***Environmentally Benign Semiconductor Manufacturing, a Joint Semiconductor Research Corporation (SRC)/NSF ERC – Class of 1996***

In 1994, The Semiconductor Research Corporation (SRC) approached NSF with the proposition that the NSF and the SRC jointly develop a program solicitation for an ERC that would be focused on topics of interest to the SRC members, jointly funded, and jointly reviewed pre-award and post-award. This partnership represented an opportunity for the ERC Program to collaborate with an industrial organization representing the semiconductor industry. It would build on the strengths of the ERC construct and the strengths of the Program in soliciting proposals for new centers, managing a competitive pre-award review process, creating funding instruments that would ensure delivery on the goals of a center, and providing effective post-award oversight to strengthen a center and weed out failed centers. These would be joined with the strengths of the SRC in direct industry/university cooperation in research and technology development.

The process began with the development in 1994 of a Memorandum of Understanding (MOU) and its approval in March 1995. The MOU spelled out the basic principles of the partnership and the characteristics of an NSF/SRC ERC. Getting to that signature stage took some time and involved the development of a new understanding by the SRC staff and its industry members of how NSF functioned as well as a new awareness on the part of NSF of the SRC’s expectations regarding intellectual property and the strengths of the SRC’s industry-focused project-level oversight system.

The initial point of contention between NSF and the SRC was SRC’s assumption that support of an ERC at a particular university would grant background intellectual property (BIP) rights to all semiconductor research previously funded at that university. NSF was wary of participating in the partnership because the SRC BIP policy applied through the ERC would have a strong ripple effect throughout the university community. However, the SRC was concerned that previously developed IP, or BIP, could block the use of research results from a given research program at the ERC. Preston brought the issue to NSF Deputy Director Joseph Bordogna’s attention; he took over from there because the BIP issue was being raised by the SRC more broadly, as it provided research funding at major research universities across the country. A meeting was held with the leaders of these universities, Bordogna, and leaders of the SRC and a compromise was reached for fair treatment of BIP that balanced the needs and interests of universities and industry. This was achieved by using NSF’s standard policy regarding intellectual property rights, whereby IP developed under the shared base research programs of any funded project or center would be consistent with the Bayh-Dole Act. Under these terms, firms that were members of the ERC at the time a patent disclosure was received by the NSF and the SRC would be granted worldwide, non-exclusive, royalty-free licenses to all inventions or other IP developed under the shared base research programs of the center. The universities involved in the ERC would remain free to license patents commercially to non-sponsoring companies. Following this resolution, Preston proceeded with the MOU.

While the MOU was in negotiation, a program announcement was being drafted jointly by NSF and SRC staffs. The announcement scoped out the partnership in terms of review, funding, and oversight and stipulated four areas for proposals: lithography (patterning); interconnections; environmental safety and health considerations in the fabrication of semiconductors; and other technologies pointing to future generations of the (SRC) Roadmap. The announcement was released in 1995 (NSF 95-77).[[1]](#footnote-1) The NSF team preparing the MOU and program announcement included Lynn Preston, Larry Goldberg (an ERC PD from the Division of Electrical and Communication Systems, with experience funding project-level efforts with the SRC), and Sharon Graham, Division of Grants and Agreements. The final MOU and program announcement were approved at the Assistant Director for Engineering level by Louis Martin Vega and at the NSF level by Deputy Director Bordogna. On the SRC side, the team included William Holton, Vice President for Research Operations, and Larry Sumney, CEO.

Twelve proposals were submitted in July 1995, after the submission of 28 letters of intent. The review process followed the standard ERC review system, except that in each stage half of the reviewers selected were suggested by the SRC staff and the other half by NSF. Proposals were reviewed initially through a mail review by the 12 members of the Technical Panel. This panel met at the SRC headquarters in Research Triangle Park, North Carolina. The process was managed by Preston and Holton and administered by Darlene Suggs, the ERC Program Assistant, who was assisted by SRC staff. As an outcome of the review, three proposals were recommended for site visit. At this stage a six-member “Blue Ribbon Panel” was formed, based on reviewer suggestions from NSF and SRC staff, which would be responsible for final review and selection.

The site visits took place from late September through mid-October, each with a dedicated review team and two members of the Blue Ribbon Panel serving as observers. The site visit reviews were managed by NSF and SRC staff and Preston and Holton attended each one, using the standard ERC Program site visit agenda and format. The Blue Ribbon Panel met on October 18-20, 1995, at NSF. The evening before the review, the panel was briefed on the goals of the partnership and the review process. Each member had received the prior reviews and site visit report for each finalist. On the first day of the panel meeting, using the standard ERC format, the panel was briefed by three members of each proposing team. After these briefings and discussions of each proposal, the panel carried out a secret ballot to determine a ranking of the proposals. They were asked to consider this ranking of the proposals the night of the first day of the panel. On the morning of the second day, they discussed any further issues, cast a secret ballot, and the outcome was the same. The winning proposal was the ERC for Environmentally Benign Semiconductor Manufacturing (EBSM), submitted by Professor Farhang Shadman and his team from the University of Arizona, the University of California at Berkeley, the Massachusetts Institute of Technology, and Stanford University.

At this stage, Holton returned to the SRC to discuss the outcome with the SRC leadership and its Board of Directors from industry. As Holton later told Preston, there was some consternation since some of the member firms had assumed that the winner would be focused on either lithography or interconnects. An influential member of the SRC Board of Directors, Yoshio Nishi, who was a Senior Vice President and Director of Silicon Technology Development at Texas Instruments, made an impassioned plea for support of the winning ERC focused on environmentally benign semiconductor manufacturing because he believed the industry could not continue to manufacture with processes that consumed large amounts of water and resulted in high levels of pollution. His argument held and the SRC Board voted to join NSF in support of the ERC at the University of Arizona.

That was the first hurdle overcome in the partnership. The second reflected the difference in management styles between the NSF and the SRC. The SRC at that time was accustomed to funding research projects in universities with very tight controls over the research, almost in a contract mode. One of the reasons that Sumney wanted to join with NSF was to understand better how to fund fundamental research and provide oversight in a more flexible mode. However, the SRC administrative staffer sent to work with Preston to develop the cooperative agreement did not understand the implications of that new type of oversight for the SRC and insisted on a traditional SRC system of tight controls. Preston called Holton and explained the dilemma. As a result, a more flexible staff person was sent to NSF to work with Preston and the staff of the Division of Grants and Agreements, and a new joint cooperative agreement was developed. The award was recommended through the NSF process, approved by the Director, and the agreement was signed by NSF, the SRC, and the University of Arizona.

The new ERC began operation in 1996 with $1.0M from NSF and an additional $1.0M provided directly to the University of Arizona by the SRC. Post-award oversight was carried out by a cross-sector team: John Hurt, an NSF ERC PD with a materials background; and Dan J. C. Herr, who was responsible for the SRC’s Section on Environment, Safety, and Health Sciences. This team carried out joint post-award oversight in the ERC mode, with reviewers coming from NSF and SRC sources. In addition, the SRC carried out its project-level technical oversight in its traditional mode.

**Energy and Water Savings Result from the Use of Ultrapure Water**

Millions of gallons of ultrapure water are used in modem semiconductor manufacturing plants during various stages of device fabrication. Ultra-purification of water requires using a lot of energy and a wide variety of chemicals. Consequently, the production of this amount of water and the disposal of an equally large volume of wastewater—which may contain hazardous contaminants—create a range of environmental, economic, and sustainability challenges.

The EBSM Center has developed technologies for both the *reduction* of water usage and the safe *treatment* of the resulting wastewater. These technologies resulted from coordinated collaboration among investigators from the ERC’s partner universities. For example, a novel sensor (the Electro-Chemical Residue Sensor) and its associated metrology software were developed for real-time and on-line measurement of residual contaminants in the nano-features of the patterned wafers. This breakthrough has a significant impact on the surface cleaning process, which is one of the largest uses of ultra-pure water. This technology, together with a process simulator and control, has reduced the water usage in some cleaning tools by over 70%.

Another group of integrated projects at the EBSM ERC resulted in the development of technologies for recovery and reuse of the water in semiconductor manufacturing plants. The technology uses a combination of on-line monitoring and process simulation for control of the recycle loop to avoid the contamination accumulation and surge issues that had previously been major obstacles in water recovery and reuse.

The vision of the NSF/SRC EBSM was: “To create and develop the science, technology, and educational methods that will lead to future semiconductor manufacturing facilities with minimal consumables (e.g., water, energy, acids, solvents, gases) and minimum emission of environmentally harmful, unsafe, and unhealthy waste materials.” This ERC established itself as the world leader in addressing issues of environment, safety, and health (ESH) relating to semiconductor manufacturing. The ERC and the SRC recognized that in the 21st century, material resources and energy will become scarce and environmental controls will become stricter; in response, semiconductor manufacture must utilize more benign “green” techniques to remain operational. For example, one of the most significant contributions of the EBSM during its time as an NSF ERC was in the area of ultrapure water (see sidebar).

Since industry tends to focus upon short-range solutions to pressing problems and leaves long-term issues to academia, this ERC was and is looked upon by industry as providing many long-range ESH solutions. That fact is evidenced by an average of 15 firms supporting the EBSM annually throughout its life under joint support from NSF and the SRC, through 2005. At the time of writing, the SRC and 21 individual firms support the ERC.

1. National Science Foundation and Semiconductor Research Corporation (1995). *Partnership in Engineering Research Centers* (NSF 95-77).p.1. [↑](#footnote-ref-1)