The University of Arizona (lead institution), Massachusetts Institute of Technology, Stanford University, and the University of California at Berkeley have jointly established the NSF/SRC Engineering Research Center (ERC) for Environmentally Benign Semiconductor Manufacturing in an effort to create the science, technology, and educational methods that will lead the semiconductor industry to a new era of environmentally benign manufacturing. The goals of the ERC are to (1) develop novel strategic solutions to existing environmental safety and health (ESH) problems, (2) create new and effective ESH-benign processes, (3) demonstrate the positive impact of design for environment on all aspects of semiconductor manufacturing, and (4) develop innovative education programs for which environmental factors are integral parts of the curriculum. Our specific objectives for achieving these goals are as follows:

• Develop a methodology for incorporating ESH factors as design parameters in the development of new processes, tools, and protocols for semiconductor manufacturing. The emphasis is on an “integrated approach,” where interactions among processes are considered, and on “process optimization” for waste minimization, rather than abatement and “end-of-the-pipe” treatments.

• Demonstrate this methodology by applying it to selected process groups that are of significant ESH concern.

• Integrate the Center activities with academic programs to provide unique learning opportunities for undergraduate and graduate students, and extend the education mission to include continuing education and short courses for those in industry who wish to update their training in this area.

• Provide a technical forum for experts from industry, research institutions, and government agencies to exchange ideas and information on ESH concerns in semiconductor manufacturing. These exchanges will be on a proactive, preventative, nonregulatory, and precompetitive basis.

Research

The semiconductor industry is a very fast-moving industry. This characteristic creates many opportunities for innovation and implementation of changes. The fast pace also presents a major challenge in planning and conducting long-term research. The challenge is to strike the right balance between long-term development, short-term relevance, and application to the present problems. The Center’s research strategy will be to maintain this balance and promote a mix of projects and activities ranging from high-risk, high-payoff research to smaller projects with more immediate applications. In all cases, the emphasis will be on fundamentals, innovative approaches, and scholarly value of the work.

An important barrier in the present ongoing research and development is a lack of integration. Environmental factors are not usually included in the design and development of new tools and processes. Integrating environmental technology into the design of processes and tools is the technical driver and the common theme of the Center’s research. The word “technology” is intended to include hardware, software, systems, and services. The focus of the present research program is on the following areas:

• Plasma processes

• Non-plasma etch, clean, and rinse processes (wet and dry processes)
• Integrated CMP and clean processes
• Water purification, distribution, and use (recycle and reclaim)
• Metrology and sensors for environmental applications
• Minimizing organic wastes, solvents, volatile organics, and hazardous air pollutants

Industrial Collaboration/Technology Transfer
The relationship between industry and universities, particularly in engineering research, is undergoing unprecedented change. Some of the factors causing this change are as follows:
• With the increased competition for shrinking research funds, there has been a much greater demand on the university community to show the relevance of their research to the needs of industry.
• Industrial endorsement and partnerships have become an important measure of the significance of a research program and its priority.
• With downsizing, industry is looking for ways to acquire technology from sources other than their own in-house research. The university is becoming an attractive resource.
• Universities are beginning to look at industry as the customer for their product (both students and technology) and to develop a supplier/customer relationship.

In our view, this is a welcome change and should be a guiding force in the future of engineering education. We are looking at the relationship with industry with the desire for partnership and not just sponsorship. At the same time, we recognize that the primary mission of the Center is to engage in fundamental studies and to maintain intellectual sophistication in our research endeavors.

Technology Transfer Strategies
The most effective method of transferring technology and expertise is to transfer experts. The Center will facilitate these transfers through placement of graduates and internships, educational leaves for the university faculty in industry, assignments for technical staff from industry at the Center, and joint research and teaching projects. We will also maintain an effective method for the timely transfer of intellectual property, licensing of patents, and joint work toward commercialization of the technology developed at the Center. Commercialization of patents and ideas is inherently a market-driven transaction that follows the law of supply and demand; thus, it is comparable to marketing any other product.

Education
Currently, no formal program exists at any major engineering department that focuses substantially on environmental concerns unique to the microelectronics industry. Our education program will involve the following key components:
• developing a new lecture course
• instituting a guest lecture program
• developing a textbook
• developing computer-aided learning materials
• identifying undergraduate and graduate research projects
• recruiting and outreach for minorities
• supporting life-long learning for practicing engineers.

Facilities
Each of the four universities involved in the Center provides laboratories, equipment, and other facilities that are used for Center activities.

University of Arizona—In addition to faculty, staff, and student offices, a library, and a conference room, the University of Arizona maintains the following Center facilities:
• an ultrapure water pilot (UPW) research laboratory with a pilot unit, various sensors and analyzers for trace analysis in water, and an FTIR/ATR unit
• a complete UPW testbed for study of water recycle and reuse
• a wet bench for rinse and chemical use experiments
• a nanofabrication facility that allows electron beam writing
• a class 1000 cleanroom with equipment for photolithography (including a holographic setup)
• an ion exchange waveguide fabrication facility
• an integrated optics characterization laboratory with equipment for fiber alignment, power and spectral measurements, and computer-controlled data acquisition
• specialized equipment for analysis of dispersed particles, including a Pen Kem Lazer Zee Meter for zeta potential measurements using microelectrophoresis and an NICOMP 370 dynamic light-scattering apparatus for measuring the size distribution of particles in suspension

Massachusetts Institute of Technology—Microsystems Technology Laboratories at MIT is home to the Center’s two principal plasma tools: an Applied Materials Precision 5000 etch tool and a Novellus Concept One PECVD tool. The Center for Materials Science and Engineering, also located at MIT, is a shared analytical facility with an extensive inventory of materials-analysis equipment. MIT also has a parallel plate rf plasma reactor for pulsed PECVD, an ECR Reactor for pulsed PECVD, and two solid-state NMR spectrometers for thin-film characterization. In addition, the Strasbaugh 6EC CMP tool has been installed in the Microsystems Technology Laboratories and is operational at this time.

Stanford University—Stanford's Center for Integrated Systems has a variety of plasma processing equipment, including a three-chamber, Applied Materials 5000 etcher; Lam TCP polysilicon, STS ICP, and PlasmaQuest ECR etchers; and an STS plasma deposition system. Stanford also has allocated 1,800 square feet of laboratory space in the new Paul Allen Extension to the Center for an ultraclean processing and characterization facility, and additional space has been reserved for future projects.

University of California at Berkeley—UC Berkeley has an inventory of experimental equipment that will be used in support of Center research projects, including two experimental CP systems for the study of PFC plasma chemistry; an experimental vacuum-beam system designed for the study of plasma-surface interactions; and a high-density plasma oxide etch system with high gas flow rates, 6-inch wafer-handling capability, and related equipment.

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NSF 96-23x