# A New Semiconductor Research Paradigm using Internet Collaboration

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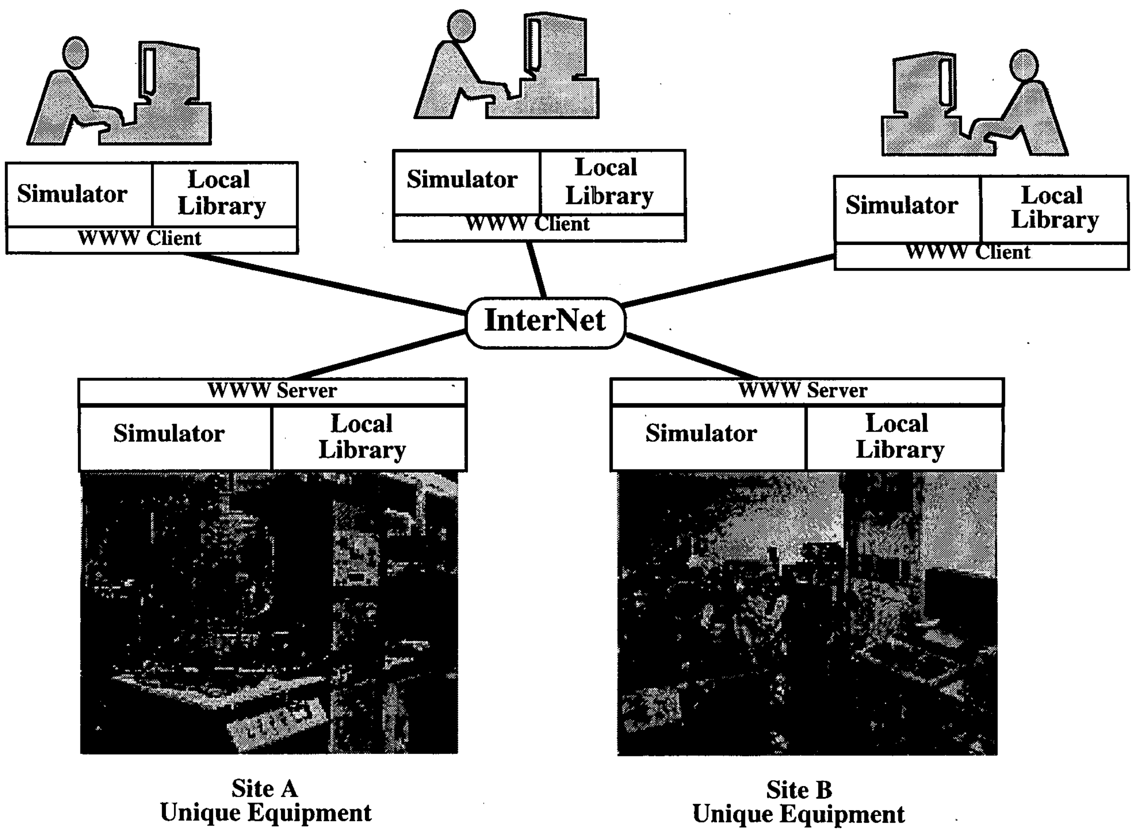
## Abstract

Continued progress in semiconductor process and device research will require new modes of collaboration and interaction. Internet technology will play a large role in creating and supporting a new distributed community of researchers. Stanford and MIT are working together to explore several elements of emerging networking technology in the context of semiconductor research. These elements include a help system, fabrication facilities database, a Collaboratory, networked process repository, remote simulation, remote process execution, remote microscope, and electronic technical publication and repositories.




## Introduction

As we look ahead to the next century, it is easy to imagine continued rapid growth of markets for semiconductor and other microfabricated technologies. There is an expected continuation of silicon-based technology evolution to the sub-tenth micron regime in the next 20 years. At the same time, new applications of the technology in fields like microelectromechanical systems promise the creation of entirely new markets for products based on closely related technology. The future looks very promising.

But, who will do the research needed to assure a continued stream of new technology? Restructuring of the industry needed to address a changing world economy over the past decade has resulted in loss of many of the industrial laboratories which produced the technological innovations of the past. Those laboratories which remain are refocused on near term problems. With lead times of 8 to 10 years for introduction of new technology, it is clear that the research resources that remain must become more effective if the pace of technological advance is to be maintained.

Stanford and MIT have launched a joint program to build a more effective research community using modern electronic networking. This program is now in its second year and early results look very promising. The program is building an infrastructure based on Internet technology for collaboration over distance; a "Laboratory without Walls." The overall goal is to create powerful new ways for geographically distributed researchers to work more effectively together to advance the field of semiconductor technology.

## Tools for Collaborative Research

In the large multidisciplinary research laboratories of the past, it was relatively easy for a researcher to get an answer to a question. It was usually only necessary to walk down the hall to take advantage of the knowledge and insight that a co-worker might have in another discipline. The culture encouraged interactions between disciplines in the belief that the opportunity for new insights are optimized at the intersection of disciplines. The translation of this culture to the Internet begins with the motivation to connect people.

**Help Exchange:** The problem of obtaining help over the Internet is a perplexing challenge, especially as the Internet grows. Most existing systems do not scale well as the number of users increase. The Help Exchange [1] has been developed to facilitate person-to-person connections, especially across disciplines in a way that improves as the number of users increases. The system is based on a taxonomy of disciplines and arbitrates a dialog between users by matching questions to experts. A researcher in one field, modeling of plasma processes, for example, can pose a question to another researcher who is an expert in a particular class of plasma equipment. This "person-to-person" approach to providing information is quite different from and complements the enormous body of work that has been underway for at least two decades to locate static information over electronic networks. Valuable information often exists only in the minds of experienced individuals and even if the information is available in machine form, human reasoning is often very valuable in identifying and utilizing context in searching for information.

**Facilities Database:** Finding the right person or other information source to help solve a problem is only a start, however. It is often necessary to find the right equipment. An inventory of University Fabrication Facilities has been placed on the Internet to facilitate the sharing of equipment and/or other scarce resources. A data base is maintained at MIT with an on-line query capability to enable a researcher to locate experimental facilities. The researcher in computer modeling of plasma processes, for example, could locate sites having equipment that could be used to verify and calibrate the models.

**Collaboratory:** Once a project is underway, real-time communication is needed. In order to accomplish this over distance, the Collaboratory was created as an integrated system for using the wealth of collaboration tools which are now available. The major problem to be solved here is the large variety and complexity of existing tools. Experts in semiconductor technology should not have to also be experts in computer science to benefit from the use of these tools. Consequently, the goal of this task was to create a tool which is "easier to use than a telephone." While the hardware and software at each site may have important differences, this task has successfully hidden the differences from the users by automatically determining the common tools that are available on any two systems. Each user is provided with a "Rolodex" which contains the addresses of collaborators. Simply clicking on a name in the rolodex initiates a connection. If the other party is "in," the caller is presented with a list of collaboration tools which are in common between the two systems. These might include audio, video, shared whiteboard, shared x-window, or other such tools. The connection is completed when the person called acknowledges the connection. At that point the requested tools are launched and a dialog may begin.

**Process Repository:** The dialog between researchers might include a detailed discussion and assembly of a fabrication process. Based on over 10 years work on process representation, a Java-based process editor has been developed which allows researchers to share process libraries and to create new process sequences based on new modules or existing modules extracted from the library. This tool may be used by an individual working alone, or in close collaboration between researchers at separate sites. It is especially important to optimize process modules for individual pieces of equipment and this tool allows researchers to benefit from work that supports use of equipment for which he/she might otherwise not be experienced.

**Remote Simulation:** The use of simulation tools to supplement empirical research is an important overall goal of the program and remote access to simulators greatly facilitates technology transfer of new work in modeling. In addition, close calibration of simulators to equipment at any given site helps to evaluate possible use of a remote facility prior to commitment to actually purchase time on that equipment. The SPEEDIE plasma simulator is the first such system to be applied in this way. A cluster of computers is dedicated to supporting remote access to the SPEEDIE simulator. Using the World Wide Web, a remote researcher may submit simulations, monitor their progress and view the results with only a common browser.

**Remote Process Equipment:** An important next step is to provide remote access to equipment. Why must a researcher be physically in the laboratory to perform an experiment? As equipment becomes increasingly expensive, the need to share such remote resources increases. As fabrication tools become more automated, the reasons for physical presence at the machine begin to disappear. Based on these trends, we have developed an architecture [2] to support the upload/download/execution of recipes, and more importantly, to capture and communicate sensor information collected during an experiment, over the World Wide Web. A plasma etch system at MIT is being made accessible over the internet to Stanford and other researchers to reduce the need for travel to a remote site. While this work is still in an exploratory stage, it is clear that remote access is technically feasible for many classes of experiments.

**Remote microscope:** A key barrier to remote execution of process or device experiments is the difficulty in inspecting the intermediate steps or results of that experiment. A remote microscope is under development, consisting of hardware (to automate stage movement and optics) and software (to control the microscope, communicate over the internet, and present a graphical user interface) [3]. The internet microscope will support visual examination and inspection at critical stages in an experiment. An additional benefit is that several geographically distributed parties can simultaneously view and negotiate control of the microscope, enabling collaborative discussion and consultation by remote experts.

**Electronic TCAD Journal:** The final step in a typical research activity is technical publication of the results. The most traditional mechanism for communication of research results between researchers has been technical conferences and journals. Much of the activity on the Internet, and especially on the World Wide Web in the past couple of years has focused on new applications of on-line media. This project is no exception and includes in its objectives the goal of greatly enhancing the capability to share technical information in the form of publications, libraries and software. The initial effort has been the successful launch of a new journal, "The Transactions on Semiconductor Technology Modeling and Simulation." This new journal, published by the IEEE Electron Devices Society, seeks to demonstrate four objectives in a high quality technical publication: a) Provide more timely access to the most recent research results, b) Provide information in forms that are otherwise unavailable in conventional printed documents, c) Provide more effective ways to find relevant information, and d) Reduce the cost to both the information provider and the information consumer. A related project, called the "Editor's Helper," is a Web-based application which is designed to assist the editor of the new journal in managing the review process.

**Technical Repository:** The journal is launched as part of a larger effort called the Technical Repository. In a parallel second track, called the Experimental Repository, experimentation is underway in developing and evaluating new and powerful new approaches to on-line publication. Work in the Experimental Repository is addressing search tools, publications which are not traditional archival publications but still valuable to the community, proactive notification of new publications in a reader's area of interest, annotated indexes, preprints, new forms of publication and on-line reader annotation of published documents.

## Summary and Future Work

The project is now in the second year of a five year plan. The activities listed above have uniformly demonstrated feasibility and work over the last academic year has been focused on testing, collecting experience with testing by users and making the tools more robust. Most of the tools have been tested extensively at Stanford and MIT. Broader release to the research community of the Self Help system, the Collaboratory, the SPEEDIE plasma simulator and the Technical Repository are planned for the Summer of 1996. The Facilities Data Base has been available for three years. Interested researchers who would like to work with us before any system is released for general use are welcome to contact us directly. Beta testers are welcome.

Overall, applications on the Internet and especially on the World Wide Web are now rapidly multiplying. Every research community is faced with the challenge of learning how to effectively use this new and very powerful communication media. Unfortunately, the rapid introduction of new tools can be confusing at least and ultimately counterproductive if they are incompatible or otherwise difficult to use. This project has concentrated on taking a pragmatic view of this new technology, adopting tools which promise to be useful and developing tools where the need is justified. On-going reports on the project are freely available on the Web as well as pointers to the tools as they can be released. Constructive critique is welcomed.

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