1986

Executive Summary

MEIS

MICROELECTRONIC & INFORMATION SCIENCES CENTER

University of Minnesota
Institute of Technology

UNIVERSITY OF MINNESOTA
TWIN CITIES

Center for Microelectronic and Information Sciences
227 Lind Hall
207 Church Street S.E.
Minneapolis, Minnesota 55455
(612) 624-5747

November 20, 1986

Dear Colleague:

Most of the programs and activities described in the enclosed 1986 Executive Summary of the Microelectronic and Information Sciences Center did not exist four years ago. MEIS programs were first implemented in 1982-83. Since that time MEIS has established research programs, initiated laboratory and curricula developments, facilitated collaborations, and begun a number of information transfer activities.

All of these developments reflect the growing strengths of Institute of Technology faculty members, graduate students and their departments in fields related to microelectronic and information sciences. Resources provided by MEIS have enabled university initiated activities to be realized. And MEIS has endeavored to promote the resulting successes among our industrial sponsors. Early goals of MEIS have been achieved through several meaningful industry-university collaborations which have developed from these interactions.

The success of MEIS has been developed through the cooperation of both university and industrial participants. As we look forward to the continuation of MEIS programs and activities, this interest, support, and participation are greatly appreciated.

Technical Reports of three MEIS team research programs are available from the MEIS office:

III-V Compound Semiconductors and High Speed Devices
Intelligent Systems
Monocrystalline Three-Dimensional Integrated Circuits

Call 624-8005 to request.

Sincerely,

Martha G. Russell, Ph.D.
Associate Director

MGR/spm

Enclosure

Microelectronic and Information Sciences Center

Commitment to Focus

Commitment to Cooperation

MICROELECTRONIC &
INFORMATION SCIENCES
CENTER

MEIS Center
227 Lind Hall
207 Church Street S.E.
Minneapolis, MN 55455

(612) 624-8005

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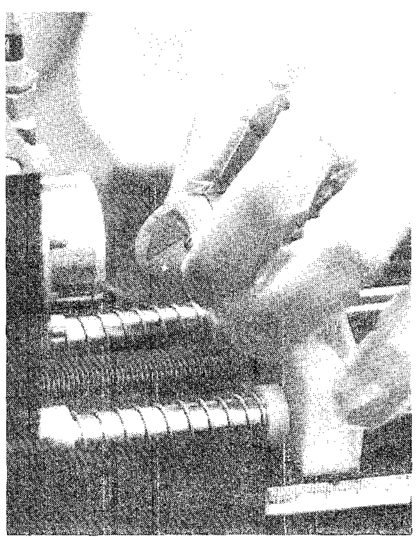
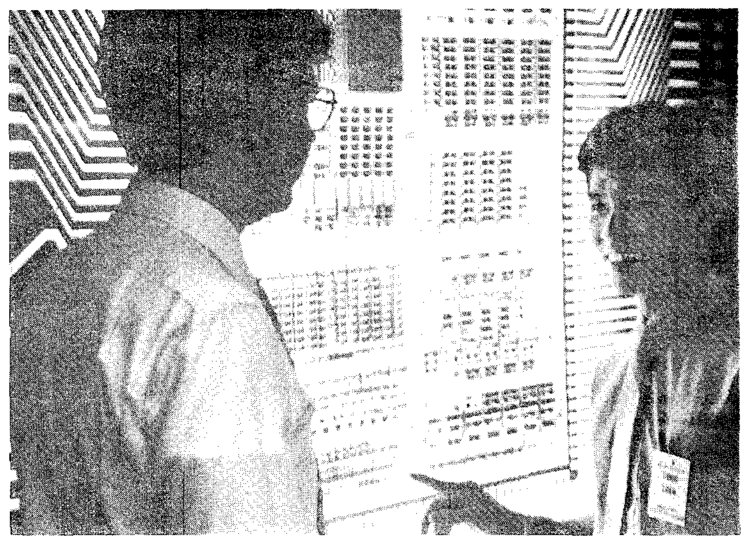
High Technology in Minnesota

Minnesota is home to more than 2,100 companies with products and services based on high technology. The leading 80 had a total gross revenue of $18 billion last year. Many of these businesses are worldwide corporations that make their headquarters in the Twin Cities metropolis. Minnesota's reliance on computers, electronics, and other high-tech businesses is strong, and the success of these companies has stimulated economic growth for the State through jobs and revenue.

The concentration of scientific and engineering experts at high-tech companies is an important strength of Minnesota. It is also a vital resource to the University of Minnesota. The University of Minnesota is an urban university located in the center of the Twin Cities. It is a land grant university with a mission of responsiveness to the surrounding community, and it is a research university dedicated to excellence in studying important problems and in educating graduate students.



Studies of the properties of materials such as silicon and gallium arsenide are important to the design and production of future microelectronic devices.



Long Tran received MEIS support while pursuing his M.S.E.E. degree and now designs integrated circuits for Honeywell.

To the companies, the University is a source of expertise, new knowledge, and recruits. To University researchers and students, the companies provide opportunities for interaction with industrial colleagues on technical problems of national significance, in state of the art laboratories. The people of Minnesota benefit from this partnership through the competitive advantage which this critical mass of cooperation gives to both the University of Minnesota and to the Minnesota high technology community.

The companies that have sponsored MEIS are national and worldwide leaders in high technology. Due to foreign competition, fiscal year 1986 was a sluggish year for the semiconductor industry throughout the United States. However, the supercomputer and telecommunications industries remained strong. In the future, leadership and profitability will require much cooperation. MEIS is sponsoring Institute of Technology research and educational programs and is enhancing University-industry cooperation that will help Minnesota companies maintain their technical capabilities.

The MEIS Mission

The Microelectronic and Information Sciences Center (MEIS) was established as an interdepartmental center in the Institute of Technology through the cooperative efforts of the University and local industry. MEIS is funded by the State of Minnesota and industrial sponsors. MEIS uses these funds to help faculty members and departments attract additional support from external grants and contracts for research activities which fuel this cooperation.

The mission of MEIS is to sponsor and conduct research, enhance education, and build university-industry collaboration in microelectronic and information sciences. Microelectronic sciences include the physical, chemical, and mathematical knowledge necessary to understand and develop technologies for circuits and devices in extremely small packages. Information sciences include the mathematical, physical, chemical, and cognitive knowledge needed for technologies of software and computer systems.

The MEIS technical community includes over 300 students, teachers, researchers, scientists, and engineers who are members of 65 professional societies.

MEIS Sponsors

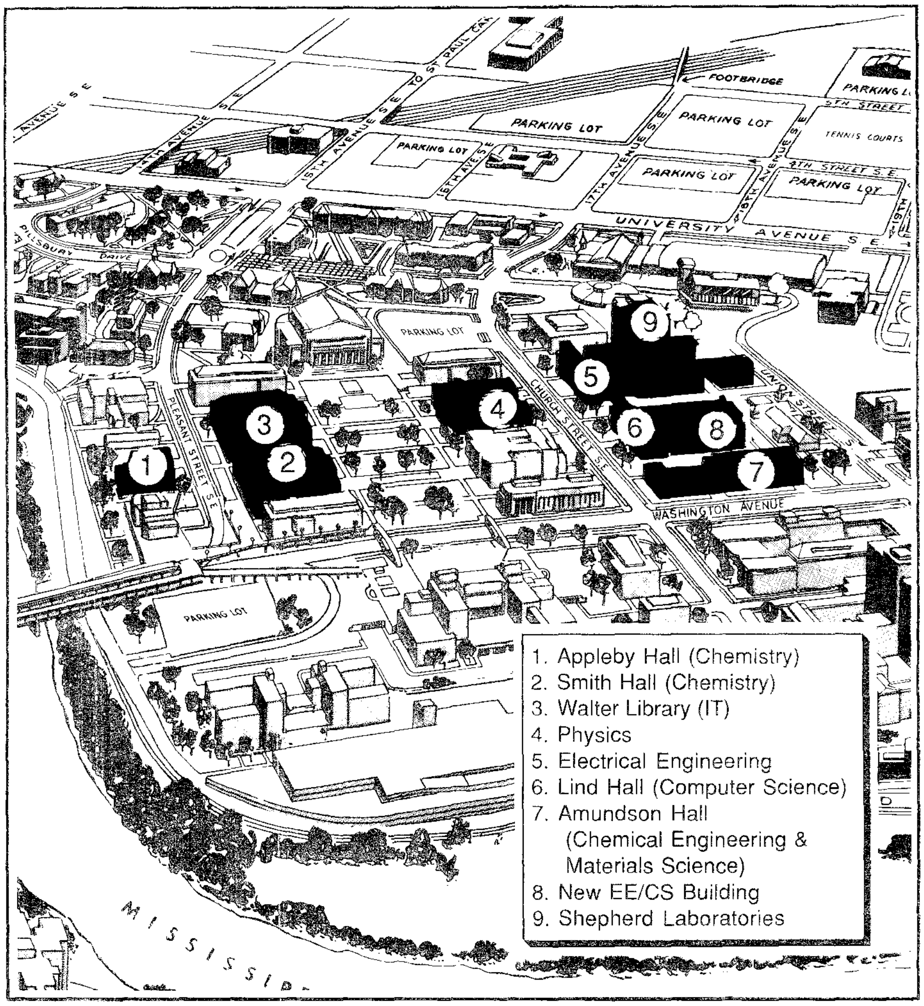
Control Data Corporation
Honeywell Inc.
Sperry Corporation
3M

ADC Telecommunications, Inc.
Cray Research, Inc.
VTC Incorporated
Zycad Corporation

State of Minnesota
Federal grants and contracts

Physically, the people and facilities affiliated with MEIS come from departments in the Institute of Technology. Their cooperation is focused on research, education, and information transfer in critical areas identified jointly by university and industry representatives in MEIS.

MEIS research is conducted in several group laboratories as well as in faculty labs located on the East Bank of the University of Minnesota.

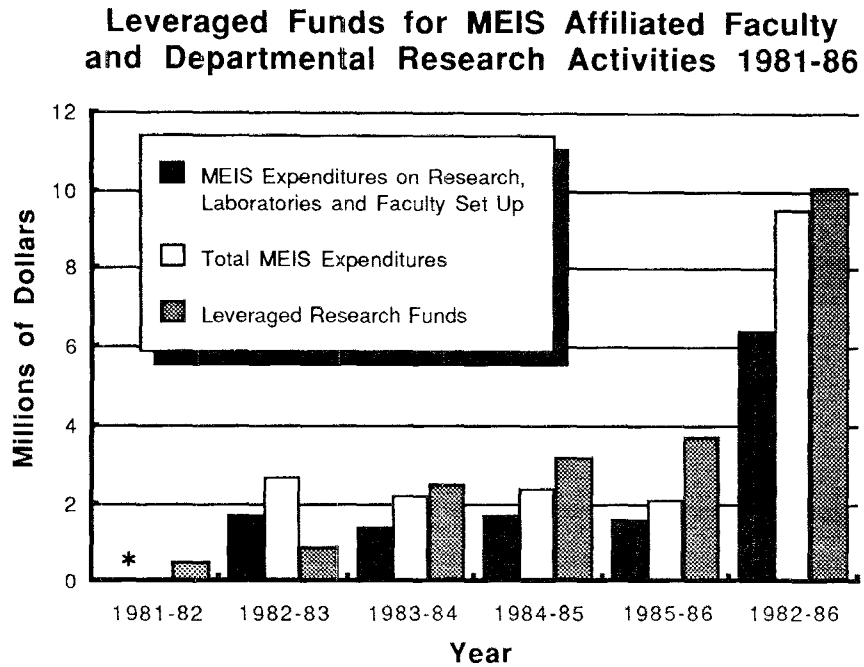


Activities on Campus

Last year, MEIS funded four team research programs and several independent projects involving faculty in five University departments: chemistry, chemical engineering and materials science, computer science, electrical engineering, and physics. Affiliated faculty members used $1.6 million in MEIS research funds as leverage to obtain for fiscal year 1986 nearly $4 million in resources from outside agencies. Together, these resources were used to construct new laboratory equipment, to support over 100 graduate students as research assistants, and to carry out research that has led to significant results and many published articles. In the past four years faculty researchers studying microelectronic and information sciences have obtained over $10 million in research contracts.

In funding research projects, MEIS plays a critical role in stimulating dialogue to identify important problems, in directing research toward issues relevant to the microelectronic and information sciences, in fostering an environment conducive to the formation of research teams, and in providing seed monies to help programs become self-sustaining.

In 1985-86, faculty and departments affiliated with MEIS obtained external support to provide $4 million for research and $4 million for graduate education.



* MEIS research programs were first funded in 1982-83.

Several research teams formed in the early days of MEIS now show the benefits of MEIS investments. A group of professors working to develop techniques and systems for high-performance computing received initial support from MEIS in 1982-83 and subsequently obtained a $3.2 million grant from the National Science Foundation to pursue this research. Another group of researchers sponsored initially by several MEIS small grants won a highly prized award of $2 million from IBM last year for materials interface research in polymers. Likewise, a subgroup which developed from a team research program has competed successfully for $450 thousand from the federal government to study nonlinear optical media.

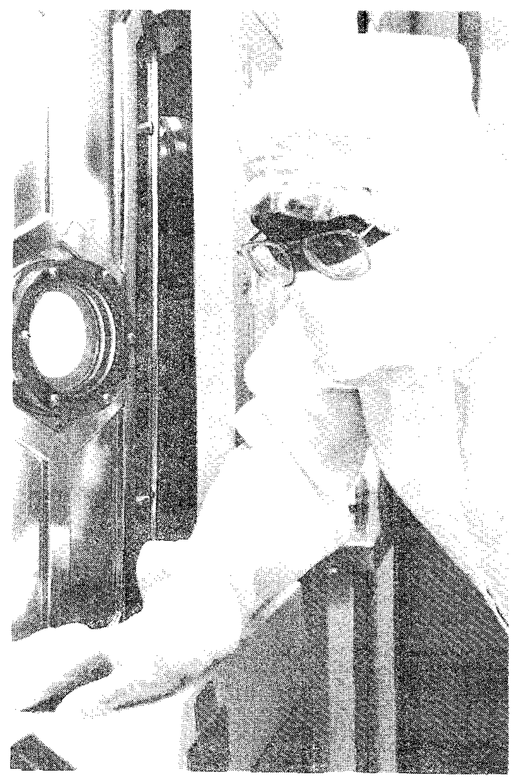
In addition to supporting research, MEIS funds have been used by affiliated departments to strengthen graduate programs. To help address the severe shortage of young scientists and engineers in the United States and in Minnesota, the MEIS fellowship program has brought more than 80 doctoral students to the University in the past five years. Half of these have come from other states to increase the ranks of scientists and engineers in Minnesota. MEIS provided $412 thousand in fiscal year 1986 to strengthen departmental programs. This was augmented by $764 thousand in contributions and equipment through the American Electronics Association (AEA) for fellowships and faculty development. Over 300 graduate students have benefited from MEIS initiatives.

Participation with Industry

The MEIS technical community is made up of over 300 students, teachers, researchers, scientists, and engineers who are members of 65 professional organizations. By encouraging interaction among people in the MEIS technical community, MEIS helps to build bridges that lead to new modes of inquiry and important new discoveries.

Interaction between faculty researchers, graduate students, and industry researchers is an important mechanism for the exchange of scientific and technical information. MEIS promotes this interaction through summer internships for MEIS fellows, seminars, cooperative projects, faculty consulting, and other programs. Thirty fellowship recipients have worked for sponsoring companies, gaining valuable hands-on industrial experience. Meanwhile, 35 professionals in local high-technology companies bring their practical experience into the classroom as adjunct professors, and teach courses in affiliated departments.

3M Software Engineer Dr. Sharon Garber collaborates with Professor Paul Johnson on an extension of MEIS research on which she worked as a graduate student.



MEIS fellow Bruce Greenwood, an etch engineer at Sperry's Semiconductor Operations, works to fabricate new devices.

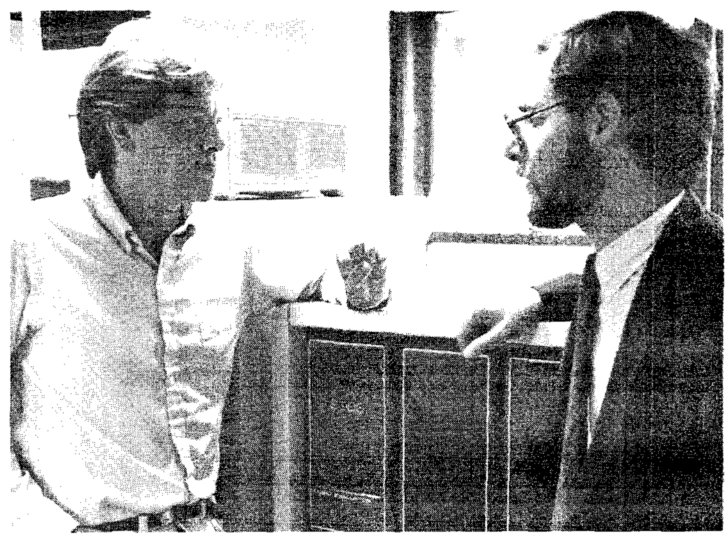
Four graduated MEIS Fellows are now working in industry. Karen Ryan and Jayaram Bhasker work in Honeywell's Computer Sciences Center. Steven Murphy works in Sperry's Computer Science Division, and Surendra Nahar works with AT&T Bell Laboratories. Karl Roenigk, who has worked on MEIS related research, will begin employment at 3M in January. David Graves and Ron Schrimpf, who worked on MEIS research projects, are assistant professors of chemical engineering at the University of California, Berkeley, and of electrical engineering at the University of Arizona, respectively.

Educational Enhancements

Resources invested in the University through MEIS have strengthened departmental graduate programs in the Institute of Technology in several ways. MEIS programs have helped to increase the numbers of outstanding graduate students, attract top quality faculty, acquire advanced equipment for teaching laboratories, and create opportunities for students to perform research in the laboratories of sponsoring companies.

Graduate students have been attracted to the University of Minnesota through the availability of fellowships and research assistantships. In 1985-86, MEIS awarded fourteen doctoral fellowships to graduate students who had excellent undergraduate records and strong interests in microelectronic and information sciences, bringing the total to sixty-six since 1982-83. Seven American Electronics Association Fellowships were also awarded. The number of graduate students and post doctoral scientists working as research assistants on projects that have received MEIS funding is well over 100, and many more are receiving support through programs that have grown out of MEIS initiatives. As these students pursue degrees in chemical engineering and materials science, chemistry, computer science, electrical engineering, and physics, they contribute a zeal for discovery to the teaching and research activities in their departments.

MEIS fellow Dr. Karen Ryan is a Principal Research Scientist at Honeywell and teaches computer science courses as an adjunct professor.



MEIS fellow Asgeir Eiriksson (left) and Professor Gerald Sobelman are using a Zycad logic evaluator to develop advanced integrated circuits.

Graduate students have also been attracted to the University of Minnesota through initiatives which have added fourteen professors to MEIS affiliated departments. The new research programs introduced by these and other professors, new courses and laboratory facilities sponsored by MEIS have further expanded the opportunities for graduate students to study microelectronic and information sciences at the University of Minnesota.

For example, the materials science graduate program in the Department of Chemical Engineering and Materials Science has been substantially enhanced through MEIS initiatives. Formerly based on metallurgy, the transition of this program to a materials science program has been encouraged by MEIS through the addition of professors, courses, and the development of synchrotron radiation, surface-interface analysis and MOCVD reactor facilities. This revised graduate program now attracts students equal in quality to the chemical engineering graduate program, which is ranked #1 nationally.

In a similar manner, MEIS has encouraged the establishment of an artificial intelligence specialization in the computer science graduate program. Through MEIS initiatives, new faculty, new courses, and an artificial intelligence laboratory in the Computer Science Department have enabled the progress of research programs and have also established educational programs which now attract talented students to the University of Minnesota to study this challenging field.

MEIS investments in departmental capabilities have enhanced the educational opportunities for over 300 master's and doctoral students at the University of Minnesota. When they enter the workforce as scientists and engineers in industry and as professors at universities, they will be important intellectual resources in maintaining state and national competitiveness in high technology. Over 80 doctoral degrees on related topics are currently in progress by MEIS supported students.

MEIS fellow Nancy Reed and graduate student Todd Reed take a break from their studies of expert systems and image processing.

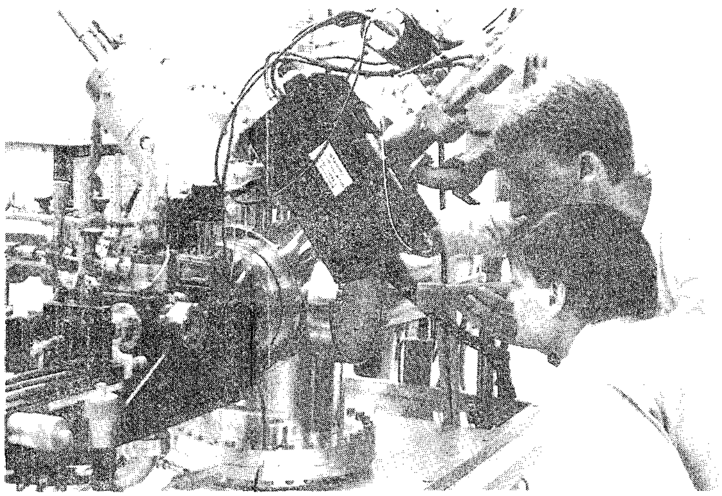
Another very important input into educational programs comes through industry scientists and engineers who teach university courses as adjunct professors. Courses and perspectives that might otherwise be unavailable to students and other faculty members are made possible by professionals in local companies who bring their expertise to the classroom. In the Electrical Engineering and Computer Science Departments, many of the adjunct professors work for companies that sponsor MEIS. Two, in fact, were MEIS Fellows. As lecturers, as members of teaching teams, and as links between industry and university, adjunct professors add synergy to educational programs.

Professor Rolf Schaumann conducts MEIS research and teaches courses in electrical engineering to future scientists and engineers.

Research Advances

MEIS researchers are investigating materials, processes, design, simulation, and applications important for microelectronic and information technologies. In microelectronics today, new discoveries about materials are having significant impacts on new designs, architectures, manufacturing, and applications. Further knowledge of microelectronic materials will be significant to the semiconductor industry, as well as to the many industries that depend on microelectronic devices.

For example, advances in the computer and communication industries require faster, smaller, and more complex circuits. To fabricate these future circuits, new surface modification techniques are needed which can achieve submicrometer-wide conductor lines, insulating gate oxides a few hundredths of a micrometer thick, and junction depths of a tenth of a micrometer or less. Advances at these dimensions require that materials and their interactions be controlled on an atomic scale.

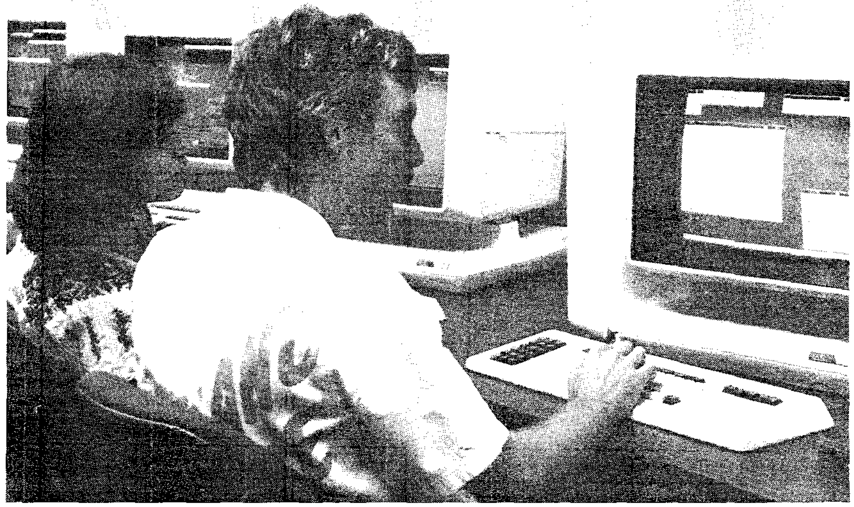


MEIS fellow Roland Schulze (top) and graduate student Rick Haasch study surfaces of materials with an electron spectrometer.

MEIS research programs include studies of both existing and new materials for microelectronics. Two materials of particular interest are silicon and gallium arsenide. Guided by new knowledge of these materials and their characteristics, researchers are developing design and simulation tools which facilitate the theoretical examination of processing techniques and device design. Processing techniques and designs developed through these simulation procedures are then investigated experimentally. MEIS researchers are studying techniques for silicon epitaxy at low temperatures and are experimenting with the use of steered ion beam techniques for fabrication.

In addition, MEIS researchers studying gallium arsenide and other III-V compounds are looking at properties of surfaces and interfaces with metals and insulators. They are also examining various controlled fabrication processes, such as molecular beam epitaxy and metal organic chemical vapor deposition. Two processes of special significance are ion implantation and film deposition in ultra high vacuum systems. MEIS researchers studying

MEIS fellow Rich Enbody uses a high-performance computer to develop advanced software programs.



novel materials, including organic and inorganic compounds, are examining the potential for fast switching, ultrafast chemical phenomena, and reversible chemical processes. New analytical instrumentation is being developed to investigate the results of these experiments.

As another example, advances in the information processing and data communication industries are also requiring increased speed and complexity. Faster design tools and more complex computer architectures are needed to handle the increasing requirements for more complex integrated circuits and intelligent computer systems. MEIS research programs are addressing a range of topics from the characteristics of design to the mathematics of computational complexity. The characteristics of linear complementarity and quadratic functions are important for parallel algorithms and for tools used in designing structured chip layout systems. Algorithms and layout systems guide the design of new computer architectures, computer systems, and computer-aided-design tools. These tools are useful in simulating, designing, and testing new operating systems and software systems, database designs, very large scale integrated circuits, and faults in circuits and systems.

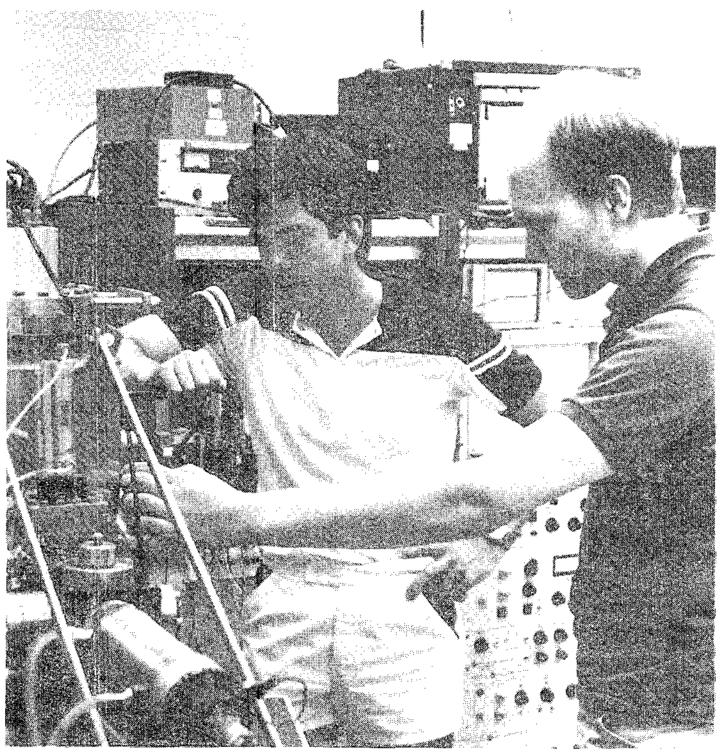
MEIS research programs in information sciences are also addressing the fundamental character of information in expert systems and in very large scale computation. For example, techniques for classifying human expertise and for characterizing the nature of problems are basic to developing tools to build and use expert systems. The geometry of images and the understanding of vision are critical to designing computational vision systems.

To provide knowledge necessary for new information technologies, MEIS researchers are developing tools to identify, recover, and manipulate the expertise needed for object definition and recognition in visual scenes.

In 1985-86, MEIS sponsored four team research programs and several individual projects, described in this report.

III-V Compound Semiconductors and High Speed Devices Program

Gallium arsenide (GaAs) is one of a class of materials referred to as III-V compounds. It is of special interest in microelectronics because of its high speed switching characteristics, its thermal properties, its radiation resistance, and its usefulness in optoelectronic applications. Devices and integrated circuits based on GaAs have emerged as strong contenders for the superfast circuits of the 1990s. For example, one of the MEIS member companies expressed interest in using GaAs for the next generation of supercomputers. GaAs is also of considerable interest in optoelectronics. While many of the applications for GaAs will be identified in the future, some have already been identified. Companies in the United States are fabricating GaAs integrated circuits of several thousand gate complexity and have produced enough GaAs monolithic microwave integrated circuits to prove feasibility, opening new opportunities for satellite broadcasting applications.



Graduate student Greg Whaley (left) and MEIS fellow Paul Pukite study new materials using an MBE system.

MEIS research in this area includes the team research program on III-V Compound Semiconductors and High Speed Devices and a few individual projects. The III-V Compound Semiconductor and High Speed Devices program has made significant contributions to scientific knowledge, to education at the University, and to industrial applications. This program is a coordinated project combining investigations of synthesis, characterization, and modeling of advanced semiconductor materials with applications in device development. This team's objectives are to incorporate new methods of surface and interface preparation of GaAs and related III-V semiconductors into new solid-state devices that will be important for high speed integrated circuits.

The team's efforts include several research thrusts and have resulted in two patents for device designs, the publication of 81 refereed papers, numerous presentations at international conferences, other universities, and electronics companies, and two workshops on III-V materials and devices at Minnesota. The group received $900,000 in research support from federal agencies and corporations for activities in fiscal year 1986. Nine new laboratory instruments were built or acquired by the team for their research. Several industrial scientists, 38 graduate students, and 17 post doctoral researchers have worked on the project during the past year.

Computational simulations using supercomputers at the University of Minnesota help establish feasibility of experimental activities based on complex theoretical considerations.

The III-V Compound Semiconductors and High Speed Devices program combines synthesis, characterization, and modeling of advanced semiconductor materials with applications in device development.

Professors in the Team:

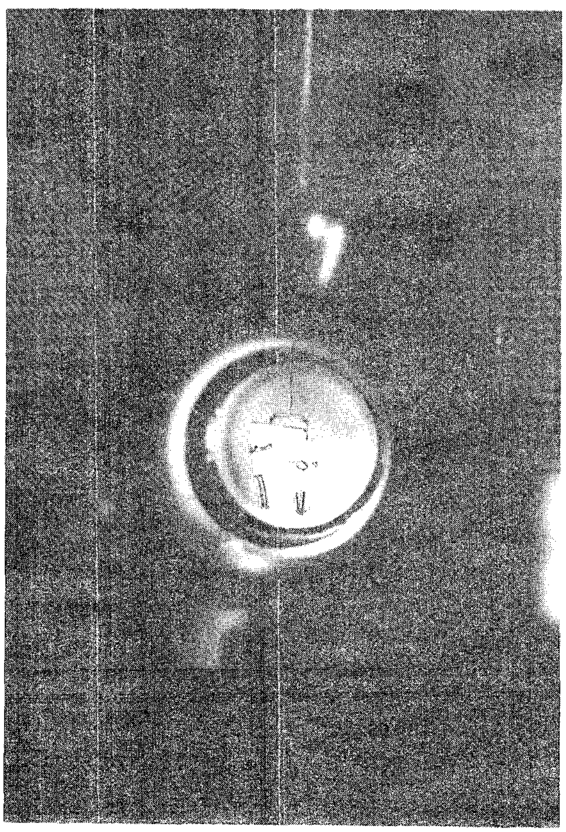
Klavs F. Jensen, Coordinator	Chemical Engineering & Materials Science
Alfonso Franciosi	Chemical Engineering & Materials Science
John H. Weaver	Chemical Engineering & Materials Science
Philip I. Cohen	Electrical Engineering
Michael S. Shur	Electrical Engineering

One thrust of this program involves studies of metal-GaAs interface properties. This project involves the examination of electrical, physical, and chemical properties of the interface. The results of these studies should lead to new methods of surface and interface control. A second thrust deals with investigations of III-V growth by molecular beam epitaxy (MBE) and metal organic chemical vapor deposition (MOCVD). More complete understanding of growth and processes will contribute to the development of films with better uniformity, reduced background impurity levels, and sharper heterojunctions. A third thrust is on characterization, modeling, and performance improvement of III-V devices. These studies incorporate the results produced in the interface modification and synthesis studies and identify promising opportunities for new device designs. The combination of novel fundamental interface research with device simulation, fabrication and processing techniques places the research team in the forefront of III-V research.

When this research program was initiated, MEIS made an investment in equipment for use in materials studies and surface analysis. The synchrotron radiation center helped to attract Professors Weaver and Franciosi to the University, and these and other MEIS investments have since been matched by federal agency funding which has been used to acquire other new instrumentation. Professor Weaver has since developed the capability to perform several specialized characterization techniques, including synchrotron radiation photoemission, LEED, angle resolved Auger electron spectroscopy, inverse photoemission, small-spot-high-resolution XPS, and electron microscopy. These techniques are being used on III-V compounds, as well as on other compound semiconductors and on polymers.

Professor Franciosi has investigated the effects of the chemical reactions that take place at semiconductor surfaces so that, ultimately, control of the kinetics of surface reactions with gaseous species and metals can be enhanced. This research has led to the development of processes which use catalytic reactions to promote the formation of new stable insulating layers on GaAs surfaces. This work could have substantial impact on GaAs device technology.

MEIS has also invested in the construction of three metal-organic chemical vapor deposition (MOCVD) reactors, which have enabled a major expansion in Professor Jensen's research. In the past year, research using these reactors, designed by Professor Jensen, has focused on the chemical and physical rate processes underlying the growth of compound semiconductor heterojunctions by metal organic chemical vapor deposition (MOCVD). The MOCVD process is a promising technique for large scale production of III-V device structures, as well as for those made of other compound semiconductors.



Gallium arsenide, seen here through the window of a vacuum chamber, is a material that can be used to make fast microelectronic devices.

Graduate student Peter Lee uses an innovative MOCVD reactor to study the growth properties of gallium arsenide and other III-V compound semiconductor materials.

These unique reactor designs were based on computational supercomputer studies of gaseous flow patterns in the reactor. Novel features of the new reactors include well controlled flow fields, short residence times, radiant heating and mass spectrometer effluent monitoring. The reactors serve a dual purpose: formation of new semiconductor materials on which electronic properties can be investigated as a function of growth conditions; and studies of chemical mechanisms and physical rate processes underlying MOCVD.

Molecular beam epitaxy (MBE) is another useful process for growing compound semiconductors and forming interfaces. Professor Cohen's research is aimed at gaining fundamental understanding of the growth of compound semiconductors. With this fundamental understanding it is hoped that it will be possible to predictably influence the properties of materials by adjusting growth parameters.

New circuit simulations contributed to the fastest integrated circuits ever made.

Professor Shur's circuit simulations, implemented on a variety of computers, contributed to the development of the fastest integrated circuits ever made. The devices were fabricated by two Honeywell scientists and showed speeds of 8.5 picoseconds at 77° K and 11.6 picoseconds at 300° K. This is one of five new device types proposed and developed by Professor Shur in collaboration with other University and industry scientists:

1. New inverted modulation doped field effect transistor (MODFET) with the highest transconductance ever observed at 300° K and at 77° K for any FET.
2. Complementary heterostructure insulated gate transistors with the highest ever observed transconductance and the shortest gate delay for p-channel devices. These devices are very stable with respect to the temperature variation and for the first time open up an opportunity for complementary GaAs logic.
3. Novel hot electron transistor with small parasitics.
4. Superlattice modulation doped transistor.
5. Tunneling emitter bipolar transistor.

Professor Shur has focused on the development of novel device concepts and analytical and computer models for simulation of ultra high speed semiconductor devices and integrated circuits. Studies of the physics of modulation doped devices have resulted in a new theory for scattering by impurities in modulation doped structures. This theory demonstrates that much higher mobilities may be obtained than previous research has indicated possible. Contributions to the development of the world's fastest integrated circuits (8.5 ps at 77° K and 11.6 ps at 300° K) have been made by personnel on this project in conjunction with scientists at Honeywell, an MEIS member company.

Intelligent Systems Program

Artificial intelligence, the technology of developing computers that can perform reasoning and learning functions normally associated with human intelligence, is important to the development of new tools that help solve complex problems and aid in decision making tasks. The MEIS team research program known as Intelligent Systems has gained prominence in this field by focusing on the construction of machine representations of activities requiring skill and expertise. These representations are developed from an analysis of the information processing requirements of tasks and from biological models of task performance. The goals of this team research program are to develop models of the processes by which difficult problems can be solved (expert systems) and to gain an understanding of the fundamental principals that underlie vision in order to build automatic vision systems for tasks, such as manufacturing, vehicle guidance, etc. (computer vision).

The Intelligent Systems group published 23 articles last year and has received $350,000 in funds from federal agencies and corporations for fiscal year 1986. The team has acquired high-performance computers, specialized software, peripherals, and cameras that provide the graphics displays necessary for artificial intelligence research. This equipment comprises an Artificial Intelligence Laboratory providing facilities for research and education in computational vision and expert systems.

Applications have been developed for pediatric cardiology, legal systems, plant pathology, auditing, reactor design, off-line quality control, product development and computed fault diagnosis.

Researchers in the Intelligent Systems team are studying human experts and developing computer programs that solve complex problems, and are studying vision to make it possible for machines to perform new tasks.

Principal Investigators:

Paul Johnson	Management Sciences
William Thompson	Computer Science
James Slagle	Computer Science

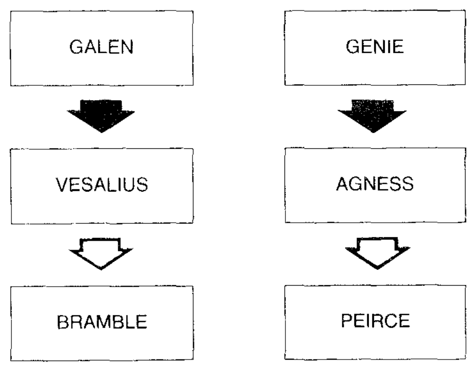
Collaborating Investigators:

John Carlis	Computer Science
Maria Gini	Computer Science
Ting-Chuen Pong	Computer Science
Mostafa Kaveh	Electrical Engineering
Harry Wechsler	Electrical Engineering
Albert Yonas	Institute of Child Development
Christopher Nachtsheim	Statistics
Glen Berryman	Accounting

In the study of expert reasoning, Professor Johnson and his team have developed methods for investigating human experts. These methods draw upon the field of cognitive science and have led to computational models for research and development in the fields of artificial intelligence and expert systems. This team has conducted specific studies of expertise in areas such as medicine, science, engineering, law, and business. During the past year, for example, the team has collaborated with researchers from the business and industrial communities to investigate expertise in auditing, product development and off-line quality control and computer hardware fault diagnosis. Together with researchers from 3M, an MEIS member company, and faculty members in the Chemical Engineering and Materials Science Department, they have studied expertise in designing chemical reactors. Based upon work in the area of computer hardware fault diagnosis, performed jointly with IBM and Control Data Corporation, another MEIS member company, a computational model called VESALIUS has been developed.

Researchers have collaborated with 3M, IBM, Control Data and others to transfer technology.

Computer programs developed by the team:



GALEN	—A stand-alone expert systems shell used successfully to implement expert systems in such widely varying fields as business auditing and plant pathology.
VESALIUS	—A program to diagnose faults in computer hardware; grew out of the GALEN project.
BRAMBLE	—A computational model of the process of reasoning by analogy.
GENIE	—An expert system providing greater representational power, simplified knowledge specification, and smaller storage requirements.
AGNESS	—A Generalized Network-based Expert System Shell; the successor to GENIE.
PEIRCE	—A logic-based language used for describing and implementing expert classification systems.

The team has also designed a program named BRAMBLE. BRAMBLE is the implementation of a computational model based on reasoning by analogy. This program is different from many typical knowledge-based systems in that it includes explicit models both of contextual knowledge and of the role of contextual knowledge in analogical reasoning.

In addition to computational models of expert systems, members of this team have developed operational systems, called expert system shells. Expert systems represent and apply knowledge obtained from a specialist in a problem domain. Since most of the software instructions to operate the system can be separated from the domain specific knowledge, one program, called an expert system shell, can be written to handle rule bases from several domains.

Professor Slagle has developed such an expert system shell called AGNESS. This shell is a successor to GENIE, a shell he developed earlier. In AGNESS, representational power is greater and knowledge specifications are simplified because representational structures are shared whenever possible. By reducing redundancies of the previous system, storage requirements are smaller, and storage efficiency is increased. The team is also in the process of developing a logic-based language, called PEIRCE, that can be used for describing and implementing expert classification systems.

MEIS fellow Malathi Char demonstrates the cameras and computers being used by the Intelligent Systems team to study vision.

In order to realize the long-range goal of developing general-purpose vision systems, the team has investigated techniques for interpreting visual data. Vision systems are needed for tasks ranging from control of robots in manufacturing to autonomous vehicle guidance, and most of the computer vision systems now in commercial use have been built for special purpose applications. Because this team's long-range goal is the development of general purpose vision systems, the team's vision research has concentrated on techniques for interpreting visual data applicable to a broad class of situations. Current efforts involve a variety of techniques in which the camera or the object is moving. These motion-based techniques have been used for finding object boundaries, determining spatial relationships, passive ranging, and recognizing certain types of objects and events.

Professor Thompson's research has led to the development of a preliminary model of a process referred to as inexact vision. Using inexact vision, reliability can be increased by designing vision algorithms that only require a partial specification of scene properties. Efforts at determining precise geometry of scene properties lead to complex, numerically unstable algorithms. Inexact vision systems may prove superior because they can handle more complex scenes.

Monocrystalline Three-Dimensional Integrated Circuits Program

The MEIS team research program on High Performance Integrated Circuits is directed toward the development of all-semiconductor three-dimensional integrated circuits. To optimize the performance and reliability of this system, the team has aimed for a single crystal semiconductor monolith containing a three-dimensional doping pattern with buried, junction-isolated devices and circuits. This team research program includes investigations of approaches to design, fabrication, and tests of such integrated circuits.

American Electronics Association grants and fellowships for faculty development have come from:

Honeywell Inc.
Cray Research, Inc.
ADC Telecommunications
Data Card Corporation
Dicomed
Zycad Corporation
Network Systems Corporation
Rosemount, Inc.
Research, Inc.
Micro Component Technology, Inc.

The High Performance Integrated Circuits team is developing technology for a three-dimensional integrated circuit made from a single crystal semiconductor.

Professors in the Team:

R. M. Warner, Jr., Coordinator	Electrical Engineering
Rolf K. Mueller	Electrical Engineering
William T. Peria	Electrical Engineering
William P. Robbins	Electrical Engineering
Alfons Tuszynski	Electrical Engineering
Anthony J. Valois	Electrical Engineering
Gottfried K. Wehner	Electrical Engineering

Team members have received over $200,000 in external funding for their research. Thirteen articles and papers related to the program have been published or accepted for publication in the past year. Two team members, Professors Warner and Wehner, along with a recently graduated doctoral student, Ron Schrimpf, have applied for a patent for a monocrystalline three-dimensional integrated circuit structure. This structure, called an orthogonal-isolator, is physically similar to a JFET having two independent gate regions, and having channel properties such that $V_t \approx 0$ (from the E-mode point of view). E-mode, D-mode, and "0-I mode" JFETS have been fabricated using quasiconventional technology for the purpose of testing numerical and analytical models experimentally.

Sputter epitaxy, one of the possible tools for fabricating the monolith, has been used to grow single-crystal silicon on silicon at unprecedented temperatures near 200°C. While device quality materials have not yet been achieved, the preliminary results are promising. In addition, a continuous wave laser annealing process has been used successfully to make tunnel junctions function as ohmic contacts for both forward and reverse biases.

To complement these design and fabrication investigations, this research program has also examined the development and use of computer controlled scanning laser acoustic microscopy (SLAM) for the nondestructive examination of three-dimensional integrated circuits. At this point in the program the SLAM has been used to image etched features 5 microns deep, on the backside of a glass slide, and to examine oxide features on silicon wafers.

Artificially Structured Materials Program

Research carried out by the Artificially Structured Materials team was motivated by the premise that the size of microelectronic devices will eventually be reduced to nanometer dimensions. The team's fundamental investigations of the characteristics of artificial structures are helping to establish the scientific knowledge needed for greater predictability in the development of nanometer scale devices. In fiscal year 1986, the team obtained $674,800 in federal funds, supported five graduate students and post doctoral researchers, and published 8 articles related to the research program.

Researchers in the Artificially Structured Materials team have discovered facts about extremely small structures that may be useful in the development of future microelectronic devices.

Professors in the team:

Allen Goldman, Coordinator	Physics
Paul F. Barbara	Chemistry
Charles Campbell	Physics
E. Dan Dahlberg	Physics
John F. Evans	Chemistry
William W. Gerberich	Chemical Engineering & Materials Science
Robert M. Hexter	Chemistry
Larry D. Miller	Chemistry
Lanny D. Schmidt	Chemical Engineering & Materials Science
Oriol T. Valls	Physics

In order to build devices at nanometer scales, scientists must know the characteristics of artificially structured materials. Knowledge about the physical and chemical characteristics of these materials is of particular importance because imperfections that might be acceptable at larger length scales may be detrimental to nanometer scale devices. Properties of materials on length scales only slightly larger than atomic dimensions cannot be inferred either by extrapolating from knowledge about the molecular level or by estimating downward from the understanding of bulk materials. Therefore, the team has developed theoretical models and has used supercomputers to simulate electronic systems at the nanometer scale in order to better understand properties of materials at these scales and to help determine which types of experiments will yield results which will best further that understanding.

Members of the team have conducted research to develop novel chemical techniques to synthesize artificial structures, to develop methods for characterizing and modeling thin films and heterostructures, to study the electrical properties of ultra thin metal films, to characterize defect structures of thin films on substrates and of heterostructures, and to measure and simulate the electron properties of the GaAs/AlGaAs heterostructures. A scanning tunneling microscope, an important new instrument used to characterize thin films and heterostructures, has been constructed by

Professor Goldman. In a scanning tunneling microscope, topographical features of a sample can be examined at the submicrometer level.

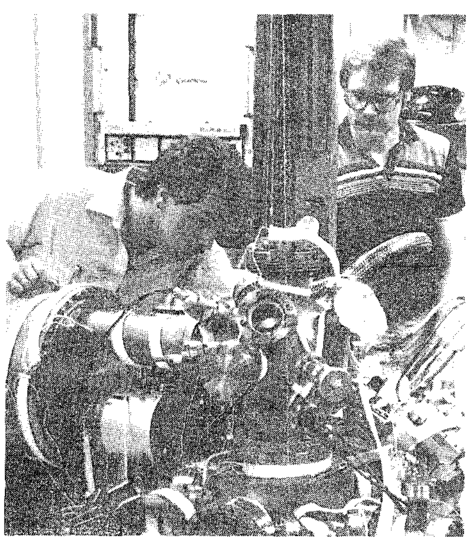
Postdoctoral researcher Max Schaible develops photo resist image for x-ray microscopy.

Individual Projects

By funding individual research projects, MEIS recognizes new research directions and maintains a broad base of expertise for building teams in the future. Twenty professors in affiliated departments have conducted individual research projects funded by small grants from MEIS. Investigations by these MEIS researchers have ranged from the development of advanced software systems to the characterization of new devices. MEIS investments in these projects have leveraged over $2.2 million in external research support.

One small grant recipient, Professor Anand Tripathi, has produced computer software with applications in a number of industrial environments. This software forms a distributed operating system that integrates a number of workstations with different architectures into one computing environment. The operating system makes it possible to develop prototypes of large distributed application systems that require large amounts of data processing and services. Examples of this type of system are found in the areas of command and control, banking, airline reservations, and office automation. In addition to the MEIS grant, support from the Graduate School and the AT&T Foundation, as well as workstations donated by Hewlett-Packard, have made it possible for Professor Tripathi to establish a laboratory for research in distributed computing. He has obtained $162,000 in additional support and has three graduate students working on the project.

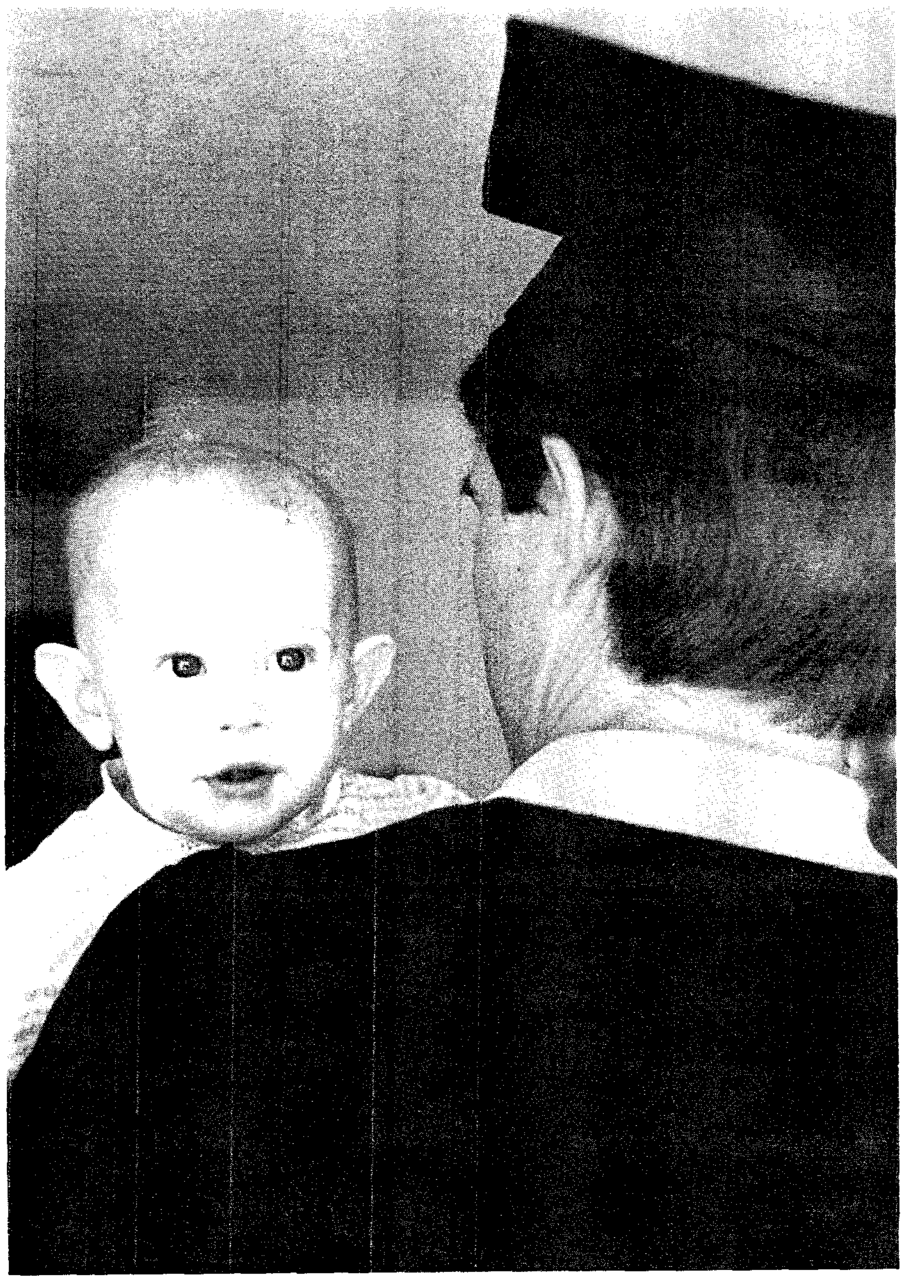
Another small grant recipient, Professor Alfonso Franciosi, has investigated the oxidation of ultra thin metal overlayers on silicon. This research has produced techniques for better control of the kinetics of surface reactions during semiconductor processing. The MEIS small grant was used to obtain an early start of the program by hiring a graduate student and providing the supplies necessary during the design stage of the experimental system. This MEIS funded start up helped Franciosi obtain $360,000 from a federal agency in support of the program. The new multi-purpose experimental system for surface analysis has yielded seven publications in international journals, nine presentations at international conferences, and a patent application for an oxidation process for silicon and GaAs surfaces.



Graduate student Al Raisanen (left) and MEIS fellow Art Wall study the surface properties of semiconductors using a vacuum chamber in Professor Franciosi's laboratory.

Emerging Research Teams

MEIS individual projects have developed individual expertise while MEIS team programs have stimulated collaboration among groups of researchers with different specialties and areas of expertise. By supporting individual as well as collaborative research, MEIS brings together researchers with related interests and coordinates and directs the formation of new groups. One emerging research team is now initiating a program in magnetic properties of epitaxial layers on AlGaAs. Another new group is investigating the use of the Zycad logic evaluator and supercomputers for very large scale integration (VLSI) design. These teams have formed around a clearly defined need or problem relevant to high-tech industry.



A recent graduate, father, and assistant professor, Dr. Ron Schrimpf is now with the University of Arizona.

MEIS is helping University researchers work with Minnesota companies to maintain and expand their technical capabilities.

An important element of MEIS' mission is to encourage collaboration among professors typically separated by the boundaries of departments and among scientists who are otherwise separated by physical or organizational barriers. MEIS has helped to bridge these gaps by funding team research programs aimed at industry-relevant discovery; by establishing a network of students, faculty and industry scientists with expertise in microelectronic and information sciences; and by opening and maintaining avenues of communication to keep the MEIS technical community growing. These accomplishments have strengthened research activities and graduate programs in several key departments in the Institute of Technology. This enhanced strength has contributed to the development of these departments and to the ability of Institute of Technology programs to be responsive to the greater community involved in microelectronics and information sciences in Minnesota.

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