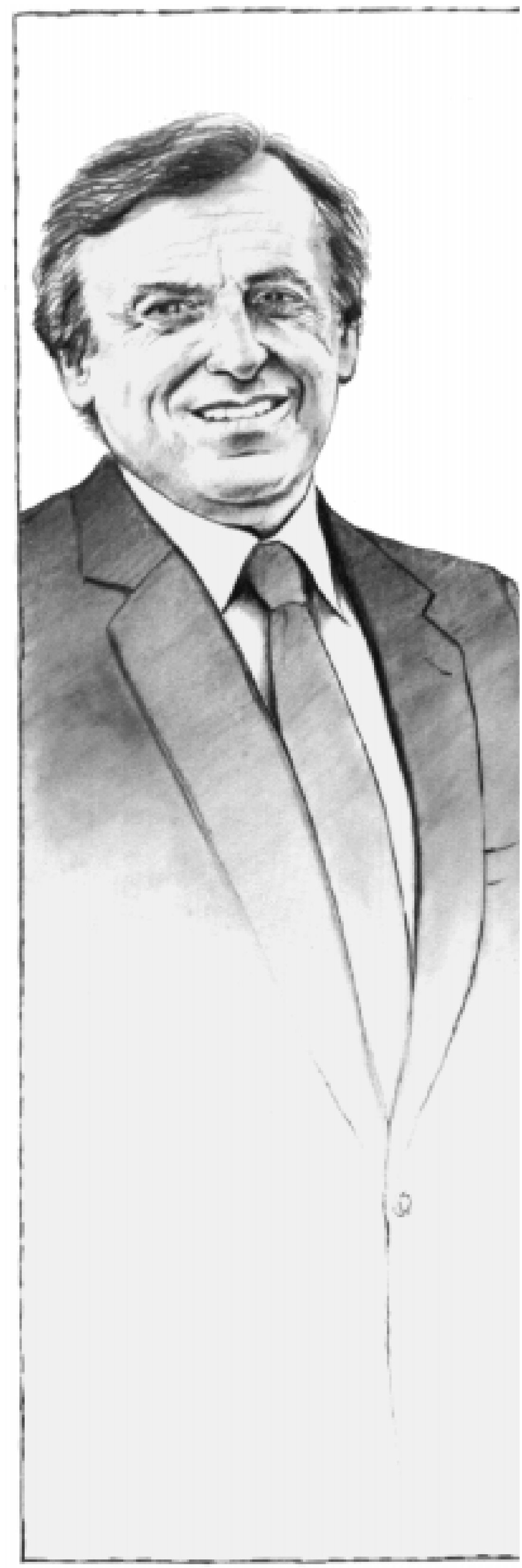
The efforts of over 300 faculty members and students in U.S. universities are now supported by the SRC to pursue research goals that are responsive to the needs of the industry. The level of academic research activity in technologies relevant to the semiconductor industry has more than doubled, and research thrusts not previously found in university laboratories are underway. Even though the products of this investment are just beginning to flow, the participating companies have recognized the worth of the research program. We cannot. however, pause to take stock. The progress obtained to date is only a beginning in meeting the challenge confronting the Industry that the SRC serves.

The SRC exists because of recognition by the industry that traditional institutional responses in the United States to world competition were inadequate. It had become clear that the U.S. share of the world semiconductor market. projected at about two-thirds of free world production, would erode if fragmented and redundant research efforts were not restructured and strengthened. A logical beginning for such efforts was academic research which had been the source of many new ideas, as well as having been the training grounds for the industry manpower that brought them to fruition. The SRC was directed to that end and has already created a $12 million per year integrated research activity. The most significant feature of this research is its emphasis on obtaining relevance without stifling creativity and intruding on academic freedom.

Even as we respond to the revitalization of the generic research base, it is apparent that the transfer of research results to industry presents another challenge to the existing institutional arrangements. The same arguments that apply to cooperation in generic research apply equally well to generic development. The possibility of extending the SRC concept into that area is now being explored.

The present level of research support is not adequate to provide the desired effective response to the competitive challenge. In the short term, Increased industry funding for the SRC, based on the growth of industry sales and membership, could result in an increase in its budget to about $20 million per year. In the longer range of over 10 years, if the ratio between SRC support and projected industry growth remains about the same and if the U.S. industry retains its market share, the SRC budget could reach $100 million. However, it is essential to recognize a danger in that the short-range SRC funding may be insufficient to allow the U.S. industry to grow to where the longer range funding levels can be reached. Thus, additional near-term funding is needed. Several solutions to this budgetary problem appear. There is a rational basis for significant direct government participation in the SRC although, to date, no direct government funding has been obtained. A second possibility is increased industry funding. The 1984 SRC budget of $13.5 million is almost exactly 0.1 percent of the value of 1983 U.S. semiconductor production. A reasonable 5-year goal should be to increase the annual research budget of the SRC to about $50 million per year through growth. direct government participation, or increased fees. At this level of support, approximately 1,000 graduate students would be supported, some major university-based responses to the research needs would be created. and mechanisms for transitioning research results to industry would be in place. There is little doubt that the universities can respond to such a challenge with high-quality productive research as they are now doing, and there is no doubt that U.S. industry needs these results to stay competitive in the world market.

Erich Bloch



During its first twenty-four months of operation, the Semiconductor Research Corporation activated a high quality, university-based research program that is now becoming productive. As both the SRC and its research program grow and develop, it is appropriate to review their status and to comment on the future based upon the experience gleaned in this formative period.

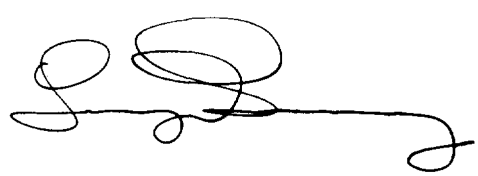
A mature SRC includes as its central core, a research program responsive to diverse Industry needs, formed through cooperative assessment of capacities and roles, and Implemented by contracts with appropriate research institutions. The research participants interact among themselves and with industry, coordinated by the SRC Program Managers, so as to collectively address goals beyond the reach of the individual participants. A hierarchical array of roles and goals thus exists and culminates in the goals of the integrated cooperative effort—the SRC. The ultimate magnitude of this effort is not known; however, the need and the potential are much larger than the present SRC program.

During the coming year, we will attempt to vertically integrate the research program, recruit additional technical staff, consolidate the program, and transition a significant portion of our supported research to industry development. Major new research thrusts were established this year in process modeling, simulation, and automation; gallium arsenide high-electron mobility transistor IC's; submicron device reliability; and packaging. Significant effort will be expended next year in attempting to expand these thrusts and in identifying additional areas of research suitable for increased effort and focus. Candidate areas that are being considered to provide focus to research efforts include:

- Maskless, resistless lithography (focused ion beams)
- Three-dimensional integrated circuits
- Integrated CAD-CAM-CAT (computer-aided design, manufacture, and test)
- 0.25-micron processing technology

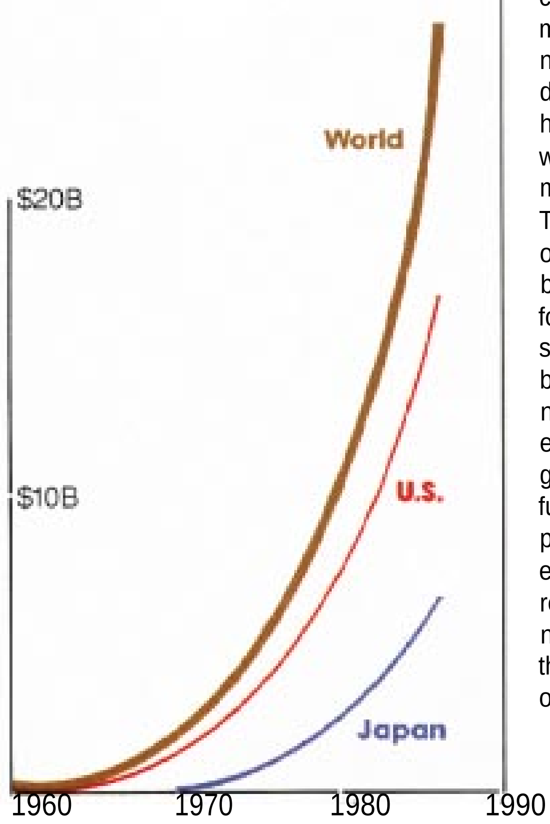
Areas such as these will be used to integrate research efforts such as new gate dielectrics, wafer scale integration, innovative fabrication technologies, design tools and concepts, isolation technologies, and submicron bipolar devices, and to provide a path toward meeting our functional goals.

In these two years, the SRC has had remarkable success in forming and implementing an innovative, cooperative research effort. Much credit is due to the member companies, the Board of Directors, the universities, the Technical Advisory Board. the University Advisory Committee, and especially the SRC staff for this success. However, the SRC is aware that the primary challenge lies ahead in solidifying the program, creating a permanent constituency, and growing to the optimum level of potential contribution to our supporting members.



Larry W. Sumney

Integrated Circuit Production



The SRC is a natural derivative of the development of semiconductor technology in the United States. The generic technology on which this industry is based was spawned by the Bell Telephone Laboratories in the years following the invention of the transistor with a major infusion of funding from the defense establishment for research in both industrial and university laboratories. The growth of the semiconductor device industry was so rapid that by the mid-1960's, developments within the industry were outpacing the ancillary research community. Both Bell and the Department of Defense (DoD) refocused their efforts to the application of the fruits of their earlier research rather than the continued advancement of the generic technology. Support of academic research shifted in emphasis to longer range, more speculative areas such as compound semiconductors. Research directed to both the near-term and long-range needs of the mainstream semiconductor industry was largely confined to the laboratories of the companies producing the devices. Both merchant producers and the growing number of captive semiconductor producers were involved. These circumstances had negative impacts. First, the companies were reluctant to share research results that might provide a competitive advantage. This slowed, but did not stop, the diffusion of new results. Second, the research efforts became highly redundant. Each company found it necessary to apply its efforts to very similar topics in order to avoid being left behind in a critical, rapidly developing technology. Gradually, research became focused on solving near-term problems, and the generic technology for the longer range future was neglected. Third, and most important, the structure of the industry and the economy resulted in an erosion of the resources available for research, and it was necessary for each company to apply these resources to current product development in order to remain competitive.

In the more recent past, it has become apparent that the magnitude and versatility of the resources that are available to even the largest companies are by themselves insufficient to sustain the pace of the rapidly developing technology. A number of government-backed programs have been initiated in the industrialized nations to meet the competitive challenge.

Except for the United States, each of these programs is characterized by a major governmental financial commitment to directly support competitive objectives of the industry and by abrogation of limits placed on domestic anticompetitive rules where they existed. As the stakes in high technology escalate with succeeding device generations, the scale of the resources that are required to continue the race will increasingly attract the attention of governments, and new rules will characterize the competition.

In the United States, the defense-funded VHSIC program is a coordinated large VLSI effort. Over $750 million has been programmed in this multiyear effort to obtain capabilities for production and application of chips with 1¼ micrometer and submicrometer design rules. This effort, however, is directed to meeting specific defense needs that deviate from those of the commercial marketplace. Moreover, VHSIC is presently focused on development, not research; and a considerable portion of the program is oriented to specific hardware needs, not generic technology. While there is a significant spillover from VHSIC into the industrial sector, VHSIC does not necessarily provide the U.S. industry with an effective response to worldwide competition.

In late 1981, executives of major U.S. companies that produce and/or use semiconductor products recognized that this erosion of the generic technology base coupled with government-financed efforts in other countries constituted an important competitive threat to their industry. Recognizing that a government-based response to this threat was unlikely, they decided to undertake a cooperative industry-initiated response. After considerable discussion, a concept emerged that has become the SRC. This concept is that the SRC will plan, promote, coordinate, conduct, and sponsor research in order to:

- Obtain improved understanding of semiconductor materials, devices, and phenomena;
- Provide the research foundation for development of new, efficient, and powerful design and manufacturing technologies;
- Increase the number of highly trained microelectronics scientists and engineers; and
- Make research results available and usable to the semiconductor community on a timely basis.

National Programs in Semiconductor Research

Japan
Substantial MITI (government) efforts on VLSI, fifth generation computer; R&D Association for Future Electron Devices (superlattice devices, 3-D IC's, hardened IC's), etc. Many nonmonetary benefits from industry structure and monolithic planning.

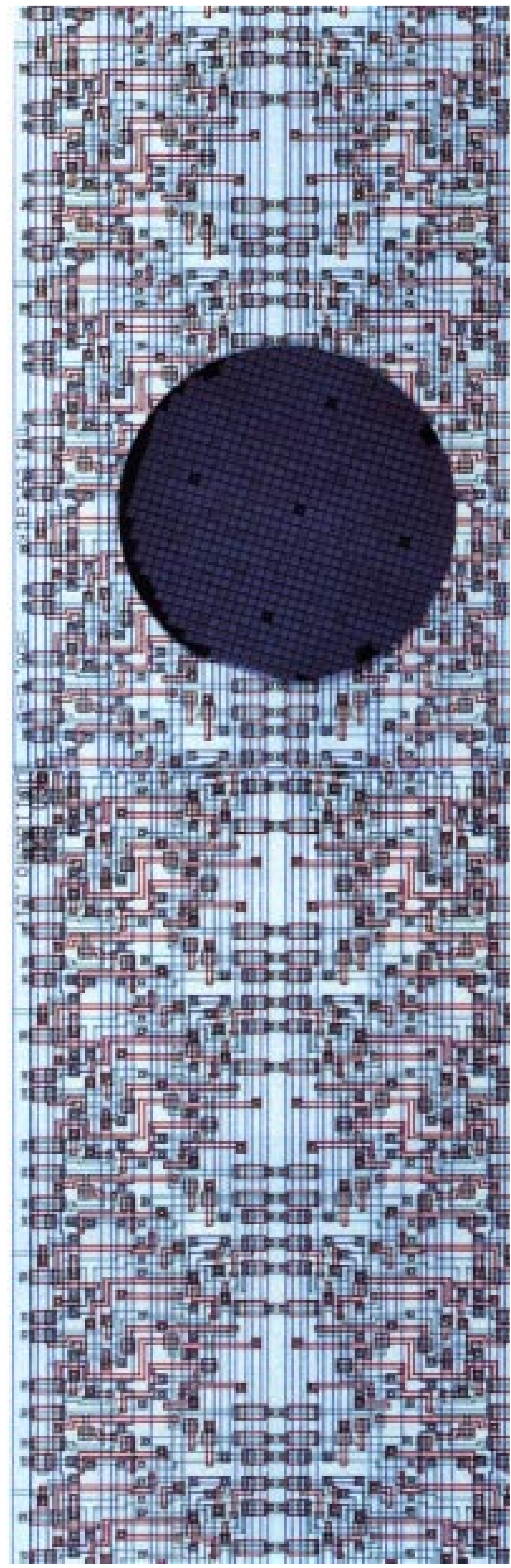
Europe
ESPRIT (European Strategic Program for Research and Information Technology) has been initiated by the European Economic Community as a 5-year, $1.3 billion venture to provide the foundation for European microelectronics in the 1990's.

Great Britain
$300 million 5-year research program on information science with major commitment to VLSI development; 75 percent ownership of INMOS; Alvey Programme in Advanced Information Technology—approximately $500 million for 5 years.

France
Nationalized and subsidized industry.

US-DOD
VHSIC program providing approximately $750 million over 5 years to obtain VLSI that meets defense needs.

US-Industry
Establishment of, and funding of, SRC research program in order to restore generic technology and enhance skilled manpower base, and to assure world leadership in this most important technology.



SRC Time Line

[illegible]	[illegible]
[illegible]	[illegible]
1965	First significant IC production
1970	First microprocessor
1973	IC production exceeds $1 billion
1977	8-BIT microprocessor
1978	VHSIC initiated
1980	First 64k RAM
1981	IC production exceeds $10 billion

1982 January — SRC Established

Corporate Member
Corporate Functions

Research Functions

Date	Event
1982 February	11 founding member companies
	SRC incorporated
March	First meeting of Board of Directors
April	First meeting of UAC
May	Executive Director hired
August	RTP chosen as site
	TAB appointed
September	Core staff hired
	Corporate offices opened
	First meeting of TAB
	First request for proposals
November	Microscience Center initiated — Cornell University
	CAD Center initiated — Carnegie-Mellon and UC/Berkeley
	Membership to 12 companies
	166 proposals received from RFP
	5 proposals selected for early funding
1983 January	IBM industry assignee joined staff
	37 proposals selected for funding
February	Membership to 13 companies
April	H-P industry assignee joined staff
May	Research program initiated with RPI
	First annual Board of Directors meeting
	Membership to 19 companies
June	3-D circuits and systems program initiated — MIT
	Manufacturing Technology program initiated — MCNC
	Publication of first SRC newsletter
	First Workshop (GaAs Devices)
July	Control Data industry assignee joined staff
	First Topical Research Conference held (Multilevel Simulation)
	First 9 SRC Technical Reports issued
August	VLSI Reliability program initiated — Clemson
September	Membership to 24 companies
1984 January	Digital GaAs program initiated — UC/Santa Barbara
	Manufacturing Automation program initiated — Michigan
	Manufacturing Simulation program initiated — Stanford
	Membership to 25 companies
March	SRC Research Program — with 2 Centers of Excellence, 7 programs, and 43 projects — attained a $12 million/year level of research activity
April	Membership to 29 companies
May	SRC Technical Reports Series to 45 volumes
	Computer-based Central Information System activated

Board of Directors

As the SRC's managing and policymaking body, the Board consists of executives of member companies who meet 4-6 times each year. The SRC Board is elected by the Board of Directors of the Semiconductor Industry Association (SIA). The Chairman of the Board is the SRC's Chief Executive Officer, presides at meetings of the Board, and provides direction to the SRC Executive Director.

Staff

The Executive Director of the SRC heads a professionally oriented staff that is responsible for leadership in the formulation, implementation, and operation of the research program. Totaling 17 persons in May 1984, this staff includes 3 assignees from member companies, 5 permanent senior staff members with relevant technical experience, and 9 additional permanent staff members who provide necessary administrative and support services.

The technical staff synthesizes a research program through knowledge, workshops, the literature, technical meetings, and interaction with the research community, governmental organizations, and foreign entities. This preliminary program is coupled to potential income estimates and the organizational goals of the SRC, proposed and advocated to both sponsors and potential contractors, and finally offered as work statements for contract negotiation. The contracts and dissemination of the resulting information are managed by the SRC administrative staff. Technical evaluation, redirection, expansion or continuation of effort, and the establishment of the total relationship of the research to the industry needs is another function of the senior technical staff.

Generation of new thrusts, recognition and propagation of important results, motivating researchers, and Integrating the individual pieces of the research into a fabric of goals, objectives, and results is the challenge of the technical area managers.

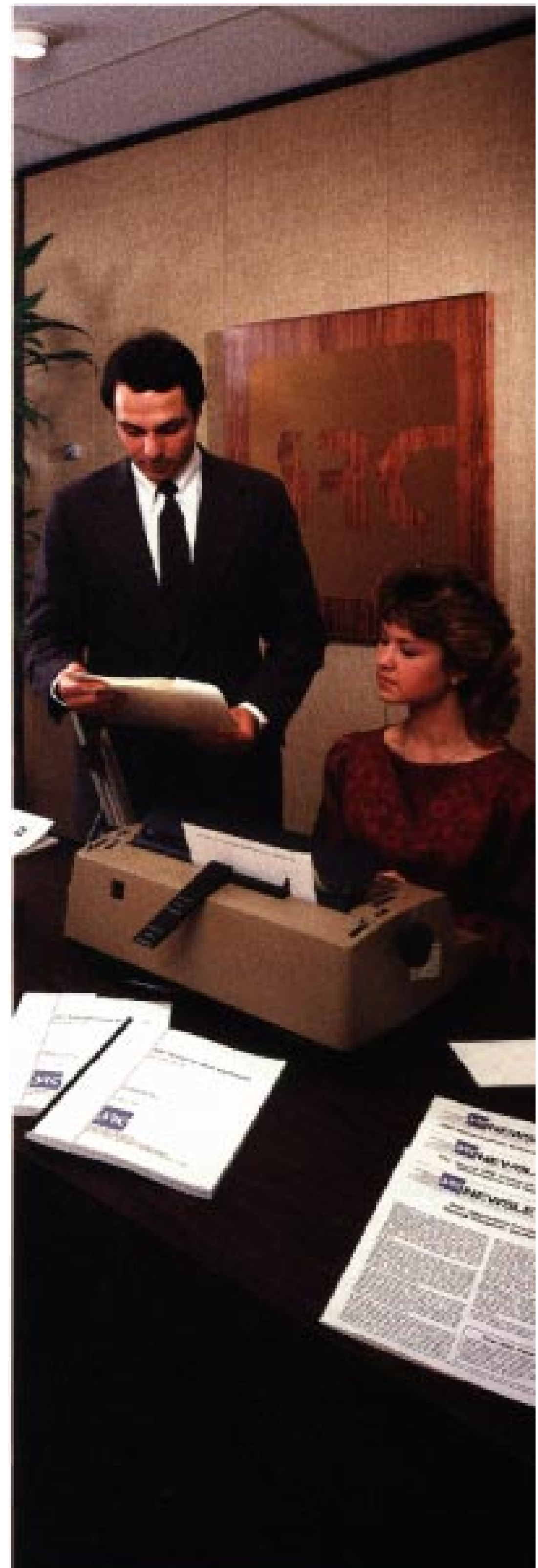
Technical Advisory Board

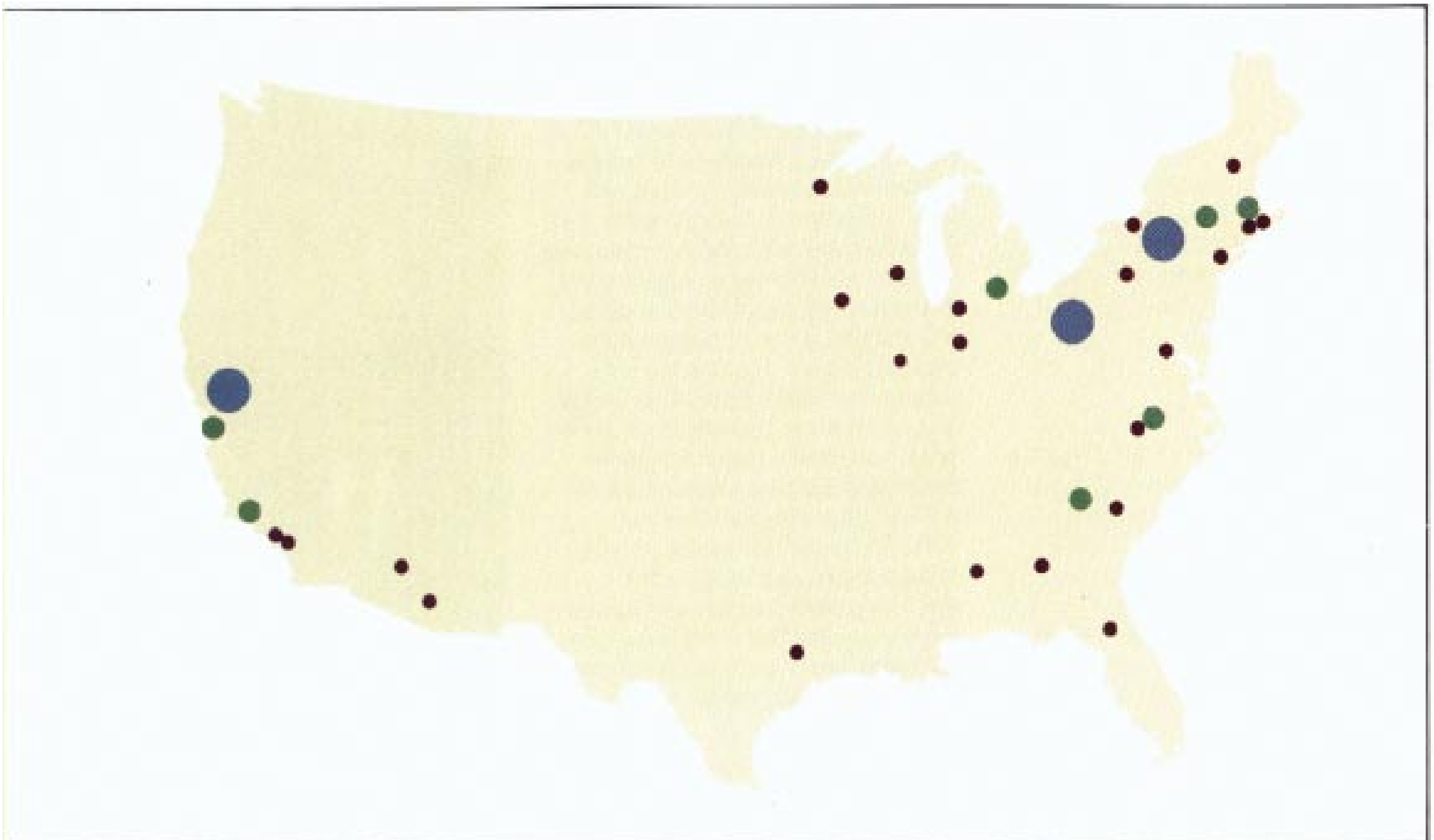
Each corporate member of the SRC has a representative on the Technical Advisory Board (TAB). The TAB advises the SRC on research strategy, identifies and prioritizes Industry research needs, and critiques plans for responding to these needs, The TAB participates in the implementation and evaluation of the research programs and reviews research proposals received by SRC and institutional participants in the research program. The diversity of experience and knowledge that the TAB provides has been an important factor in the initiation of a quality research program and will continue to assure its relevance as the program grows and matures.

The role of the TAB has expanded to deal with the program output. TAB members provide the essential interface that optimizes the flow of information to their companies and arrange for participation in SRC workshops and research conferences.

University Advisory Committee

The SRC University Advisory Committee (UAC), which first met in 1982, consists of faculty members from universities that are considered to be major participants in semiconductor research. This committee advises the SRC on policy, program, and university interactions. Since that initial meeting, the UAC has established itself as an independent, self-perpetuating committee that both initiates and responds to SRC requests for advice on the structure and performance of the cooperative industry-university relationship embodied in the SRC. These have included critical reviews of contract provisions, patent policy, and industry-university interfaces. These and continuing reviews of program initiation procedures, the technical focus of the research, and the impacts of SRC have been very influential in the development of the SRC.





Centers of Excellence

University of California/Berkeley
Carnegie-Mellon University
Cornell University

Programs

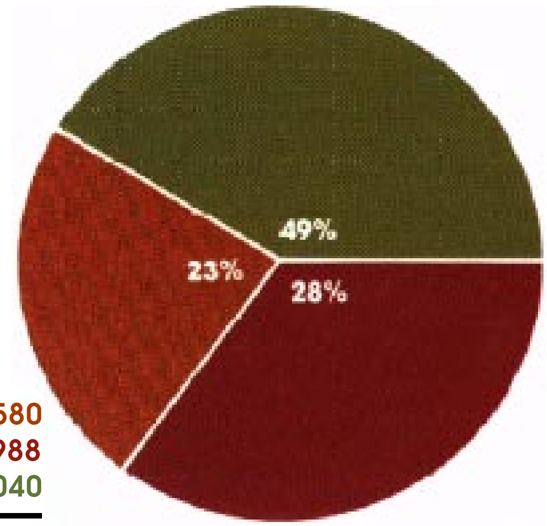
University of California/Santa Barbara
Clemson University
Massachusetts Institute of Technology
University of Michigan
Microelectronics Center of North Carolina
Rensselaer Polytechnic Institute
Stanford University

Projects

University of Arizona
Arizona State University
Brown University
University of California/Los Angeles
Carnegie-Mellon University
Columbia University
Cornell University
University of Florida
Georgia Institute of Technology
University of Illinois/Urbana-Champaign
University of Iowa
The Johns Hopkins University
Massachusetts Institute of Technology
Microelectronics Center of North Carolina
University of Minnesota
Mississippi State University
University of North Carolina/Chapel Hill
University of Notre Dame
The Pennsylvania State University
Purdue University
University of Rochester
University of South Carolina
University of Southern California
Stanford University
The Texas A & M University
University of Vermont
University of Wisconsin
Yale University

SRC Mission

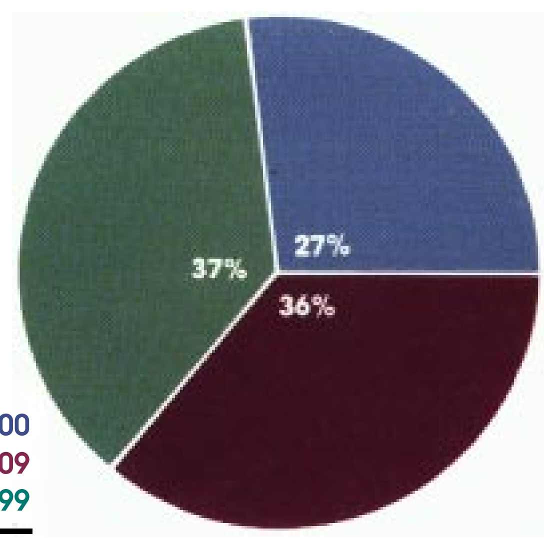
In providing its financial support, the semiconductor industry is addressing two objectives: research results, and more university graduates with relevant training. The second objective follows from the first, for SRC research is performed in university laboratories. The SRC's research program involves contracting with universities for research tasks defined and prioritized to be consistent with a research strategy. To assure relevancy, the SRC, working closely with its member companies, has first defined the technology areas of interest and then the technical goals that serve to guide the research toward specific results. Since it is impossible to cover thoroughly all of the required technology, it is necessary to prioritize the candidate areas and allocate funds accordingly. "Research," in this case, must be understood to be the advancement of understanding and the creation of knowledge as opposed to investigations that follow well-defined paths with detailed milestones that leave little of real significance to be discovered.



Manufacturing Sciences	2,708,580
Design Sciences	3,349,988
Microstructure Sciences	5,765,040
Annual Budget	**$11,823,608**

Program Structure

As of May 1, 1984, the SRC research program reached a level of 53 contracts with 35 universities. Three universities participate in Centers of Excellence; seven in Programs; and the remainder in Projects. Centers of Excellence are so-designated by the Board of Directors and are recognized as premiere institutions for which the SRC intends to maintain substantial support. Programs are also recognized as commitments to support for extended periods, during which time the quality and productivity of the research is assessed for potential selection as a Center of Excellence. Projects are defined research tasks extending up to 3 years, or beyond, if the requirement persists and the work is outstanding.



SRC Centers	3,177,400
SRC Projects	4,371,409
SRC Programs	4,274,799
Annual Budget	**$11,823,608**

Program Manager's Overview

The microstructure sciences program is providing the research knowledge base and student training for the future development of high-speed, low-cost, ultra-large-scale integrated (ULSI) circuits. The research program at its present level will provide a necessary but less than sufficient condition to achieve the defined industry goals for 1990. Although the predominant emphasis is on evolutionary generations of silicon devices, the research activity addresses many of the required revolutionary techniques that are required to achieve the goals. An important subsidiary objective is to identify alternate technologies such as gallium arsenide and molecular lattice phenomena which could possibly supplant the evolutionary integrated circuit in certain applications.

Specifically, SRC research is addressing the generic technology knowledge that is required for 0.5 micron to 0.25 micron feature sizes in complementary field-effect transistors with all their complex interactive effects and fabrication ramifications. At these dimensions, the control of less than 10,000 electrons determines the device and integrated circuit electrical characteristics and reliability behavior. This level of integration requires a quantum improvement in scientific understanding to help solve the relevant engineering problems. The research that is underway addresses new insulator and gate materials, low temperature and controlled deposition of materials, device isolation, pattern transfer including dry etching and maskless techniques, contact holes, and multilevel interconnection metallurgy. It also is obtaining insight into interface state formation due to hot electrons, processing effects, and radiation. Segments of this research will also provide immediate benefits for present industry development programs.

The potential benefit of fabricating submicron integrated circuits is that they may provide higher circuit speed at lower energy consumption, reduced chip size for equivalent function, and higher levels of integration. The device size reduction and thus computer circuit density improvement is achieved by decreasing the lithographic feature dimensions, which requires a corresponding reduction of the vertical structure dimensions. Speed and energy consumption improvement is obtained from lower operating voltages, shorter transit time for the device electrons, and reduced loading capacitance. The smaller silicon area per computer function provides a higher manufacturing yield and thus a reduction in costs. For example, integrated circuit memory chips are projected to cost one millicent per bit within the next few years, This is a sevenfold cost reduction with a similar speed improvement for this most important computer function. This trend can continue through the SRC research in microstructure sciences.

Research Program

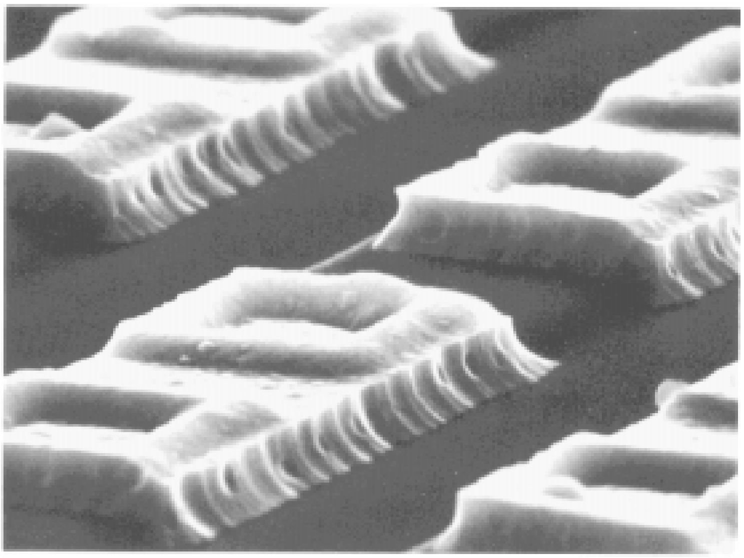
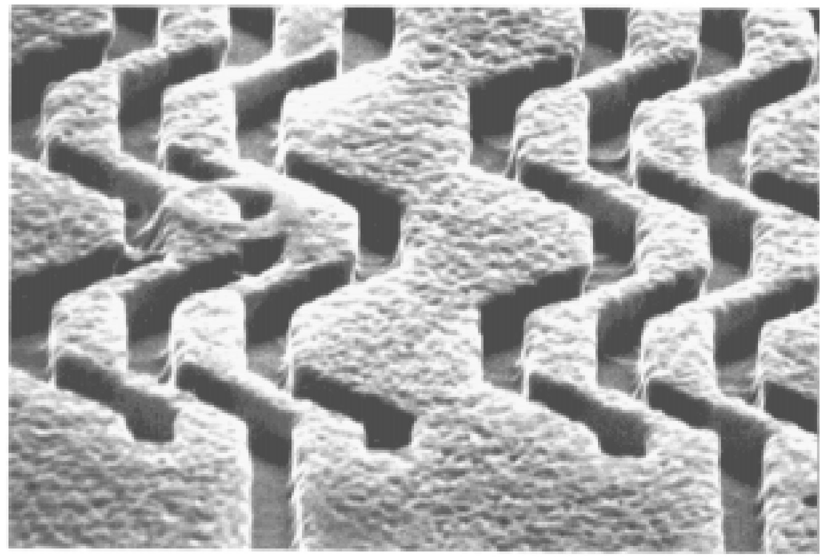
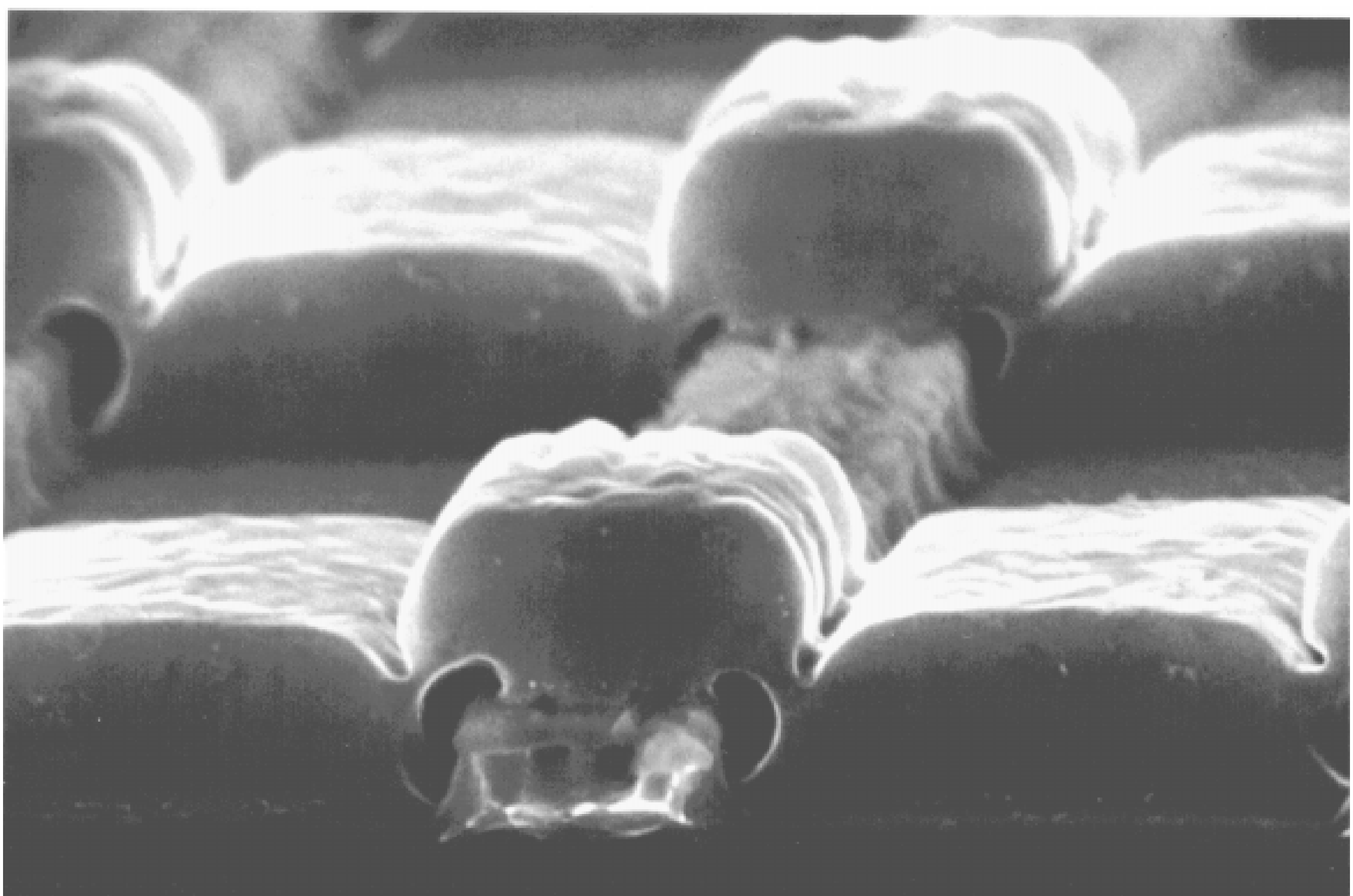
The Microstructure Sciences research program consists of (a) one center: the Cornell-SRC Center for Microscience and Technology; (b) three programs: at RPI on Advanced Beam Systems Technology, at MIT on Three-Dimensional Circuits and Systems Technology, and at the University of California at Santa Barbara on Digital Gallium Arsenide Research; and (c) twenty-three research projects. The projects address specific research problem areas in materials and phenomena, device structures and behavior, interconnections and contacts, and processes. The project research is presently addressing relatively short-range research topics but will evolve to longer range research that addresses the most critical problems defined by the research goals, i.e., the achievement of material, process, and device capabilities for megagate equivalent high-speed logic operations on silicon chips. This will require creativity in many research areas in order to solve the presently perceived problems or to provide radically different approaches in function implementation in semiconductors. The present research program is a strong and positive first step toward these goals.

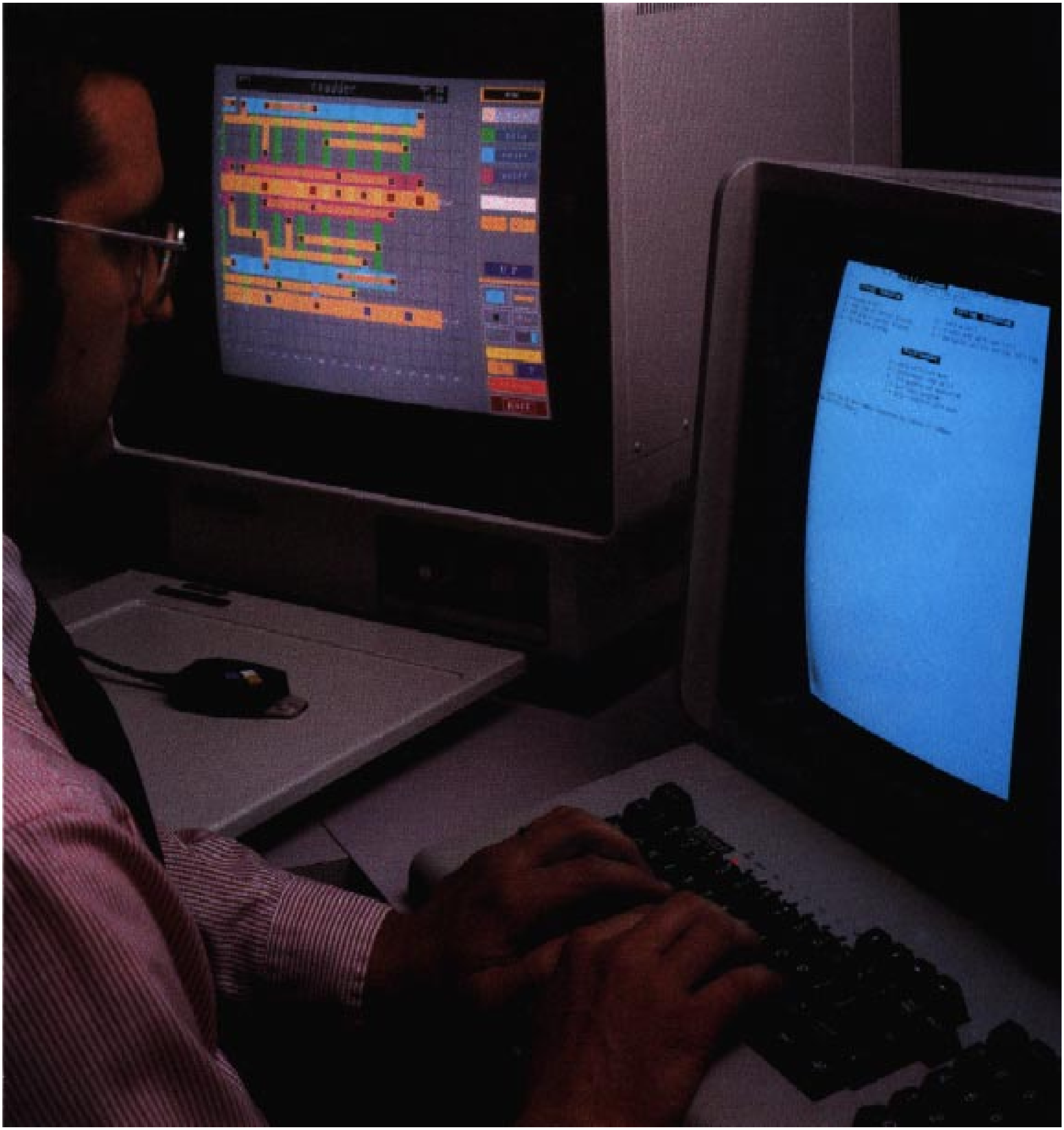
Significant Achievements

- A grafting technique has been demonstrated that improves PMMA resist sensitivity to X-ray radiation by several orders of magnitude. This could eliminate the need for high-energy synchrotron X-ray sources. The technique also shows promise for other types of radiation exposures, such as electron, UV, and photon beams.
- A 0.3-micron gate length MOSFET device has been modeled and fabricated with encouraging results.
- Single-crystal GaAs has been grown on silicon wafers to construct light-emitting diodes (LED) to replace wired interconnects in high-speed silicon circuits.
- A germanium-silicon heterostructure has been demonstrated for the shallow, low-contact resistance to n^+ silicon that is required for submicron devices.
- Based on a theoretical model, the impurity concentration in silicon depositions with molecular beam epitaxy can now be predicted.
- Research on multilevel interconnects has demonstrated a unique microwave ion source for dry reactive ion etching of insulators to provide the promise of using a wider range of gaseous etchants.

SRC Research Goals

- **Integratable high-speed logic elements with state discrimination capability in the 5- to 10-femtojoule range**
- **Compatible interconnection technology**
  - **— Mixed technologies**
  - **— Low-impedance conductors**
  - **— Low-impedance contacts**
  - **— Wafer scale integration**
- **High density D-RAM's**
- **Logic chips with greater than 1-million gate equivalents**
- **Accurate 16 bit A/D and D/A conversion**
- **Field-reconfigurable chip technology**



Program Manager's Overview

It is generally agreed that the integrated circuit (IC) design process is hierarchical in nature and that it begins at an abstract level and proceeds to progressively greater levels of detail. Progress from the abstract to the specific is not monotonic in practice and usually involves significant Iteration between the various levels of design. The human mechanism for mapping from one level of abstraction into another is not well understood and is thus very difficult to automate. Also, the verification that an implementation at one level of abstraction achieves the specifications given at a higher level is usually quite difficult and is often computationally intensive.

The current research program, because of limited resources, does not effectively address all significant problems in IC design. Two particularly pressing problem areas for which an investment of research funds would pay large dividends are (1) design concepts and (2) design tools for the non-IC specialist. In the case of design concepts, new design ideas are needed to achieve high-performance systems that are not bound to traditional architectures and that can provide reliable performance in the presence of both permanent and transient VLSI component failures. The second area that deserves increased emphasis is that of providing highly automated design tools that allow a nonsophisticated designer to achieve a quality product by describing the functional, electrical, and mechanical environments of the semiconductor system at a high level of abstraction. This clearly involves much more than what has been popularly called "silicon compilation," and will require a much better understanding of the process of transition between different design levels. The existence of such a design vehicle could bring the use of VLSI to a much wider set of engineers than has been possible to date.

Research Program

The focal point of the SRC Design Sciences research program is the provision of a research infrastructure necessary for the synthesis of design automation systems that provide one to two orders of magnitude increase in designer productivity relative to current capabilities by the year 1990. The research is being conducted in a university setting and thus has the additional advantage that skilled graduate students are made available to the industrial and university communities.

The university research team is composed of two Center programs and 14 individual university projects that focus on various phases of the design process. Research at the Computer-Aided Design (CAD) Centers of Excellence was begun in November of 1982, and the 14 projects were awarded in early to mid-1983. The SRC-University of California/Berkeley Center of Excellence in CAD has a long history of research in IC/CAD and is oriented toward the device level perspective of design. The close ties of the UCB program with the semiconductor industry has resulted in an evolving portfolioof design tools that are especially well suited for use by the expert designer. The SRC-Carnegie Mellon (CMU) Center of Excellence in IC/CAD is strongly supported by its achievements in the synthesis of digital systems. The emphasis of the CMU Center research program is on the development of design automation software that aids in the design of digital systems starting from a high-level behavioral description. One objective of this research is to facilitate the design of integrated circuits by system designers who might not be expert IC designers.

The 14 university projects were selected by the SRC staff with the help of the Technical Advisory Board. Funding was approved for research in each of the conventionally defined levels of IC design.

Significant Achievements

- An optimal VLSI realization for the discrete Fourier transform.
- A computer algorithm (AIDE) for the high-level design of analog circuits.
- Testable design methods for CMOS-speed independent circuits.
- An algorithm (SLAP) that maps Boolean equations into efficient VLSI layout.
- An implementation of the relaxation method for circuit simulation that reduces storage requirements and increases the rate of convergence.
- A method for dynamically detecting microprocessor control sequence errors.
- A new circuit compaction method based on the use of optimization algorithms.
- Extension and refinement of FABRICS, a program for statistical representation of process variations and for reflecting their effect on circuit parameters.
- An advanced building block design system (BBL) for layout that provides top-down design for custom VLSI chips.
- UNIGRAFIX, a program for displaying and/or printing three-dimensional polyhedral devices, based on simple and terse descriptions.

SRC Research Goals

- **Chip functional designs with 10X performance advantages over existing state-of-the-art**
- **Chip functional designs with reduced interconnection requirements**
- **Design capabilities at 10^8 logic element, 10^{11} bit memory level**
- **Affordable generic testability methods with >95 percent fault coverage**
- **Reconfigurable and/or fault tolerant design methodologies**
- **Hierarchical design systems that require <6 engineering man-months between system specification and error-free layouts**

Program Manager's Overview

The SRC member companies almost unanimously agree that there is no more important task for the SRC than elevating semiconductor manufacturing technology from an art to a science. This interest in manufacturing derives from their understanding that they readily can compete in the development of new services and novel designs, but they are limited in their ability to compete in production technologies.

The principal concerns being addressed by SRC manufacturing sciences research are predictability and control of the fabrication process. At least an order of magnitude of improvement in this capability is needed for the industry to remain competitive. Specific areas of focus are integrated processing systems that provide both the specification and control of the manufacturing operations, hierarchical simulation and modeling tools for predicting the results of manufacturing processes, and development of analytical techniques and sensors necessary to provide real-time feedback and control of the individual process steps. Other important areas of concerns are the reduction of defect levels, basic understanding of device reliability physics, and the packaging needs for future VLSI devices.

To meet our aggressive SRC manufacturing goals, it is necessary to develop linkages between the universities and industry. industry must help the universities define the fundamental problems in manufacturing. Transfer of the research results to the participating companies is a major challenge to the SRC.

The guiding philosophy of the SRC manufacturing sciences research is the quantification, control, and understanding of manufacturing processes necessary to achieve a predictable and profitable product output in the competitive environment of the next decade.

Research Program

Until very recently, the university academic community has not been involved in manufacturing-related research. One of the major challenges that SRC faces is to convince academia that manufacturing research is "worthwhile" and then to point them in productive and relevant directions. In addition to individual project awards, programs and centers will be established both through negotiation and competition. These programs and centers will comprise team efforts with themes that correspond to areas of the strategy or goals that are deemed to be of significant importance. This concept can include multiple-institution activities. Of importance to the manufacturing sciences research program will be the establishment of a development effort that will provide a vehicle for bringing together the results of many related SRC-sponsored research projects to verify the accomplishment of SRC goals and to enhance the transfer of technology to the supporting companies. The ultimate goal is distinct leadership in manufacturing technology for VLSI devices resulting from a continuing flow of research results to SRC member companies.

Research projects are currently underway in process modeling and simulation at Stanford, advanced processing technology at the Microelectronics Center of North Carolina, automation at Michigan, packaging at Arizona, and VLSI reliability at Clemson. These large programs are supplemented by research projects on analytical instrumentation and packaging.

Significant Achievements

Although the major components of the manufacturing sciences programs were initiated as recently as early 1984, they have already achieved the following:

- The controlled introduction of dislocations in an epilayer has been demonstrated by germanium introductron during growth.
- A two-step annealing process to expel fluorine introduced during BF_2 implants has been developed.
- A new and innovative technique developed for thermal management in VLSI packages.
- Size spectra of contaminants ranging from 0.01 to 10 μm have been obtained in a clean-room.

Research Goals

- **Quality controls that permit production of chips with defect densities below 0.25/cm^2**
- **Process automation permitting wide product mix from same fabrication lines and a 5X improvement in productivity**
- **Reduction in fabrication line capital costs for a given production level**
- **Real-time correlation of process, device, and circuit models in the production environment**
- **Cost-effective package technologies that extend to:**
  - **— 100 W dissipation**
  - **— High-speed interfaces**
  - **— Optical input/output**
  - **— 400 ports**
- **Product quality and improvement in chip reliability of 2X without burn-in**
- **Materials and controls that eliminate yield degradation due to material variables**
- **Metrology techniques and accuracies that support other manufacturing sciences goals**

Program Manager's Overview

The prime goal of the SRC is to provide a research program that makes major contributions to the generic research base of the industry. Since research involves increased understanding of a subject, the contributions of this research can only occur through effective information dissemination and technology transfer to industry users. Thus, the implementation of these processes will continue to be a major activity for the SRC.

The traditional information dissemination mechanisms for university research include conferences, journals, and private communications. These mechanisms are time consuming, inefficient, and often ineffective from an industrial perspective. The SRC members have a strong interest in rapid information distribution in order to gain whatever advantage that may accrue from early application of the research. A secondary need for rapid dissemination derives from the need to coordinate SRC contracts among the many universities in order to speed the progress of related research programs and avoid repetitive research. A third motivation is to obtain close to real-time feedback from industrial experts to help enhance the relevancy and productivity of the research projects.

Significant breakthroughs in university research are often difficult to identify and quantify. Even when identified, the only certain method for successful technology transfer involves the transfer of the persons who are involved in the research. The traditional mechanism of hiring the student upon completion of research does not satisfy the needs of multiple SRC members. Alternatives must be developed.

The SRC Information Dissemination and Technology Transfer activities address these unique needs. Most of the SRC research programs are now completing their first year. Initial efforts have concentrated on implementing a good information dissemination plan. As the research proceeds, the focus will shift to technology transfer to industry.

Information Dissemination

At present, the SRC circulates information to member companies and its research community through newsletters. publication mailings. a Technical Report Series, Workshop and Topical Research Conference proceedings and other information-interchange meetings. The SRC Information Central will make research data bases available online to member companies.

Newsletter.

The SRC Newsletter is published monthly and is distributed to members as well as to all other Interested persons. Articles seek to inform readers of the SRC's activities and polices. and progress by research participants. To inform members of technical material available for their exclusive request, titles of recent publications plus abstracts from the SRC Technical Report Series have been listed in each issue.

Contract Reports.

Research project progress reports are currently distributed to the SRC's Technical Advisory Board sub-committees, the project mentor. and to other Interested persons. These reports give early notice of research findings and serve as indicators of common problems and trends, As an example. contamination is frequently cited as the main cause for delays in bringing up new laboratory equipment. Solutions are well-known in industry; however, new graduate students must rediscover the problems. The SRC can minimize this lost time by assisting members in more effective use of available information. One trend which has been identified is the increasing use of computer-controlled Instrumentation. Labs have a tendency to create original software to collect data, rather than make use of widely available, off-the-shelf software. The SRC can participate in establishing standard practices that will allow research to proceed more effectively.

Prepublications.

Research participants are required to submit all conference and journal papers to the SRC before publication in order that the SRC can be sure that the university and investigators have proper patent coverage and to provide an early awareness service to all SRC members. The value placed on this service will be determined in the near future.

Technical Report Series.

Research documents that are deemed to have significant technical value are formally bound and distributed through the SRC Technical Report Series.

Workshops and Topical Research Conferences.

These meetings provide SRC members with the unique opportunity to exchange technical views and information in an informal setting with research program participants Restricting the attendance to a small number allows each member full access to the research personnel and to research results not generally available until much later.

SRC Information Central.

Data bases on research projects and subjects are being assembled at the SRC in a VAX-11/780. When this system is fully operational, the staff from member companies and the research community will have access to this information via dial-in ports, CSNET and other network options. This informal exchange process is designed to remove distance barriers and to permit rapid interchange relevant to ongoing research by many interested persons.

Technology Transfer

Technology transfer involves bringing together people who are familiar with a new technology and the people who wish to use it. The SRC has put into place a number of structures that bring these people together: meetings, including workshops and topical research conferences; industrial assignees; mentoring; and researchers-in-residence.

A program for bringing SRC-supported graduate students to the attention of member companies for recruiting purposes, a gatekeeper network, computer conferencing, access to CAD facilities, and specific development programs are some of the activities being planned and implemented to expand the SRC's technology transfer capabilities.

The most concrete example of technology transfer will be technology developments that are direct outgrowths of SRC research, since these development efforts can be directly measured. Accordingly, the SRC is addressing and developing thrusts that bridge the research-application gap in order to complete the transfer process. The first such development effort is now being formulated.

SRC Industrial Mentor Program.

Industrial Mentors are knowledgable technical people in member companies who are assigned to help university contractors in their research programs through provision of advice, guidance, and, where appropriate, services or equipment. This program is viewed as particularly valuable by university researchers because the industry specialists provide expertise, and, where relevant, laboratory resources that help research projects move forward in a more timely manner. The Mentor serves as a mechanism for identifying useful technology for transfer.

Researcher-in-Residence Program.

The Researcher-in-Residence is an industry scientist or engineer who spends an extended period in residence at the university participating in the SRC-funded research project. These assignees are normally given faculty-equivalent positions, and are the most effective agents for transferring technology to member companies. Similar opportunities also exist for other levels of industry personnel, such as the position of visiting research associate. In all cases, both the assignee and the university benefit from the research participation.

Industrial Assignees.

In addition to Researchers-in-Residence, the SRC also has on its staff employees of member companies for defined periods of time (generally more than one year) who participate in the management and monitoring of the research program. These individuals broaden the SRC's awareness by using their industrial expertise to identify promising technology and arrange for appropriate transfer to members.

Future Directions

The innovative character of the SRC and its relative youth limit the precision with which the future course of the organization can be charted. For example, the research emphasis, currently the sole raison d'être for the SRC, may possibly be altered to include a development thrust. Discussions on the role of the SRC in providing the required bridge from research to application (i.e., development) are taking place, but the nature of this transitioning organization and the role of the SRC in it have not been decided. It may be that more than one such cooperative development. each with a different focus, may be required.

Within the mainstream research of the SRC, the future will differ in both research and operational characteristics from today's program. With respect to the research characteristics, first, the present program structure predates the definition of research goals. Second, the program balance between technical subject areas is, to some degree, a product of the past conditioning of the university research community by government agencies whose goals are different from those of the SRC. Third, perusal of the present research agenda reveals technical subjects of great importance to future VLSI that are not now being addressed. Last, and most importantly, in working with its member companies and the universities, the SRC has gained some valuable experience that will be applied in the future. Thus, as the research program progresses, each of the issues will be addressed and, highly dependent on the funding that becomes available, the research agenda will address the full range of VLSI/ULSI needs and opportunities.

Operationally, the SRC future is one of consolidation, assessment, strengthening, and expansion. Consolidation is occurring as membership solicitation activities are phased down and the rate of program expansion becomes necessarily less as the funding levels stabilize. At the same time, the research output of the SRC is increasing, and the electronic linkage to member companies and research participants is coming on line to handle this increased output. Assessments of the research program and of the SRC are being carried out to help shape our future course. Without waiting for the assessment results, improved quality control procedures are being instituted, and the cooperative research concept is being promulgated. The idea that is embodied in this concept is that cooperative research is optimized by providing each participant, member company, university principal investigator, and SRC staff person with full information on the role of each element of the research program, the roles of related elements, and the parameters of the research program so that each cooperator may optimize his actions, thus producing a corporate optimum.

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**Dr. Holton will assume responsibility for Microstructure Sciences on June 1, 1984, since Dr. Agusta will return to IBM later in the year.*

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