BUILDING FOR THE 21st CENTURY

1994 ANNUAL REPORT

Cooperative Research

Semiconductor Research Corporation

Mission

It is the mission of the Semiconductor Research Corporation to solve the technical challenges required to keep the United States number one in the global semiconductor industry.

Goals

In order to meet this mission, the SRC will work with the semiconductor industry to develop and implement a research program that is consistent with the Semiconductor Industry Association's National Technology Roadmap for Semiconductors. The SRC will rapidly transfer results of this research program to SRC-participating companies and organizations, maximizing the satisfaction and return on investment of SRC participants. Finally, the SRC will educate scientists and engineers in areas relevant to industry needs. By providing technical leadership, championing the Roadmap and leveraging the investment of SRC participants, the SRC strives to be the world's best research-management organization.

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The Annual Report of the Semiconductor Research Corporation is published each year to summarize the directions and results of the SRC Research Program, present the formal financial report, and provide information on activities and events of the SRC industry/government/university community for the previous calendar year.

This report is available to any interested person by requesting SRC Publication Number S95013.

Cover photo courtesy of Texas Instruments Inc.

Message from the President and the Chairman

1994: SRC Year in Review – Research, Roadmap and Return on Investment

For the North American semiconductor industry, 1994 was a year of cooperation and vision. The SRC was at the forefront, building research infrastructure for the next century. The SRC worked closely with the Semiconductor Industry Association (SIA), SEMATECH and other industry and government leaders to formulate industry research goals in the National Technology Roadmap for Semiconductors, and to align and focus industry efforts on these goals.

By defining industry needs for the next 15 years, the Roadmap helps guide investment decisions, decrease gaps in technology efforts and coordinate national research and development efforts.

The SRC's program of industry wide, generic, pre-competitive research is consistent with the long-term approach of the Roadmap. The risks inherent in long-term research are shared by the more than 60 semiconductor industry companies and organizations that comprise the SRC. These participants also share a steady output of innovative semiconductor technologies for commercialization and benefit from students entering the workforce well-trained in technology areas key to the industry's future.

SRC Benefits Participants

Larry W. Sumney

Owen P. Williams

In 1994, the SRC funded and managed more than $29 million in research contracts at 49 major North American universities and research institutions. This world-class research, in fields as diverse as process technology, computer-aided design, and modeling and simulation software, helps ensure the North American semiconductor industry's continued competitiveness both now and in the next century. The SRC also supported the education of scientists and engineers in industry-relevant sciences, ensuring a workforce ready to meet the industry's needs. Finally, the SRC research program resulted in 21 new patents in 1994, demonstrating the SRC's commitment to providing its participants with an advantage in applying leading-edge technology.

SRC participants can quickly transfer this new technology from the universities, leveraging their SRC investment into tangible products. The SRC continually seeks to improve its technology-transfer efforts. To this end, the SRC Board of Directors, at its first-ever Board retreat, developed a plan to minimize research-cycle time and improve technology transfer. A significant action item from this plan was the decision to create a new SRC Research Catalog, distributed electronically. This catalog will provide concise, specific information on the SRC research portfolio and allow SRC participants to easily and precisely track and assess SRC research activities. The catalog – the first edition of which will be available in the summer of 1995 – will help ensure that research results are transferred to SRC participants in a timely manner for rapid commercialization.

We wish to thank the many scientists, engineers, managers and officers from SRC-participating companies and universities who made 1994 such a fulfilling year for the SRC. A special thanks to Daniel Fleming, who provided solid leadership as chairman of the SRC Board of Directors in 1994, before retiring from IBM in August. We pledge to build upon these efforts in 1995, strengthening the SRC research program and continuing to align it with the Roadmap to meet industry needs. We will continue to pursue new technologies, file patent applications, communicate research benefits and transfer technology rapidly to our participating companies and organizations.

This Annual Report briefly profiles the exciting research conducted in 1994 through the SRC research program, as well as several impressive technology-transfer results of this program. The SRC remained committed to maximizing the return on investment of SRC participants in 1994. This commitment will continue in 1995 and beyond, into the next century.

Sincerely,

Larry W. Sumney
President

Owen P. Williams
Chairman

What is the SRC?

The Semiconductor Research Corporation, a consortium of more than 60 companies and government agencies, plays a crucial role in planning, directing and funding the semiconductor industry's pre-competitive, long-term research. The SRC directs an integrated program of applied research conducted by faculty and graduate students at dozens of leading universities and research institutions across the U.S. and Canada. Through the SRC, participating companies, government agencies and universities work together to advance semiconductor technology capabilities.

The SRC has invested and managed almost $300 million in semiconductor research since its formation by the SIA in 1982. SRC research dollars have sponsored hundreds of faculty members and more than 1,000 graduate students hired by the semiconductor industry. The SRC is committed to transferring research results to SRC participants. To this end, the SRC has sponsored more than 1,000 conferences and workshops, and SRC-sponsored researchers have published more than 8,000 research reports. The SRC also has been responsible for 90 patents issued and another 142 applications on file.

Along with numerous industry-relevant research results (some of which are detailed later in this Annual Report), the SRC's technology-transfer efforts continue to strengthen the semiconductor industry's workforce. Through work on SRC-funded research and exposure to corporate engineers involved with the SRC Industrial Mentor Program, more than 100 graduates enter the workforce each year with a strong background in microelectronics. The SRC supported 855 students at 49 universities in 1994. SRC-sponsored researchers account for about 10 percent of all electrical and computer engineering Ph.D.s granted each year.

The semiconductor industry's participation in the SRC research program has resulted in:

- Timely and effective transfer of research results to SRC participants for commercialization;
- Incorporation of unified research goals for the semiconductor industry into the SIA National Technology Roadmap for Semiconductors; and
- Graduate students – the future leaders of the industry – educated to meet industry's needs.

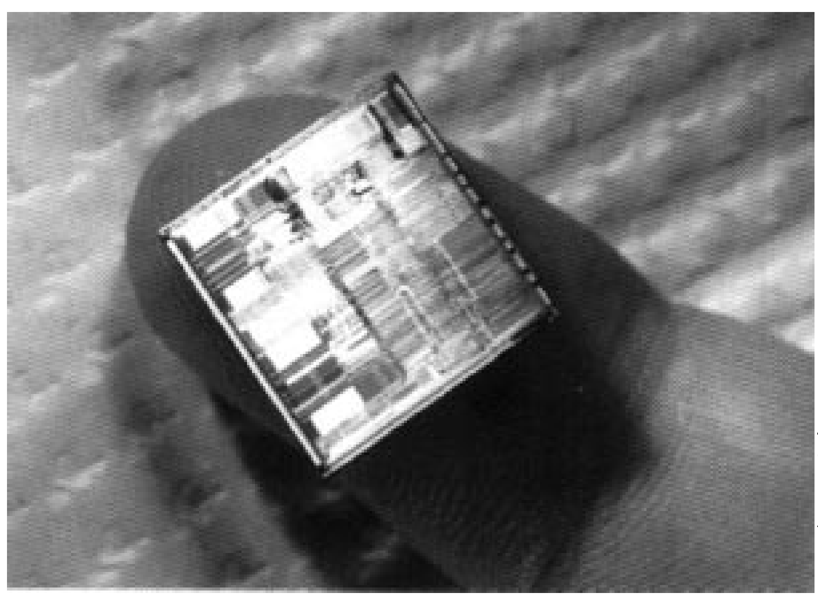


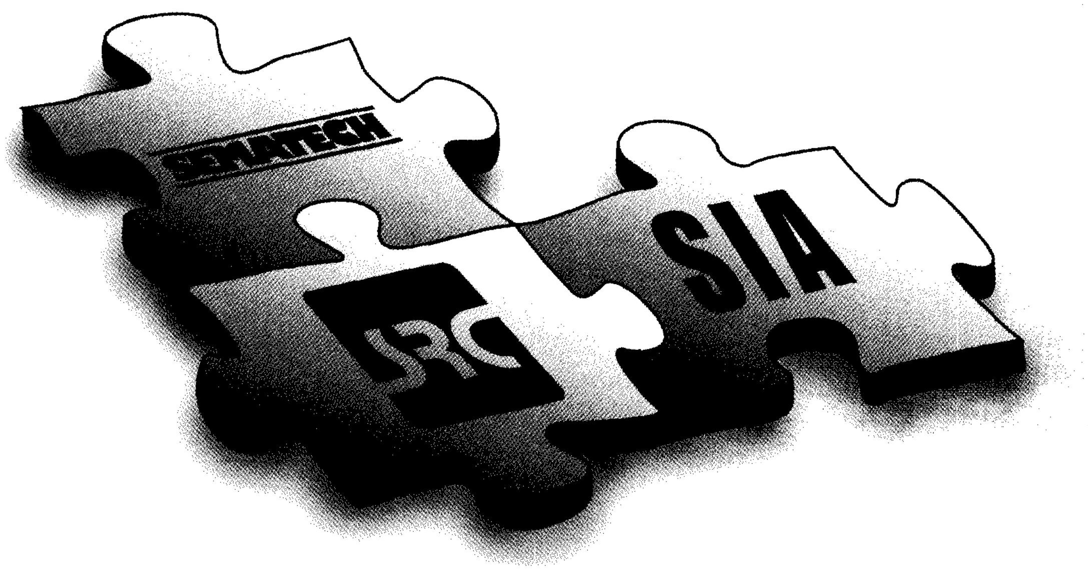
Photo courtesy of Intel Corporation.

Through the SRC, participating companies, government agencies and universities work together to advance semiconductor technology capabilities.

A Unified Industry

"One element that we are counting on very heavily is the ability in this country to put our individual differences aside and work as a team."

– Robert N. Noyce, co-inventor of the integrated circuit and co-founder of Intel Corporation



In 1977, five American semiconductor leaders – Robert Noyce, Charles Sporck, Wilfred Corrigan, John Welty and W.J. Sanders III – came together to create the Semiconductor Industry Association (SIA). Why? Increasing economic and political factors were threatening American leadership in semiconductors, and the SIA was created to formulate industry positions on trade, technology and economic policies and communicate them to governments around the world.

As issues were identified, the SIA addressed them with a spirit of teamwork and dedication. In 1982, in response to the industry's need for long-term research to develop the next generation of technology, the SIA created the Semiconductor Research Corporation (SRC), with Erich Bloch, then an IBM vice president, as its chair.

Through the SRC, the industry provides resources and direction for pre-competitive semiconductor research at North American universities. The SRC's innovative management of long-term semiconductor research at these universities provides industry with a stronger research and employee base, two critical components of competitiveness.

In 1987, the SIA worked with the SRC, Congress and the Department of Defense to form SEMATECH, one of the most successful ventures in industry-government-university cooperation, This consortium – made up of U.S. semiconductor manufacturers and the Advanced Research Projects Agency – has played a key role in addressing the critical issues facing the United States in semiconductor manufacturing technology.

During 1992, the SIA drew upon the resources of the SRC and SEMATECH to formulate the first National Technology Roadmap for Semiconductors. The SIA also worked with the SRC, SEMATECH and the U.S. government to form the Semiconductor Technology Council. Both the Roadmap and the Council address the technical challenges facing the industry into the next century.

SIA. SRC. SEMATECH. The road to global competitiveness is paved with teamwork.

I994 SRC Activities

Aligning With the Roadmap

The SIA's National Technology Roadmap for Semiconductors identifies national technology research and development needs as a guide for long-term, strategic investment decisions. These unified needs are a result of the cooperation and consensus of researchers in industry, academia and government, whose relationships are continually strengthened through the SRC research program.

In late 1994, the SRC announced the restructuring of its research program to mirror the Technology Working Groups in the Roadmap. The SRC revised its research program into eight science areas for 1995: Design; Process Integration and Device; Environment, Safety and Health; Lithography; Interconnect; Materials and Bulk Processes; Packaging; and Factory Sciences.

The Roadmap underwent its first update in 1994 to keep it current with industry needs. As a result, the Roadmap now extends to .07-micron technology requirements for the year 2010, a generation beyond the original Roadmap, which covered five generations to .10 microns in the year 2007.

The longer-term approach of the revised Roadmap is in accord with the SRC's research program. With the relentless demand for denser and larger integrated circuits at a steadily lower cost-per-function, and the enormous investment required to develop new methods and technologies, SRC participants share the risks and benefits of the SRC's long-term research.

Cooperation & CRADAs

The SRC, working with the SIA and Semiconductor Equipment and Materials International (SEMI), has been actively promoting broader linkages between the U.S. Department of Energy National Laboratories and the semiconductor industry. One effort has focused on the creation of a modular Cooperative Research and Development Agreement (CRADA), the first of its kind to be made available to an entire industry to improve that industry's relationship with federal research agencies. CRADAs are contractual agreements between private companies or organizations and federal government agencies in which both parties agree to collaborate on mutual research goals. Shared objectives, costs, and research results are included. The modular CRADA created by the SRC provides a template for individual companies to use in developing future CRADAs. The approved language of this modular CRADA is expected to significantly reduce negotiation time for future agreements.

The SRC Board of Directors has established a goal: to augment and broaden the SRC university research program by identifying new funding sources. In 1994, several years of discussion and negotiation resulted in the initiation of a CRADA to address an array of needs in semiconductor modeling and simulation. This is an area of great importance to both industry and government as they undertake the design, development and manufacture of increasingly complex integrated circuits. The initiation of cooperative industry-government research in this technology area is expected to establish a pattern for future cooperation based upon mutual objectives and recognized capabilities.

The SRC has taken the lead role in establishing this semiconductor modeling and simulation CRADA for the industry. Because the CRADA is a long-term, generic cooperative effort, the potential exists for future CRADAs that will focus on technology advancement rather than on specific product goals. This focus on technology advancement is viewed by both industry and government as a proper role for the National Laboratories.

In this era of rapid change in the research and development structure of the semiconductor industry, the SRC's pursuit of these CRADAs is another example of the SRC's responsiveness to the needs of its industry participants.

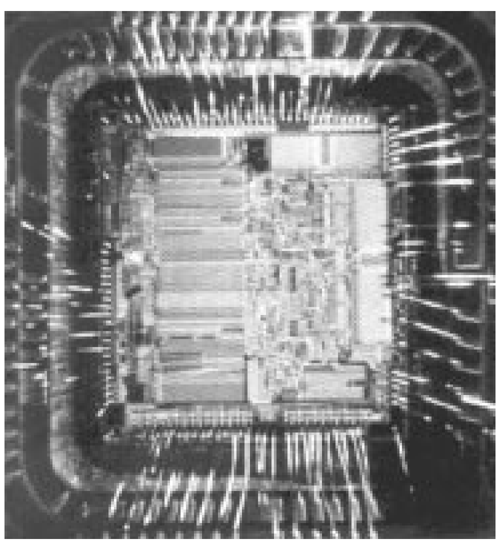
ES&H – Focus on the Environment

Responding to the needs of its participants and the industry as a whole, the SRC worked with the SIA and SEMATECH on an aggressive plan to manage complex environmental issues related to technology development. The plan's goal is to design and manufacture each new generation of chips with processes that minimize environmental impact by using fewer chemicals, less water and energy and by generating less waste.

In 1994, the SRC initiated a limited survey to quantify environment, safety and health (ES&H) content in the Manufacturing Process and Lithography science areas. This survey will be updated in 1995.

To meet the needs of its participating companies for novel, high-performance approaches to manufacturing in ES&H technology areas, and to align its efforts with the SIA Roadmap, the SRC has created a new science area focused on ES&H for 1995.

Photo courtesy of Motorola Inc.



The SRC has invested and managed almost $300 million in semiconductor research since its formation by the Semiconductor Industry Association in 1982.

Planning for the Future

The SRC Board of Directors held its first Board retreat in September 1994 to discuss strategic issues facing the SRC and its participants and to explore future opportunities for the SRC. These opportunities include collaboration with government agencies to address research areas not covered by the SRC research program. The Board developed a plan to address issues such as: keeping SRC-sponsored research relevant to SRC participants; minimizing research-cycle time; and improving SRC technology-transfer efforts.

One of the most significant action items that resulted from the Board retreat was the decision to create a new SRC Research Catalog, distributed electronically. This catalog, championed by SRC Chairman Owen Williams, will provide concise, specific information on the SRC research portfolio. It will allow all SRC participants, from working engineers to corporate executives, to easily and precisely track and assess the research supported by the SRC. The first edition of the catalog is scheduled for release in the summer of 1995, with regular updates thereafter.

The Board retreat provided the SRC with a strategic plan to address current issues and adapt to future technology needs. Through their Board members, SRC participants provide clear guidance on their needs and how the SRC ought to address those needs.

SRC-Participating Companies and Organizations

Investing in the Industry's Future

The SRC's strength is its ability to bring industry relevance to university research and to transfer research results quickly from universities and research organizations to industry for commercialization.

The SRC's participating companies, organizations and government agencies make these technological advances possible. More than 60 companies and government agencies fund the SRC's work, leveraging their own research and development dollars to achieve a substantial return on their investment.

Members

Advanced Micro Devices Inc.
Alcoa
AT&T
Digital Equipment Corporation
Eastman Kodak Company
Eaton Corporation
E-Systems Inc.
Etec Systems
Harris Corporation
Hewlett-Packard Company
IBM Corporation
Intel Corporation
LSI Logic Corporation
MIA-COM
Motorola Inc.
National Semiconductor Corporation
Northern Telecom
Praxair Inc.
Texas Instruments Inc.
Westinghouse Electric Corporation

Associate Members

Lawrence Berkeley Laboratory
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
MCC
Oak Ridge National Laboratory
Sandia National Laboratories
SEMATECH
The MITRE Corporation

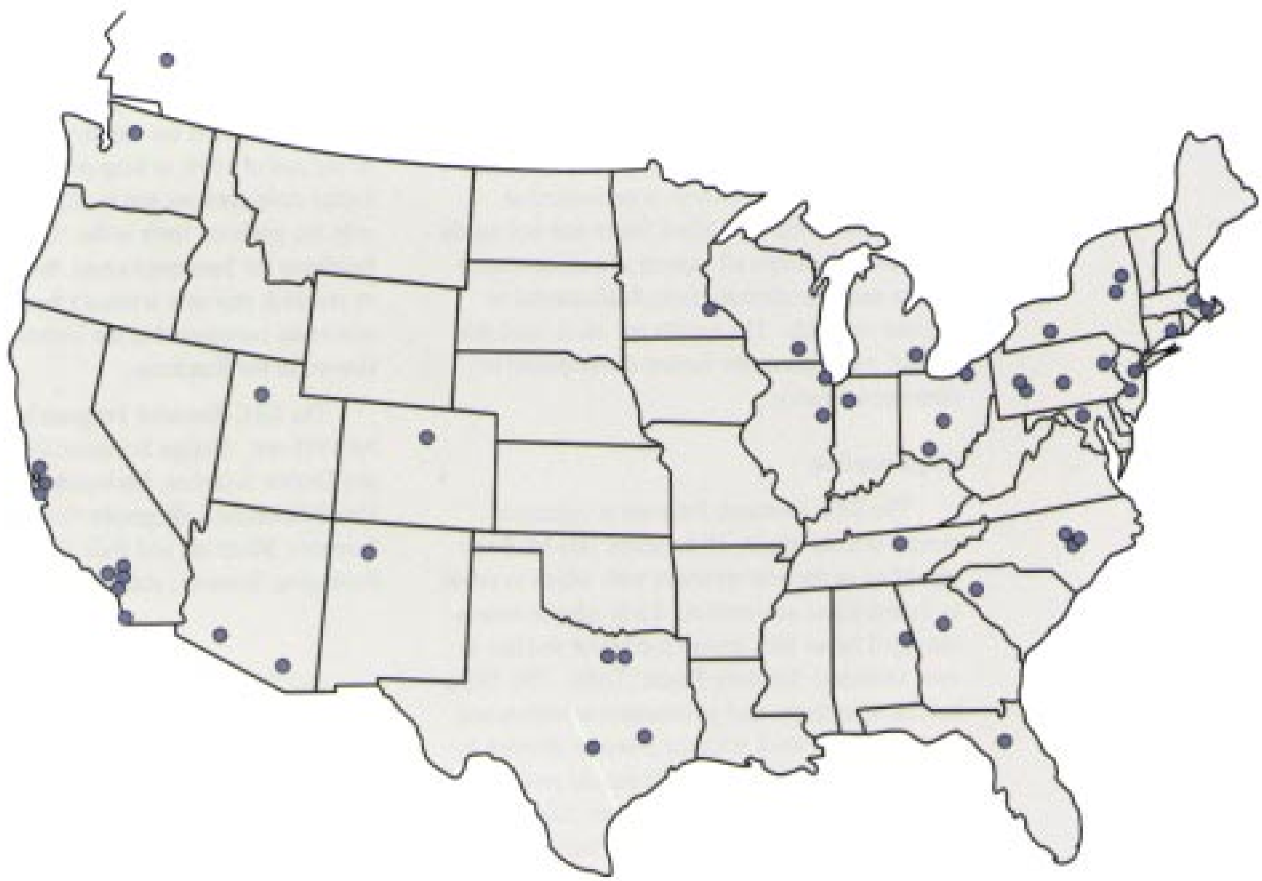
Affiliate Members

AG Associates
ANACAD Electrical Engineering Software Inc.
Analogy Inc.
BTA Technology Inc.
CVC Holdings Inc.
Dawn Technologies
DesignAid
DTX/Thermacore Inc.
Emergent Technologies
Famtech/Speedfam Corporation
Hestia Technologies Inc.
Ibis Technology Corporation
Integrated Electronics Innovations
Integrated Silicon Systems Inc.
IntelliSense Corporation
Matrix Integrated Systems Inc.
Meta-Software Inc.
Mission Research Corporation
OEA International
Omniview
PDF Solutions
Process Technology Ltd.
Prometrix
Q-metrics Inc.
SILVACO Data Systems
Solid State Measurements Inc.
SRI International
Sunrise Test Systems
Technology Modeling Associates Inc.
Techware Systems Corporation
Tyecin Systems Inc.
Verity Instruments Inc.

U.S. Government Participants

Army Research Office
National Institute of Standards and Technology
National Science Foundation
National Security Agency
Office of Naval Research
Wright Laboratory

SRC-Participating Universities and Research Institutions



Universities and Research Institutions

University of Arizona
Arizona State University
Auburn University
Boston University
University of British Columbia
University of California at Berkeley
University of California at Irvine
University of California at Los Angeles
University of California at San Diego
University of California at Santa Cruz
University of Southern California
California Institute of Technology
Carnegie Mellon University
Case Western Reserve University
University of Cincinnati
Clemson University
University of Colorado at Boulder
Cornell University
Duke University
Duquesne University
University of Florida
Georgia Institute of Technology
University of Illinois at Urbana-Champaign
Lehigh University
University of Maryland
Massachusetts Institute of Technology
University of Michigan
MCNC
University of Minnesota
University of New Mexico
North Carolina State University
Northwestern University
North Texas Research Institute
University of North Texas
The Ohio State University
Pennsylvania State University
Princeton University
Purdue University
Rensselaer Polytechnic Institute
Rutgers University
Stanford University
State University of New York at Albany
Texas A&M University
University of Texas at Austin
University of Utah
Vanderbilt University
University of Washington
University of Wisconsin
Yale University

The SRC Research Program

Overview

The primary focus of SRC efforts on behalf of its participating companies and organizations is its research program. Through this comprehensive program, long-term research is performed at universities across the United States and in Canada. This research covers all aspects of semiconductor design and manufacture, from fundamental to applied research. The results are made available to SRC participants for further development or commercialization.

Organization

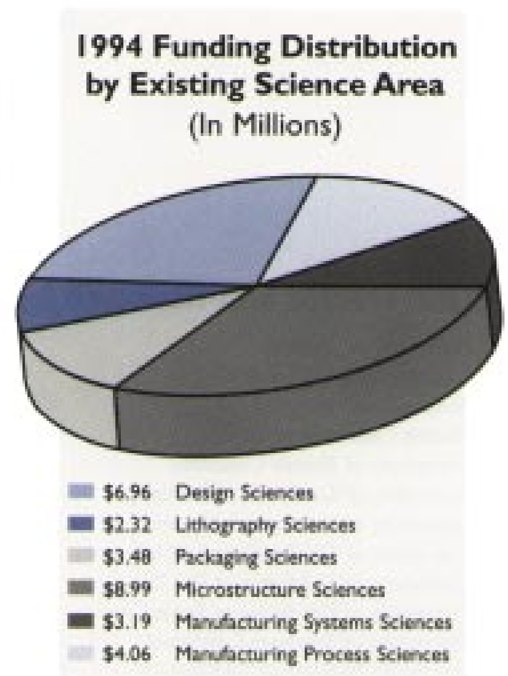
The SRC Research Program is organized around science areas. Historically, this has been identified as the best structure with which to relate to industry and universities. Each science area is managed by an SRC research director and has its own Technical Advisory Board (TAB). The TABS consist of industry and government scientists and engineers who work with the research director to: plan research strategy; conduct annual reviews and foster technology transfer at university sites; evaluate research proposals; and provide technical guidance to university researchers. Each science area also benefits from industrial mentors who are assigned by member companies to give individual assistance to university research teams.

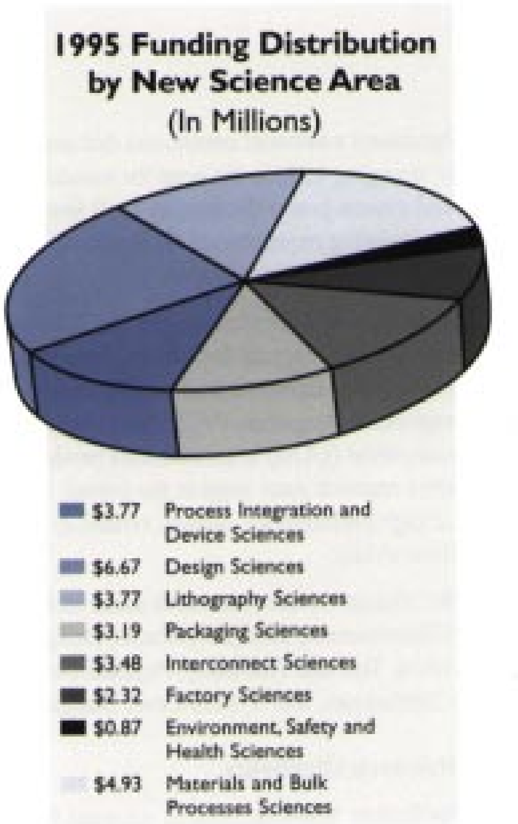
In 1994, the SRC Research Program was organized into six science areas: Design Sciences; Manufacturing Process Sciences; Manufacturing Systems Sciences; Lithography Sciences; Microstructure Sciences; and Packaging Sciences. The focus and priorities of each are described briefly in the following pages.

New Science Areas for 1995

The SRC's research program is updated constantly to meet the industry's emerging needs. At the end of 1994, to keep pace with rapid technological developments and to align its research efforts with the goals set forth in the National Technology Roadmap for Semiconductors, the SRC reassigned its research into new science areas for 1995. These new areas correspond to the Technology Working Groups in the Roadmap.

The SRC Research Program's science areas for 1995 are: Design Sciences; Process Integration and Device Sciences; Environment, Safety and Health Sciences; Lithography Sciences; Interconnect Sciences; Materials and Bulk Processes Sciences; Packaging Sciences; and Factory Sciences.





1994 Investment

In 1994, 138 research contracts and grants were awarded by the SRC to 49 North American universities. The SRC invested $29 million in these contracts and grants, distributed among the six SRC science areas.

The SRC also supported 855 graduate students in 1994. Of these, 105 received their degrees, with the majority taking jobs at SRC-participating companies and organizations.

Building for the 21st Century

By focusing on well-defined research goals that adhere to those set out in the National Technology Roadmap for Semiconductors, and by guiding and prioritizing long-term research efforts, the SRC Research Program ensures that the North American semiconductor industry is prepared for the challenges of the next century.

Transferring Key Technologies to Industry

One of the most important roles of the SRC is to transfer results rapidly and effectively from SRC-supported research to SRC-participating companies and organizations, and from there to the industry as a whole. The SRC is a vital link in the technology chain, bridging the gap between valuable pre-competitive research and production of competitive products.

The SRC's Concurrent Technology Transfer System has redefined technology transfer as a multi-directional, concurrent process among industry, academia and government, throughout every stage of development – from planning through commercialization.

Since its founding in 1982, the SRC has contributed many elements to the nation's overall technology base. Some of 1994's technology-transfer highlights are described in the following pages.

Design Sciences

Peter W.J. Verhofstadt, Director

Design Sciences addresses the need to rapidly design integrated circuits and enormously complex systems that achieve specified levels of function and performance, while ensuring that the resulting products are manufacturable with high yield, testable to high levels of confidence and operable with high reliability.

Challenges

To enable the domestic industry to maintain its world leadership in design and computer-aided design, and to handle the almost exponentially increasing complexity, design sciences research (and subsequently, the commercial development and implementation of computer-aided design tools) must move in several directions:

1) from single component to system level (e.g., multi-chip modules);
2) across the product-development cycle;
3) to higher levels of abstraction;
4) toward coverage of – with much greater sophistication – analog and mixed-signal circuits in addition to the classical digital design; and
5) to inclusion of software (especially embedded) as well as hardware.

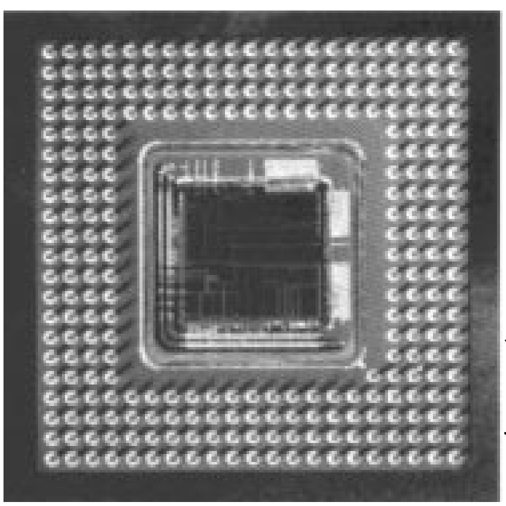


Photo courtesy of Intel Corporation.

The need to rapidly design integrated circuits and enormously complex systems is addressed by the SRC's Design Sciences research.

Significant additional constraints that are quickly emerging include the need for reduced chip- and system-power dissipation at all levels and the escalating requirements for workable test, testability and diagnosis solutions.

To address these challenges, the SRC Design Sciences research program focuses on areas which support the rapid, economic and testable design of very large-scale integration (VLSI) and ultra large-scale integration (ULSI) semiconductor products. Sponsored research must support the overall SRC goals of high performance, quality, reliability and manufacturability.

SRC Design Sciences research areas include: Design Environment, Design Synthesis, Design Verification, Test and Testability, Physical Design, Design Techniques, and System Level Design.

1994 Research Highlights

The Design Sciences research program funded 25 research contracts at 19 North American universities in 1994, with a total value of $6.96 million. These contracts supported 61 faculty members and 173 graduate students, 35 of whom graduated in 1994. More than half these graduates are now employed at SRC-participating companies or SRC-supported universities.

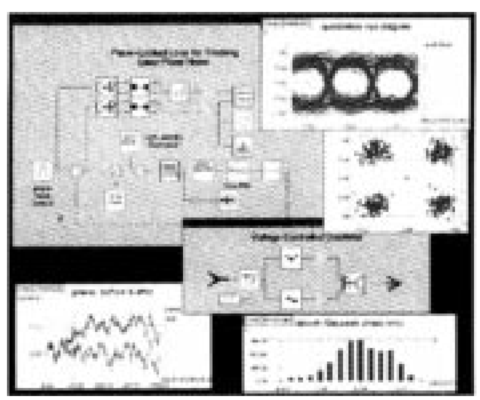
In 1994, the emphasis of SRC Design Sciences research was on high-level design technologies and low-power system design. Design Sciences research highlights for 1994 include:

- University of Washington – Professor Carl Sechen and Washington researchers have developed a new parallel version of their standard-cell placement tool, TimberWolfSC. The parallel row-based placement program is five- to seven-times faster than previous versions of TimberWolf and demonstrates near-linear speedup with the number of workstations, for up to 10 workstations.
- Carnegie Mellon University – Professors L. Richard Carley and Rob A. Rutenbar and their research team have developed a new approach to the problem of analog circuit synthesis and have implemented a pair of tools: ASTRX is a circuit compiler that generates performance-prediction modules, mapping the component and voltage values in circuits to the performance metrics specified by the user. OBLX uses the information from ASTRX to produce a circuit design that best meets input specifications. Using the tools, circuits that had taken days or weeks to synthesize with previous methods have been designed in a few hours to a few days. The performance of the resulting circuits is typically within five percent of specifications; previously available tools typically achieved performance within 20 percent.

Technology Transfer Highlights

- University of California at Irvine – Professor Daniel D. Gajski and his UC-Irvine team have developed SpecSyn, a suite of advanced system-level design tools featuring the SpecCharts graphical-design capture environment. SpecSyn enables high-level design of complex digital systems. Ranging from behavioral synthesis to silicon, the software presents a capability that cannot be obtained from CAD vendors to date. Several member companies are investigating the use of SpecSyn for product design.

- **University of California at Berkeley – Professors David G. Messerschmitt and Edward A. Lee and their research team have released a new version of Ptolemy, an advanced system-level, object-oriented design tool. Ptolemy 0.5 is specifically targeted at the design of reactive and embedded systems, including signal processing and communications systems. It is especially useful in heterogeneous systems that involve interactions of diverse models of computation and mixtures of implementation methods, ranging from hardware to software to algorithms. Ptolemy currently runs on Sun, DEC, H-P, SGI and PC platforms. Berkeley researchers have also created a small version of the program, Ptiny Ptolemy, which dramatically reduces the investment in time and disk space required for users to test the system. The Ptolemy system has been widely distributed and is being investigated for use by several member companies.**



The University of California at Berkeley's Ptolemy 0.5 addresses system-level design and implementation of reactive and real-time systems.

Manufacturing Process Sciences

Daniel J.C. Herr, Director

The Manufacturing Process Sciences (MPS) research program focuses on robust processes and process tools that have the capability and flexibility to produce advanced integrated circuits. MPS explores the feasibility and manufacturability of innovative approaches to high-density, ULSI circuits. Driving these innovations is the SIA Roadmap, which specifies technologies that will make it possible to manufacture integrated circuits with feature sizes down to 70 nanometers.

Challenges

Among the challenges that face MPS researchers are:

- Minimizing and controlling contaminants during wafer processing;
- Developing deposition processes and equipment with low thermal budgets that can deposit ultrathin films with required properties;
- Improving the capability to plasma etch anisotropically, at high rates, with uniformity and without damage; and
- Creating circuit-reliability models that can be integrated into the design process.

New Science Area Alignment for 1995

In late 1994, to align its research efforts with the goals set forth in the National Technology Roadmap for Semiconductors, the SRC dissolved the MPS science area. A large number of MPS research thrusts have been incorporated into three new science areas for 1995: Interconnect Sciences; Environment, Safety and Health Sciences; and Materials and Bulk Processes Sciences. These new areas correspond to the Technology Working Groups in the Roadmap.

1994 Research Highlights

The MPS research program funded 34 research contracts at 16 North American universities in 1994, with a total value of $4.06 million. These contracts supported 57 faculty members. Twelve of the 103 MPS students supported by the SRC graduated in 1994, with the majority of these taking jobs with SRC-participating companies.

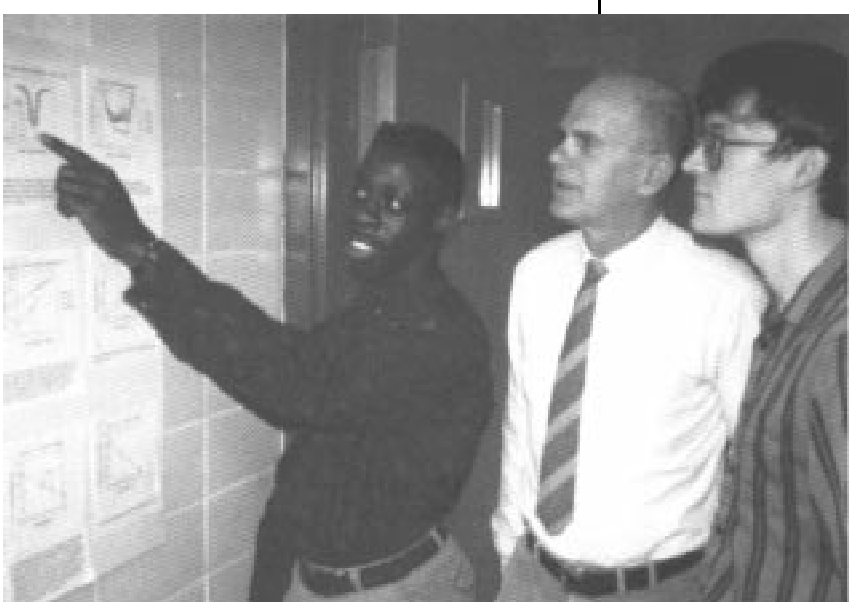
MPS research highlights for 1994 include:

- University of Arizona – Professor Farhang Shadman and his Arizona research team have developed techniques to filter contaminants from gases, chemicals and water. Shadman's team investigated a prototype reactive membrane to filter corrosive gases and a catalytic filter to remove hard-to-oxidize dissolved and particulate organic impurities from ultra-pure water. By reducing contaminants, wafer yield is increased. These results are now being transferred to the supplier community.
- Clemson University – Professor David J. Dumin and researchers at Clemson have developed a comprehensive physical description of the relationships between thin oxide wearout, breakdown and reliability. Trap generation is measured inside the oxides as they wear out, and the trap densities are coupled with a statistical description of breakdown based on extreme value statistics to produce time-dependent dielectric breakdown (TDDB) distributions. It appears that all commercial oxides wear out at approximately the same rate, independent of the fabrication process.

The Clemson research has been applied to other insulators, particularly oxynitrides, where the role of the nitrogen atoms on trap density and low-level leakages has been determined. Low-level leakage measurements have predicted that oxides thinner than 10 nanometers will not meet the data retention requirements of electrically erasable programmable read-only memory (EEPROM) oxides. The technology needed to duplicate Clemson's wearout, breakdown and trap-generation measurement technology has been transferred to several SRC member companies.

Technology Transfer Highlight

• University of Arizona and Stanford University – Professors Harold Parks and Robert Helms and their research teams -with assistance from mentors such as Baylor Triplett of Intel – have collaborated to develop and release new software that determines contamination levels on silicon (Si) wafers. The software predicts the levels of trace metals deposited on wafers from the level of the metals in the process fluids. SRC-participating companies, including AMD, Intel and Texas Instruments, are using the software. New software (to be released in mid- 1995) will add the capability to calculate surface metal-induced gate oxide defect densities. This model is based in part on data generated by past SRC-supported work at the University of South Florida (Professors Lubek Jastrzebski and Worth Henley). Howard Huff's SEMATECH Si Council is assuming responsibility for coordinating future activities and archiving the software.



Clemson graduate student Terry Hughes (left), explains wearout measurements in CMOS/EEPROM oxides to Professor David Dumin (center) and fellow graduate student Ron Scott

Manufacturing Systems Sciences

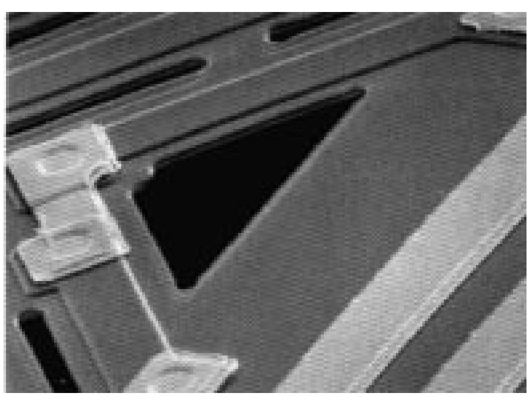
John H. Kelly, Director

The goal of the Manufacturing Systems Sciences (MSS) program is to provide software tools and methodologies that enable efficient and effective application of computer technology to achieve rapid design transfer and the manufacture of low-cost, high-performance integrated circuits and systems.

SRC MSS research focuses on: yield simulation and prediction; yield diagnostics and rapid learning; factory tool control; and factory layout and subsystems integration and automation. Key factors driving MSS research are: automation; tool control; flexibility and programmability; rapid yield learning; cycle-time reductions and work-in-process scheduling; and capital productivity.

Challenges

MSS also addresses advanced tool control to reduce process variability and post-process data acquisition through research in fuzzy logic and neural net tool-control strategies. To meet the need for enhanced capital productivity, research is conducted in work-flow modeling, including work-in-process logistics analysis. The need to reduce time-to-market at lowered cost and to achieve flexibility in the programmable factory is addressed by research in modeling and simulation.



Pixel imagers in development at the University of Michigan offer remote temperature resolution of better than I°"C.

This research documents the fundamental understanding of factory-, tool- and process-performance parameters, allowing for exploration of various manufacturing options.

MSS research areas include: Equipment Automation and Process Control; Factory Automation and Management; and Rapid Learning.

New Science Area Alignment for 1995

In late 1994, in order to align its research efforts with the goals set forth in the National Technology Roadmap for Semiconductors, the SRC renamed and refocused the MSS science area for 1995. The new Factory Sciences area corresponds to a Technology Working Group in the Roadmap.

1994 Research Highlights

The MSS research program funded eight research contracts at six North American Universities in 1994, with a total value of $3.19 million. These contracts supported 46 faculty members and 86 graduate students, seven of whom graduated in 1994.

MSS research highlights for 1994 include:

University of Michigan – Professor Kensall Wise and his team at the University of Michigan's Center for Automated Semiconductor Manufacturing have developed both passive and active pixel imagers that offer remote temperature resolution of better than 1°C in process-control applications. The thermal-imaging devices are based on a standard complementary metal-oxide semi-conductor (CMOS) process with a final micro-machining etch from the front used to thermally isolate the pixel structure. On-chip electronics, ambient multiplexing, signal conditioning, ambient temperature measurement and self-testing.

• University of California at Berkeley – Professor Costas Spanos and his team have developed new adaptive and flexible multi-step controllers to apply to sequential manufacturing "lithography" steps, including wafer coat, exposure, post-exposure hard bake and resist development. In addition to the usual input parameters for this sequential control problem, the new approach allows the adjustment of the percent-solvent-retained in resist during resist spin-off. Real-time statistical process-control (SPC) data were used to validate improved uniformity of resist pre-etching profiles. Significant reductions in cumulative critical dimensions were achieved. The Berkeley results could be applied to plasma-etch as well, for more integrated solutions to control poly- and metal-line widths of semiconductor products.

Technology Transfer Highlights

• University of Colorado – SILVACO Data Systems, an SRC affiliate member, is planning a I995 release of a commercialized derivative of the general-purpose Artificial Neural Network (ANN) developed by Professor Roop Mahajan and his team of researchers at Colorado. The ANN software is used to map complex, non-linear, multi-variable input-output data. Colorado and SILVACO researchers successfully modeled virtual wafer fab-simulation data from SILVACO, and indications from SILVACO are that the Colorado ANN algorithm may provide up to a ten-fold reduction in ANN training time, compared to the company's current algorithm.

• University of California at Berkeley and Carnegie Mellon University – Professor Ramakrishna Akella and his Berkeley research team, working with CMU researchers led by Professor Andrzej J. Strojwas, have developed new approaches and algorithms for yield management and learning, using in-line defect monitoring. This research provides both an understanding of the sources of yield improvement in sub-micron process fabs and cost-based, fab-wide, inspection-sampling approaches to achieve superior yield management. The researchers have worked with KLA Instruments to develop prototype software incorporating this research. AMD is also implementing research results on advanced yield-improvement techniques for cost-efficient, etcher-inspection sampling. Other companies using the Berkeley-CMU research include Texas Instruments and Digital Equipment.

University of California at Berkeley and Carnegie Mellon University researchers and KLA Instruments interns work together on software to improve yield.

Lithography Sciences

Daniel J.C. Herr Director

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SRC Lithography Sciences conducts research that will enable the production of robust lithographic materials, processes, control methodologies and process tools that have the capability and flexibility to produce integrated circuits through the early part of the next century.

Lithography research focuses on deep submicron optical lithography as a low-cost extension of current mainstream tools. New resists, deep-ultraviolet optics and phase-shift masks provide significant research challenges at features sizes of 0.25 microns and below. X-ray lithography is also being investigated as a second system for meeting this pattern-transfer need and for extending into the sub-0.25 micron range.

Challenges

The primary goal of lithography is to resolve and transfer patterned features reproducibly. Research that contributes to a fundamental knowledge base, integrating materials, processes and tools, will enable enhanced development-cycle times for advanced lithographic technologies and will strengthen a collaborative domestic infrastructure. Orders of magnitude improvements in metrology capability are required to provide non-destructive, *in situ,* real-time measurements at specified dimensions, concentrations, temperatures and pressures.

The 1994 investment priorities in the SRC Lithography Sciences portfolio addressed identified needs in the following critical-gap areas: Resists, Alignment and Overlay, Masks and Materials, Critical Dimension Metrology, Modeling and Pattern Transfer, Contamination and Systems.

1994 Research Highlights

The Lithography Sciences research program funded 23 research contracts at eight North American universities in 1994, with a total value of $2.32 million. These contracts supported 23 faculty members and 57 graduate students. Of these students, seven graduated in 1994, and all but one accepted positions with SRC participants.

Wisconsin professor James Taylor reviews resist research with graduate student Carla Nelson.

Lithography Sciences research highlights for 1994 include:

- University of Texas at Austin and Cornell University – Professors Grant Willson and Jean M.J. Fréchet and their teams have demonstrated the feasibility of formulating advanced resist materials that can be cast from and developed with water, with the goal of reducing the amount of toxic and organic waste produced by semiconductor manufacturing facilities. They also explored the relationships between the physical properties of organic casting solvents and their performance.
- Stanford University – Professors R. Fabian Pease and C. Neil Berglund and Stanford researchers have investigated ways to minimize the spatial correlation of mask errors as a function of specific factors associated with advanced e-beam mask-writing tools.

Resist-User Facility

The SIA Roadmap called for the semiconductor industry to leverage existing resources, such as research by universities, national labs and industry suppliers. To this end, Daniel Herr, SRC director of Lithography Sciences, and Peter Freeman, of SEMATECH, worked together to establish a resist-user facility at MIT's Lincoln Labs. This unique collaborative effort brings together SRC-sponsored university researchers with resist suppliers to evaluate formulations for advanced imaging materials on exposure tools.

Technology Transfer Highlights

- **University of California at Berkeley – Professor Andy Neureuther and his UC-Berkeley team have continued development and research on their lithography simulator, TEMPEST (Time-domain Electromagnetic Massively Parallel Evaluation of Scattering from Topography). The simulator, which can now formulate and simulate three-dimensional problems, has been applied to the study of phase-shifting masks by AMD and IBM.**

- **University of Wisconsin – Professor Franco Cerrina and his colleagues at Wisconsin's SRC Center of Excellence in X-ray Lithography (CXrL) have continued to explore the manufacturing issues of X-ray lithography. In 1994, they released the latest version of their simulation software package for the X-ray lithography process, CXrL ToolSet. This software has been installed at numerous SRC-participating companies, including Motorola, IBM, AT&T and AMD. Professor James W.Taylor and his Wisconsin team have continued their research and evaluation of resist materials for resolution and exposure latitude of 0.25 microns. Results of their statistically designed experiments have been applied by Motorola and IBM.**

University of Wisconsin graduate students Dan Laird (left) and Matt Laudon (standing) discuss X-ray lithography with Professor Roxann Engelstad.

Microstructure Sciences

William T. Lynch, Director

Microstructure Sciences is concerned with the semiconductor device itself and with the physics and chemistry of novel processes. It also addresses issues related to the evaluation of new materials, TCAD modeling of devices and processes, and interconnect and integration issues.

University of Utah graduate student Yunji Huang performs experimental work on SCM measurements.

Microstructure Sciences draws its strength from university programs that span the electrical engineering, computer science, chemistry, physics and materials science departments. Diagnostic and computer-science facilities exist at many universities, and several operate IC-fabrication labs with etching, deposition and lithography equipment that is suitable for deep-submicron structure development. The combination of creativity, analysis and predictive modeling, driven by industry goals but not directly connected to product applications, permits a flexibility not available in industry. Industry interaction through programs like the SRC Mentor Program ensure the research effort is industry-relevant and results are transferred quickly to industry.

Challenges

The strategic direction of Microstructure Sciences is to:

- shift the focus of device technology from a lithography-dependent, standard-shrink approach by introducing creative structures and process architectures;
- provide improved predictive modeling;
- conceive circuit elements that are yield-tolerant of manufacturing defects and parameter variations; and
- recognize opportunities for paradigm shifts that redirect engineering efforts to circumvent current technology limitations.

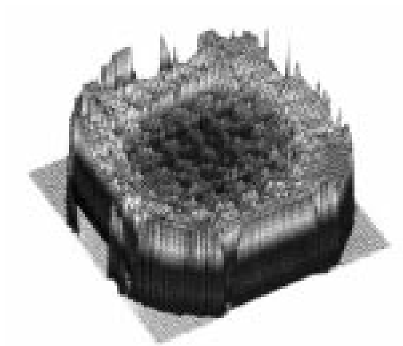
Specifically, Microstructure Sciences addresses advanced technology modules that are not part of the current mainstream. It is responsible for all architectural design/process flow and active-device forecasting. Some possible examples are SiGe epitaxial processes, silicon-on-insulator, 3-D active layers, known good-die testing and neural-network structures.

New Science Area Alignment for 1995

In late 1994, in order to align its research efforts with the goals set forth in the National Technology Roadmap for Semiconductors, the SRC merged parts of Manufacturing Process Sciences with Microstructure Sciences to create three new science areas for 1995: Process Integration and Device Sciences; Interconnect Sciences; and Materials and Bulk Processes Sciences. These new areas correspond to the Technology Working Groups in the Roadmap.

1994 Research Highlights

The Microstructure Sciences research program funded 47 research contracts at 21 North American universities in 1994, with a total value of $8.99 million. These contracts supported approximately 120 faculty members and 200 graduate students, 39 of whom graduated in 1994. More than half of these graduates are now employed at SRC-participating companies or universities.



A surface plot from MIT's Full-Wafer Imaging Interferometer, showing full-wafer etching rate uniformity.

Microstructure Sciences research highlights for 1994 include:

- University of Utah – Professor Clayton C. Williams and his colleagues have developed a method for extracting local-carrier density profiles from Scanning Capacitance Microscopy (SCM) measurements. Utah researchers have demonstrated a novel feedback technique that significantly simplifies and improves the accuracy of the SCM data inversion. They have also developed an approximate physical model and numerical algorithm that allows for the inversion of data several orders of magnitude faster than standard 2-D and 3-D simulators.
- University of North Texas – Professors Jeff Kelber and Guillermo Nuesca and their team have conducted research on the interfacial chemistry and adhesion properties of diffusion barriers. Research on the chemical interactions between a copper (Cu) metal organic chemical-vapor deposition (MOCVD) precursor and the substrate-surface impact adhesion, contact resistance and film microstructure has yielded important insights concerning integrated pre-cleaning and low-temperature MOCVD on titanium nitride (TiN) surfaces. Surface studies of tantalum (Ta) have revealed an unusual surface chemistry which may indicate robust adhesion even under conditions of extreme surface contamination. The research also suggests that Cu/Ta adhesion may prove more robust than Cu/TiN under "real world" deposition conditions, such as conditions of partial surface oxidation typical in industry practice.

Technology Transfer Highlights

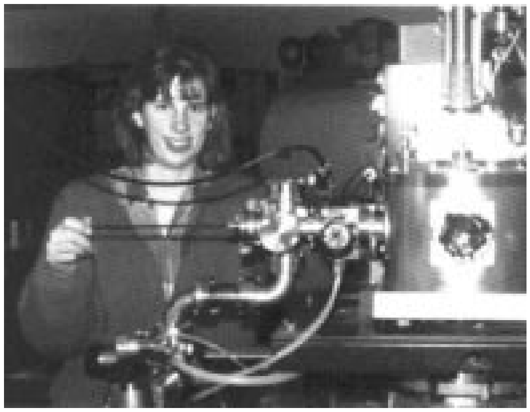
- Massachusetts Institute of Technology – Professor Herbert H. Sawin and researchers at MIT have developed the Full-Wafer Imaging Interferometer, a powerful tool for studying thin-film patterning via directional plasma etching. The interferometer has proven highly successful in measuring etching-rate uniformity, end point, and aspect ratio dependent etching (ARDE). Etching rate variations as small as one percent can be reliably measured with the device. Former students of Sawin have started a new company, Low Entropy Systems Inc., to commercialize the interferometer. Finally, several SRC-participating companies, including Motorola, Texas Instruments, Digital Equipment and IBM, currently are using the plasma-etch diagnostic device.

- University of Florida – Professor Jerry G. Fossum and his colleagues at Florida have developed SOISPICE, a device/circuit simulation tool for deep-submicron Silicon-on-Insulator (SOI) Complementary Metal-Oxide Semiconductor (CMOS) technologies. SOISPICE contains compact but physical models for thin-film SOI MOS transistors. The models have device structure-dependent parameters, and hence have predictive capabilities. SOISPICE is thus useful for SOI technology design as well as circuit design. The tool is widely used in industry at companies such as IBM, Texas Instruments, Intel, Motorola and Digital Equipment to assess and design SOI CMOS for low-voltage applications.

Note: Technology-transfer courses for both of the above research results were held in 1994. These courses help ensure that new technologies supported by the SRC are made available to SRC participants for rapid commercialization.

Packaging Sciences

John H. Kelly, Director



Cornell graduate student Nancy Stoffel loads polyimide samples into an ion-beam analysis chamber.

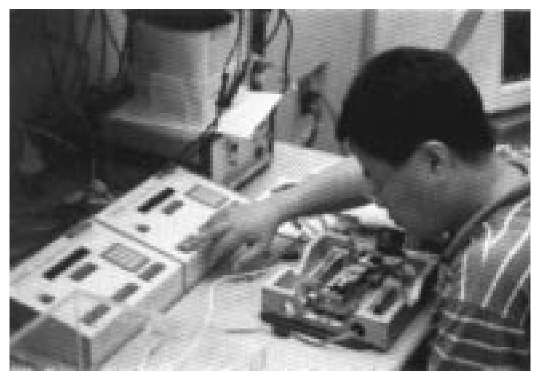
The increasing speed and density of integrated circuits is putting ever more stringent requirements on the package to remove heat generated by ICs in order to maintain operating temperatures consistent with high reliability. The SRC Packaging Sciences research program focuses on providing the information, tools and methodologies for the design and fabrication of packaging structures in order to satisfy the electrical, thermal/mechanical and reliability requirements of future packages.

Challenges

The electrical and thermal/mechanical characteristics of the package are critical elements in the overall performance of packaging systems. Therefore, the contributions of the package to system characteristics must be accurately predicted and taken into account in the system-design phase. Highly sophisticated software tools have been developed for IC design and simulation; similar tools are needed for the package. The eventual goal is to integrate the IC-design and package-design systems to provide a single-system environment for analysis, design and simulation. This environment will include package manufacturability constraints.

A segment of SRC research, therefore, is directed toward building and verifying models of package structures and integrating these models into a user-friendly design environment. Adherence to existing representation and software standards is important. Research in reliability focuses on two areas: composite materials and mechanical stresses.

SRC Packaging Sciences research areas include: Analysis, Design and Simulation; Heat, Signal and Power Distribution; Materials and Measurements; and Package Reliability.



Purdue University graduate student Young-Seok Kang performs micro-tensile stress measurements on polymer thin films.

1994 Research Highlights

The Packaging Sciences research program funded 16 research contracts at 13 North American universities in 1994, with a total value of $3.48 million. These contracts supported 60 faculty members and 72 graduate students. Four of the five students who graduated in 1994 now are employed at SRC-participating companies or SRC-supported universities.

Packaging Sciences research highlights for 1994 include:

- University of Texas at Austin – Professor Paul Ho and UT researchers have developed a Differential Capacitance Dilatometer capable of measuring the vertical thermal expansion coefficient (CTE) of polymer thin films. This measurement is essential for structural-integrity assessment of plastic packages. Quantitative results have been obtained for polyimide films as thin as two microns, quantifying the effect of molecular structure on the thermal anisotropy.
- Cornell University – Professor Edward J. Kramer and his team of researchers have experimented with intermixing polyimides to form strong bonds and increase fracture toughness. Polyimides have good mechanical properties, suitable electrical-insulating characteristics and superior thermo-oxidative stability, making them an attractive class of materials for use in electronics, particularly as insulators. Their poor self-adhesion is a problem that makes the production of multi-layered structures difficult and expensive. The Cornell team has developed a process for cladding commercial polyimide film with a thin layer of a different polyimide so that it can be laminated to itself or to metals by applying heat and pressure.

Technology Transfer Highlight

- Purdue University – Professors Cho-Yen Ho and Hui Li, Gabriela Marinsecu, Yung-Yu Chen and Purdue researchers have continued their work on the SRC/CINDAS Microelectronics Packaging Materials Database. This PC-based database contains evaluated data on the thermal, mechanical, electrical and physical properties of selected microelectronics packaging materials. The data is available on diskette, along with database management software that includes a self-contained graphics package for display and manipulation of retrieved data. Developed by Purdue's Center for Materials Information and Numerical Data Analysis and Synthesis (CINDAS), the database is the single most requested technical product from the SRC. Updated every four months and distributed widely to hundreds of users in the SRC community, the database is an effective vehicle for transferring engineering and technical information for microelectronics packaging applications to SRC-participating companies and organizations.

Graduate student John Pellerin adjusts an atomic-force microscope at Purdue University while working on CINDAS-related research.

Technical Excellence Awards

Recognizing Outstanding Research

The SRC Technical Excellence Awards were established in 1992 to recognize outstanding research and create a bond between student and faculty researchers and the SRC's industrial participants. Awards are based on scientific merit, relevance to the technical objectives of the SRC and the semiconductor industry, creativity and technology-transfer potential. In 1994, two research teams were selected as winners of the 1993 Technical Excellence Awards, which were presented at an awards luncheon coinciding with the SRC's June 1994 Operations Review and Board of Directors meeting in Research Triangle Park, N.C.

The 1993 Technical Excellence Award winners were:

Accelerated Ion-Doping During MBE Si and $Si_{1-x}Ge_x$ Film Growth

Science Area: Microstructure Sciences

Contributors: Professor Joe Greene and Dr. Lucia Markert (a former graduate student and SRC Fellow, now employed by AT&T and on assignment to SEMATECH), University of Illinois at Urbana-Champaign.

Impact: This technology involves a molecular-beam epitaxial technique for atomic-level control and incorporation of dopants for nanometer-scale device fabrication. This technique is now used in laboratories around the world and has accelerated the development of new devices.

Device and Process Simulation for Assessment of Advanced IC Technologies

Science Area: Microstructure Sciences

Contributors: Professor Mark Law, Dr. Heemyong Park (former SRC graduate student, now employed at Motorola Inc.), and current SRC graduate students Chih-Chuan Lin, Minchang Liang and Stephen Cea, University of Florida.

Impact: The Florida team's technology is a new, object-oriented simulator for devices – Florida Object-Oriented Device Simulator (FLOODS) – and for processes – Florida Object-Oriented Process Simulator (FLOOPS). This technology allows rapid prototyping of new models by eliminating the need for detailed knowledge of the entire simulator. FLOODS and FLOOPS technology has been assimilated rapidly by industry and technology computer-aided design (TCAD) vendors with significant savings in development time through rapid addition of new modules.

Professor Mark Law and graduate student Stephen Cea work on simulations at the University of Florida.

SRC Industrial Mentor Program

Industry Relevance and Technology Transfer

The SRC Industrial Mentor Program enhances the value of SRC research to industry and provides SRC-participating companies with early access to key technologies. In 1994, the program included 530 participants from 28 member companies and organizations. Scientists, engineers and managers who participated in the SRC Industrial Mentor Program are associated with specific, SRC-funded university research tasks. These experts provide perspective and insight into industry needs, helping focus the research on these needs, as well as accelerating the research and transferring results to their companies. Student and faculty researchers receive the benefit of direct interaction with industry engineers, as well as access to corporate resources.

Wisconsin researchers Matt Laudon (right) and Doug Resnick, who work closely with Motorola mentor William Johnson, perform an experiment to verify modeling results.

To recognize and honor the significant contributions made by the participants in the SRC Industrial Mentor Program, the SRC presents its annual Outstanding Industrial Mentor Awards. Six mentors were chosen to receive this award in 1994:

Charvaka Duvvury of Texas Instruments Inc. (Dallas, Texas), mentors Professor Steve Kang's Electrical Overstress/Electrostatic Discharge (EOS/ESD) project at the University of Illinois at Urbana-Champaign. Through collaboration on this Design Sciences research contract, Duvvury and Kang have filed two patents, co-authored a book and jointly published five conference and three journal papers. Duvvury also has arranged numerous summer internships at Texas Instruments for doctoral candidates.

William Johnson of Motorola Inc. (Tempe, Ariz.), is a mentor in Manufacturing Process Sciences. He works with Professors Franco Cerrina, James Taylor and Roxann Engelstad in their X-ray lithography research at the University of Wisconsin. Johnson has specifically worked with Engelstad and her students on mechanical modeling of mask designs and fixturing, an effort that led to a national industry standard for X-ray masks.

Robert Simonton of Eaton Corporation (Beverly, Mass.), has been a mentor to Professor Al Tasch at the University of Texas in the area of Microstructure Sciences since 1989. Simonton has helped with research strategy and provided key experimental support in both ion implantation and ion-implant analysis, performing more than 800 closely controlled implants for this research program during the past six years.

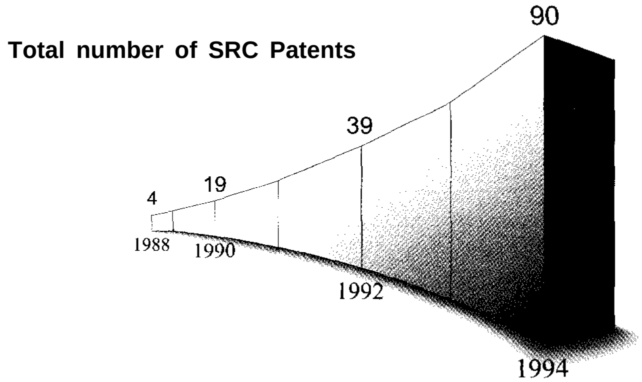
Rick Scott of SEMATECH (Austin, Texas), mentors a Manufacturing Systems Sciences contract at Texas A&M University. Scott has worked diligently with Professors Don Phillips and Brett Peters and their students to chart and guide semiconductor-manufacturing research efforts. His dedication is exhibited by his bi-weekly trips from Austin to Texas A&M (a four-hour drive, round-trip) to ensure industry relevance for the students' research.

Rex Lowther of Harris Corporation (Melbourne, Fla.), has served as a Microstructure Sciences mentor to Professor Mark Law at the University of Florida for the past six years. Lowther has been a champion of Florida's FLOODS and FLOOPS software effort and has been actively involved in global TCAD activities, such as the SIA TCAD Roadmap Subcommittee. In the area of device simulation, he adopted Florida's version of PISCES as the Harris standard.

Ravi Kaw of Hewlett-Packard Company (Palo Alto, Calif.), has served as a Packaging Sciences mentor to Professor John Prince and his team of University of Arizona researchers since 1988. Kaw was instrumental in sponsoring two successful equipment grants from Hewlett-Packard to the Arizona research program, one for an RF network analyzer and the other for an HP 700 series workstation. He has also provided valuable feedback to the researchers in their development of electrical modeling and simulation software.

Intellectual Property

Patented Technologies Add Value for SRC Participants



The SRC's value to the industry's technology base includes appropriate protection of intellectual property rights that result from SRC research. The SRC has a worldwide, unrestricted, royalty-free, non-exclusive license to these patents, as well as the ability to sub-license the patents to SRC participants.

In 1994, the SRC continued to strengthen its intellectual property portfolio with the filing of 23 new patent applications and the issuance of 21 U.S. patents in the following research areas: advanced devices; circuit design; contamination and defect control; deposition processing; interconnect; and lithography. Of particular significance were the patents in advanced devices and lithography:

Advanced Devices

Selected highlights of novel portfolio additions in the area of advanced devices include:

- A completely self-aligned bipolar junction transistor using selective epitaxial growth. Also, the development of a Silicon-on-Insulator (SOI) device formed by epitaxial overgrowth from the trench side walls;
- A heterojunction Field-Effect Transistor (FET) with enhanced carrier mobility and device-speed performance;
- A Metal Oxide Semiconductor (MOS) transistor with an oxynitride gate dielectric resistant to degradation under channel hot electron stress, exhibiting an order of magnitude longer lifetime compared with conventional silicon-oxide MOS devices;
- A SOI MOSFET, comprising electrically isolated segments, with improved current characteristics and electrostatic discharge protection; and
- A capacitorless Dynamic Random Access Memory (DRAM) cell on SOI substrate with a large READ current, and a simple fabrication process that is compatible with general purpose SOI Complementary Metal Oxide Semiconductor (CMOS) and 10-mask, fully-complementary SOI Bipolar CMOS processes.

Lithography

Lithography portfolio additions for 1994 were in the areas of masks, patterning and alignment. Of particular note were several patents for the development of unique photoresist compositions for making microelectronic structures:

- A silicon incorporated polystyrene-diene block copolymer that exhibits high-resolution and selectivity, while retaining high etch-resistance for electron-beam imaging;
- A positive-tone photoresist containing novel diester dissolution inhibitors that has demonstrated superior imaging speed; and
- A crosslinking agent made with water-soluble sugar that is environmentally more compatible than current resists.

The SRC proactively seeks to protect and preserve intellectual property assets resulting from SRC-sponsored research. One such example is the AWESPICE algorithm developed at Carnegie Mellon University (CMU). In 1994, the SRC initiated a subsequently successful request for re-examination of a U.S. patent issued to a Japanese firm. The patent described binary decision algorithms previously developed and disclosed by SRC-funded researchers at CMU. The AWESPICE algorithm, issued as a U.S. patent in 1994, involves the addition of nonlinear models (transistors) to the linearized interconnect simulator AWE. It allows very fast simulation of large interconnect structures driven by non-linear devices, such as a chip driving a multichip module substrate.

1994 SRC Patents	Inventor Institution	Patent Number	Issue Date
Triple Self-Aligned Bipolar Junction Transistor Integrated Circuit and Fabrication Method Therefor	Gerold Neudeck and Rashid Bashir Purdue University	5,286,996	2/15/94
Bilayer Resist and Process for Preparing Same	Christopher Ober et al. Cornell University	5,290,397	3/1/94
Process for Metal Deposition for Microelectronic Interconnections	Adam Heller et al. University of Texas at Austin	5,292,558	3/8/94
Ultrapure Water Treatment System and Method of Utilizing Same	Farhang Shadman and Robert Governal University of Arizona	5,302,356	4/12/94
Apparatus and Method for Uniform Microwave Plasma Processing	Joseph Cecchi and James Stevens Princeton University	5,302,803	4/12/94
Method and Apparatus for Simulating a Microelectronic Circuit	Ronald Rohrer et al. Carnegie Mellon University	5,313,398	5/17/94
Charge Monitoring Device for Uses in Semiconductor Wafer Fabrication	Wieslaw Lukaszek Stanford University	5,315,145	5/24/94
Method of Shallow Junction Formation in Semiconductor Devices Using Gas Immersion Laser Doping	Emi Ishida et al. Stanford University	5,316,969	5/31/94
Linear Voltage to Current Converter Including Feedback Network	Seyed Zarabadi and Mohammed Ismail The Ohio State University	5,317,279	5/31/94
Bilayer Resist and Process for Preparing Same	Christopher Ober et al. Cornell University	5,318,877	6/7/94
Self-Timing Integrated Circuits Having Low Clock Signal During Inactive Periods	Wojciech Maly Pranab Nag Carnegie Mellon University	5,324,992	6/28/94
Method for Making Masks	Y.M. Liu et al. University of California at Berkeley	5,326,659	7/5/94
Selective Deposition of Doped Silicon-Germanium Alloy on Semiconductor Substrate, and Resulting Structures	Mehmet Ozturk et al, North Carolina State University	5,336,903	8/9/94
Langmuir Probe System for Radio Frequency Excited Plasma Processing System	Sam Geha and Robert Carlile University of Arizona	5,339,039	8/16/94
Integrable MOS and IGBT Devices Having Trenched Gate Structure	Percy Gilbert et al. Purdue University	5,349,845	9/20/94
A Dual-Gated Semiconductor-on-Insulator Field Effect Transistor	Gerold Neudeck and Suresh Venkatesan Purdue University	5,349,228	9/30/94
Field Effect Devices Having Short Period Superlattice Structures	Kang Wang and Jin Park University of California at Los Angeles	5,357,119	10/18/94
Massively Parallel Addressable Array Cathode	Noel MacDonald Cornell University	5,363,021	11/8/94
Positive Resist Pattern Formation Through Focused Ion Beam Exposure and Surface Barrier Silylation	Mark Hartney et al. Massachusetts Institute of Technology	5,362,606	11/8/94
Process and Apparatus for the Use of Solid Precursor Sources in Liquid Form for Vapor Deposition of Materials	Alain Kaloyeros et al. State University of New York at Albany	5,376,409	12/27/94
Method for Automatically Generating Test Vectors for Digital Integrated Circuits	Janak Patel and Thomas Niermann University of Illinois at Urbana-Champaign	5,377,197	12/27/94

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