

MEASUREMENT SCIENCE AND MANUFACTURING SCIENCE RESEARCH

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ABSTRACT

The SRC* was established to enhance the competitiveness of the U.S. semiconductor industry through the support of university research and education. Emphasis is being placed on (1) creating and maintaining a generic research base in integrated circuit technologies in the U.S. university community; (2) insuring a continuing supply of highly qualified students (and the faculty required to educate them) to support the growth and innovation of the industry; and (3) broadening the U.S. university base of microelectronic research and education through establishment of centers of excellence, seeding new efforts, and developing new curricula.

The research program of the SRC is managed as three overlapping areas: Manufacturing Sciences, Design Sciences and Microstructure Sciences. A total of 40 universities are participating in the performance of over 200 research tasks.

During the past year, the goals and directions of Manufacturing Sciences research became more clearly focused through the efforts of the Manufacturing Sciences Committee of the SRC Technical Advisory Board (TAB).

The mission of the SRC Manufacturing Research is the quantification, control, and understanding of semiconductor manufacturing processes necessary to achieve a predictable and profitable product output in the competitive environment of the next decade.

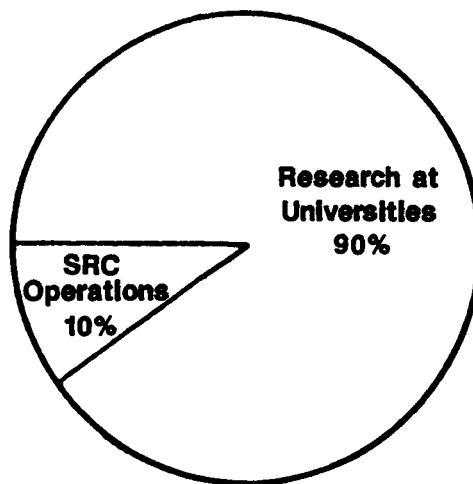
The 1994 integrated circuit factory must demonstrate a three-level hierarchy of control: (1) operation control, (2) process control, and (3) process design. Operational control covers process flow execution and inventory control. Unit processes and their control must assure that the equipment yield the anticipated results at the expected particulate contamination level. Particle transport to a wafer surface and capture by that surface depend on many variables such as aerosol velocity and particle size. While gravity is a minor mechanism for submicron aerosol capture by a wafer, it can be the dominant mechanism for capture of larger aerosol particles. Diffusion, interception, and inertial impaction are the classical mechanisms by which filters capture submicron particles; they apply to wafers as well. All the aerosol properties that influence these mechanisms will affect particle deposition on a wafer. In addition, the wafer surface itself may be a significant variable primarily through electrical capture forces. Electrical charges on a surface create electrical capture forces that can make up an important mechanism for the deposition of submicron aerosol particles on that surface. Electrostatic forces will receive special emphasis in upcoming studies of particle transport at the Research Triangle Institute. The use of patterned, electrical biased silicon substrates to deliberately create local areas of potentially enhanced electrical capture is proposed as part of the test matrix. The dependence of particle deposition upon electrical forces will thus be studied with higher spatial resolution than heretofore possible. Appropriate test structures include both metallized patterns on oxides and oxidized silicon surfaces.

*Semiconductor Research Corporation (SRC).

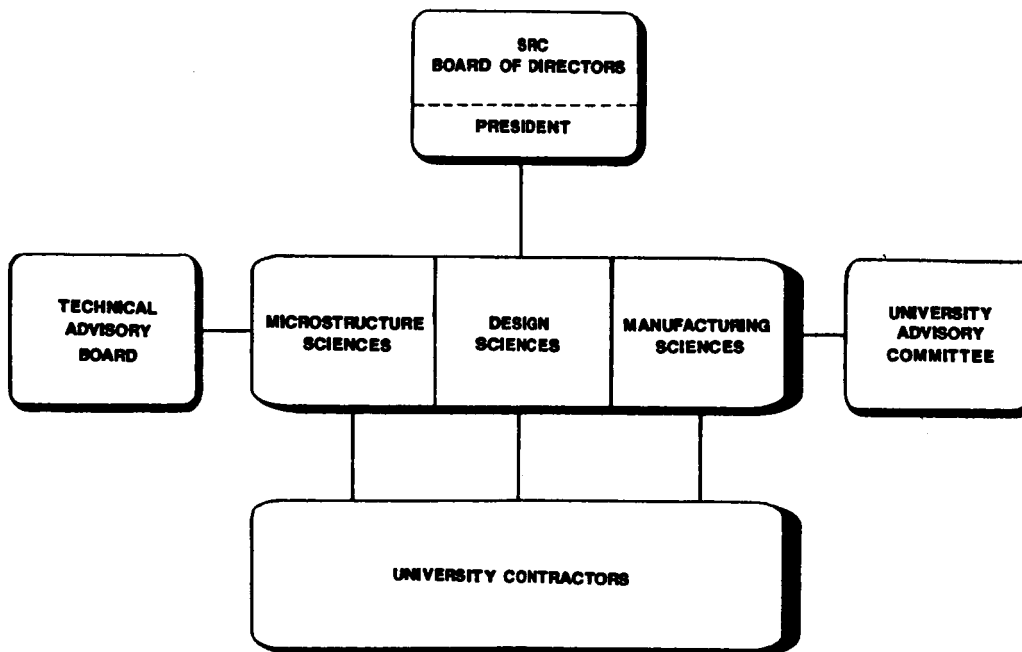
Subsurface imaging methods are important for evaluation of device geometries which are inherently three-dimensional. Accurate depth profiling methods are necessary for failure analysis and process evaluation. SRC research at the University of North Carolina at Chapel Hill has shown that the electron-beam-induced current (EBIC), BSE, and Time-Resolved Capacitive Coupling Voltage Contrast (TRCCVC) imaging modes provide information about buried structures and layer thickness. At submicron dimensions, mechanical probing of devices is nearly impossible and usually destructive when applied to integrated circuit fabrication technology. The electron beam of the scanning electron microscope (SEM) is an alternative to mechanical probes and is a standard tool in the microelectronics industry. Unfortunately, many of the SEM imaging modes can potentially induce damage in radiation-sensitive devices. Low energy (< 1 keV), nondestructive SEM imaging techniques that avoid radiation damage are being developed and modeled in this SRC project. Capacitive coupling voltage contrast (CCVC) is a low-energy method that provides both voltage and depth information of structures buried under passivation. CCVC utilizes the dynamic response of low energy electrons near the surface to changes in voltage or differences in structure depth. Voltage resolutions of 40 mV have been recorded using this technique, with a spatial resolution of less than one micrometer. Depth profiling has been performed on both biased and floating devices. Analysis can be performed during manufacturing, since no bias is required and no mechanical probing is needed. The inclusion of adaptive control will be a result of fully functional computer-integrated manufacturing (CIM) and computer-aided fabrication (CAF). Process design covers the monitoring and feedback functions to assure that the process parameter targets are met and that process-induced defects are kept in control. The SRC/University of Michigan Program in Automated Semiconductor Manufacturing is using reactive ion etching (RIE) as a process vehicle for examining key issues associated with automated sensing, control, and facilities integration. A dual-chamber SEMI-1000 RIE is now installed and is being interfaced with a 10Mbs MAP network in Michigan's new Solid-State Fabrication Facility. This network will be used in a prototype test bed for process automation, offering a guaranteed response time, message prioritization, and a hierarchical facility architecture. Software drivers for this network have now been developed as well as a network interface for the SECS protocol. Companion work in advanced RIE process modeling now allows the calculation of two-dimensional microstructure etch topographies for a variety of etching parameters. These models will facilitate the automatic fine-tuning of etch characteristics and process interpretation via an RIE expert system, also under development. Work on monolithic integrated sensors for pressure, gas flow, and gas analysis will provide additional data for equipment control.

The challenge is to continue to refine the process by which the industry, government, universities, and the SRC staff carry out semiconductor research to increase the effectiveness of this team effort and to provide a more productive response to the need for a continuing flow of new knowledge, creativity, and innovation.

The Members Dollar



SRC STRUCTURE



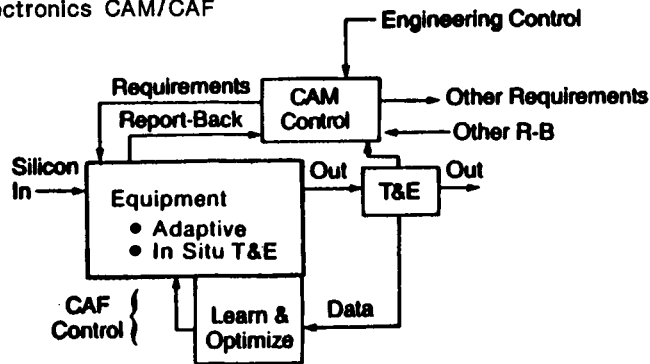
**An Industry View of the Future
Direction of Manufacturing Science
(through 1995)
Generated by the TAB Manufacturing Sciences Committee**

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**Future Directions of the
Manufacturing Sciences Program**

1. Microelectronics CAM/CAF



2. Process Inspection and control

- Measurement/analysis automation
- Machine vision

3. Microelectronics Manufacturing Engineering

- University - SRC Program

MAJOR TRENDS — SEMICONDUCTORS

- Submicron, MLM, CMOS drives manufacturing
- 8 Inch Wafers — Now through 1990
- 10 Inch Wafers — 1990 through 1995

**THE FUTURE = AUTOMATED
MANUFACTURING**

Sources: Genus and SRC

EQUIPMENT IMPLICATIONS

Commodity

- Lowest yielded die cost
- Optimized, dedicated equipment
- High capacity, high utilization
- High operating reliability
- Machine automation, CAM
- Factory automation
- 8 and 10 inch wafers

ASIC

- Shortest manufacturing cycle
- Flexible, dedicated equipment
- Lower capacity, high availability
- High operating and standby rel.
- Machine automation, CAM
- Factory data base automation
- 6 and 8 inch wafers



**AUTOMATED, ADAPTIVE
MANUFACTURING**

Sources: Genus and SRC

SEMICONDUCTOR EQUIPMENT BUSINESS

- 580 companies worldwide (1985)
 - 72% USA
 - 19% Japan
 - 9% Europe
- Top 50 supply 72% of total sales
- Most are 1 product companies
- Average sales = \$10.9 M/yr/company
- Highly fragmented industry

Source: VLSI Research Inc., and Genus

Semiconductor Capital Investment Plans
(Unit = \$1 Million)

Company	Initial Investment	Percentage Change from Previous Year	Fiscal 1985		Percentage Change from Previous Year	Planned Investment	Percentage Change from Previous Year
			Actual Investment (Estimated)	Revision from Plan			
Hitachi	450	0	300	-33.3	-33.7	N/A	Down
Toshiba	600	- 18.9	500	-16.7	-32.4	N/A	Down
Mitsubishi Electric	350	- 0.1	290	-17.1	-17.3	225	-22.4
NEC	700	0	600	-14.3	-14.3	N/A	Down
Fujitsu	500	- 23.7	250	-50.0	-61.8	N/A	Down
Oki Electric	160	- 12.1	125	-21.9	-31.3	N/A	Down
Fuji Electric	65	- 11.0	60	- 7.7	-17.8	35	-41.7
Matsushita	450	- 20.0	300	-33.3	-45.0	200	-33.3
Sony	200	127.9	175	-12.5	86.9	175	0
Sanyo	60	—	61	1.7	—	26.5	-56.6
Tokyo Sanyo	230	46.0	235	2.2	49.2	150	-36.2
Sharp	200	14.3	180	-10.0	2.9	N/A	Level
Total	3,965	- 3.2	3,076	-22.4	-24.9	—	Down

Source: Nihon Kogyo Shimbunsha

WORLDWIDE SALES FORECAST

(\$ Millions)

	<u>1979</u>	<u>1984</u>	<u>1989</u>	<u>CAGR</u>
Semiconductor ICs ¹	10,500	16,500	37,100	13.5%
Semiconductor Equipment ²	1,417	6,306	8,082	18.9%
Wafer Processing Equipment ²	714	3,080	3,798	18.2%
Deposition Equipment ²	214	662	980	16.4%
CVD Equipment ²	49	218	326	20.9%

Sources: ¹Montgomery Securities, Jan. 1986 (for years 1980, '85, '90)

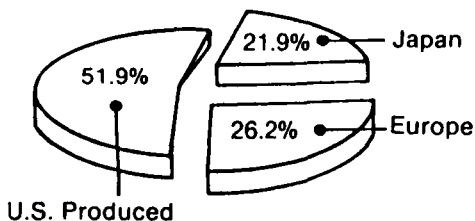
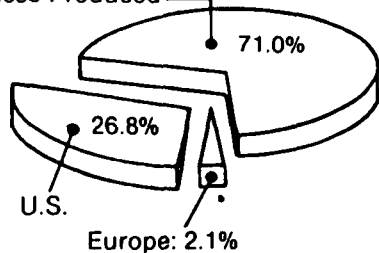
²VLSI Research, Inc., and Ganus

1985 SEMICONDUCTOR EQUIPMENT SALES

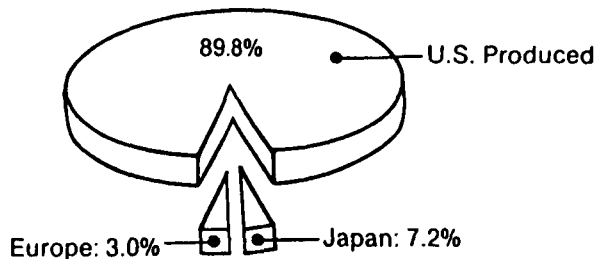
Japanese Consumption: \$3.1B

European Consumption: \$0.6B

Japanese Produced



U.S. Consumption: \$3.6B



Source: VLSI Research, Inc.

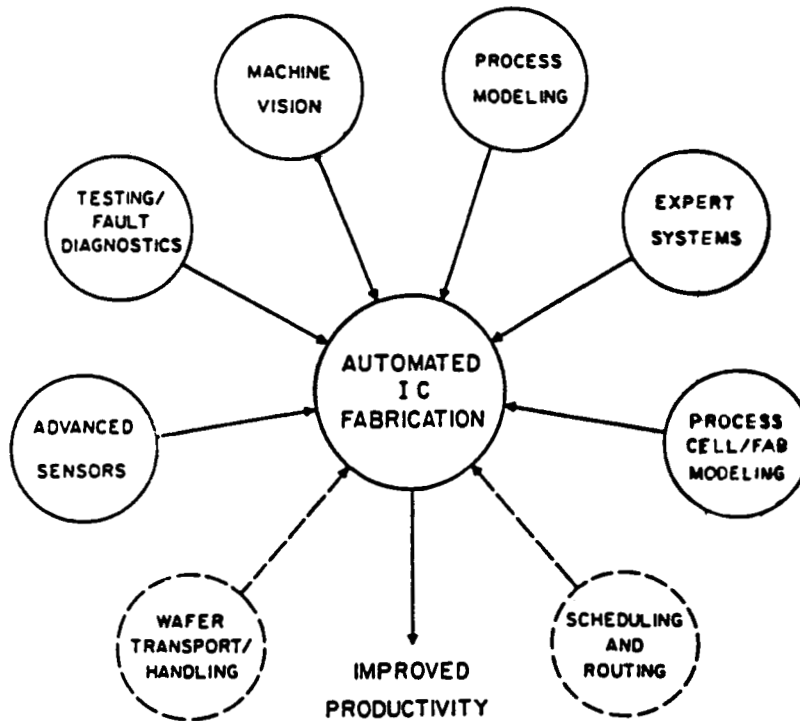
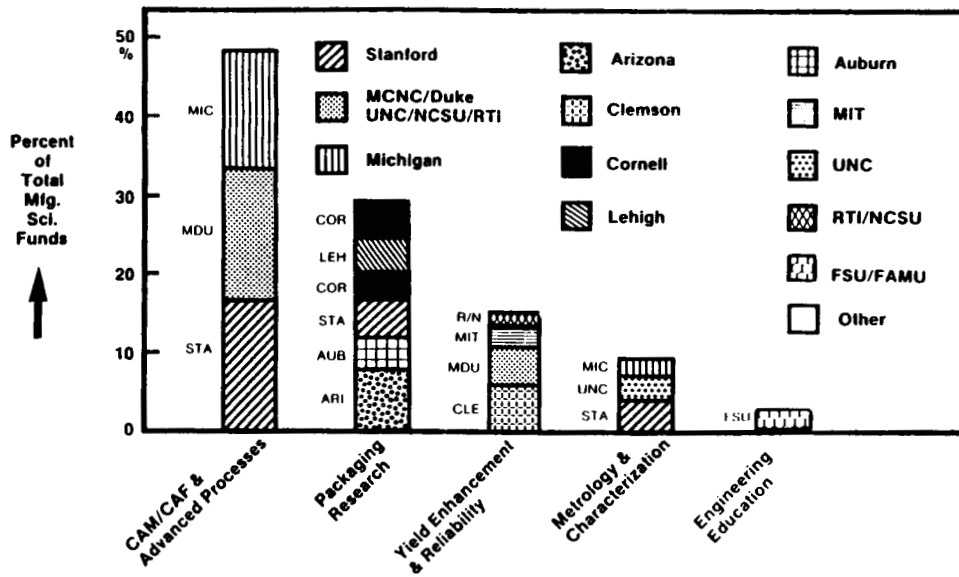
MAJOR TRENDS — SEMICONDUCTOR EQUIPMENT

- Device requirements drive equipment
- New technologies, materials
 - obsolescence of old
- In situ integration of manufacturing steps
- CAF and CAM = Automated adaptive manufacturing
- Business shakeouts, consolidations
- IC manufacturer, more involved in equipment technology developments
- Joint customer/supplier ownership of performance in operating environment

PROGRAMS

- University of California, Santa Barbara - GaAs HEMT
- Stanford University - Manufacturing
- University of Arizona - Packaging
- University of Florida - Submicron bipolar
- MCNC - Manufacturing
- Clemson University - Reliability
- RPI - *In situ* processing
- University of Illinois, Urbana-Champaign
Reliable architectures
- MIT - Advanced processing
- University of Michigan - Manufacturing automation

**Manufacturing Sciences
Principal Thrusts
\$5.13 M**



**THE SRC/UNIVERSITY OF MICHIGAN
PROGRAM IN AUTOMATED SEMICONDUCTOR MANUFACTURING**

Manufacturing Sciences Significant Accomplishments

1. Stanford
 - Microcapillary Cooling Technique
 - Thermal Resistance of $0.04^{\circ}\text{C}/\text{Watt}/\text{cm}^2$
2. MCNC
 - Shallow Junctions Demonstrated; 0.15 Micron
 - Germanium Pre-amorphitization,
Followed by Boron Implant Results in
4x Hole Mobility
3. Michigan
 - Developed 32 Element Thermal Imager
 - Temp. Resolution Less Than 0.1°C
 - Broad Spectral Range, 0.3 to 30 Microns
 - Broad Dynamic Range
 - For In-Situ Non-Contact Monitoring
4. Arizona
 - Interactive Electrical-Thermal Simulation
System
 - 2-D Capacitance Calculator
 - 2-D Inductance Calculator
5. Auburn
 - Demonstrated Hybrid Approach to Wafer
Scale Integration
6. Publications
 - 38 approvals into Technical Journals