Cornell Submicron Facility Dedicated

Finally out of temporary quarters, the National Research and Resource Facility for Submicron Structures also finds its 5-year grant up for renewal

On 16 October, Cornell University dedicated a $3.8-million laboratory that houses the National Research and Resource Facility for Submicron Structures. When the submicron facility was established 4 years ago, observers wondered if a university could compete with industrial laboratories in making significant advances in microstructure fabrication, an exceptionally high technology business in which expensive equipment can quickly become obsolete. They also wondered if many university scientists would forsake their customary habit of working in departmental laboratories and be willing to travel to a national center to do research. As the submicron facility enters the last year of a 5-year National Science Foundation (NSF) grant, the answer to the first question is a clear yes; the facility is living up to the research part of its name. Renewal for a second 5 years now seems likely, but the amount of the award will hinge on how effective Cornell has been as a resource for researchers nationally. The jury is still out.

Submicron objects are 1 micrometer or less in size. Facility director Edward Wolf, who came to Cornell from the Hughes Research Laboratories in Malibu, California, likes to say that his province encompasses dimensions ranging from the 2-micrometer width of metallic conductors in the most advanced commercial integrated circuits, such as computer memories or microprocessors, to the few angstroms of the diameter of an atom. The goal of the submicron facility is a fundamental understanding of how to make very tiny structures and of what happens in them once they are made. The mechanism by which electrons propagate down a metal wire only a few atoms wide is not the same as that in ordinary metals, for example.

Although microelectronics is the most obvious commercial application of the kind of knowledge generated at the submicron facility, it by no means dominates activity there. In fact, Cornell's electrical engineering school has only recently begun to recruit experts in integrated circuits made from silicon. Up to now, the school's expertise in semiconductors has been in gallium arsenide and other compounds, which are used for high-speed microwave and optical devices, but not yet for densely packed microcircuits. Other projects span the range from microchambers for studying cell growth and division to sensitive detectors for radio astronomy.

Cornell won the submicron facility in an intense 1977 competition among 18 universities. NSF awarded Cornell $5 million to be spent over 5 years with the understanding that the university would chip in some of its own funds for a building. Fund raising went so well that Cornell was able to corral the entire $3.8 million needed for the new laboratory. NSF also issued supplemental grants totaling $1.6 million over the last 3 years to enable the submicron facility to add staff and thereby better serve outside users.

An additional source of support has been industry. As has become common in academe, there is an industrial affiliates program, which with 23 members provides about $200,000 of discretionary money each year. IBM has given the submicron facility $500,000 to develop its user program, and other companies have donated equipment or provided it at less than the market price.

Research at the facility falls into one of two categories: that directed toward new microstructure fabrication techniques and that directed toward application of existing techniques. The problem of generating and replicating the ultraminiature patterns of integrated circuits or other microstructures falls in the first category. The usual photolithographic process is limited by the wavelength of light to making structures no smaller than about 1 micrometer. Now coming into limited use is electron beam lithography, in which a computer-controlled, scanning electron beam directly writes a pattern into an electron-sensitive polymer called a resist. The energy of electrons scattered back into the polymer from the underlying material is high enough to also expose the resist (proximity effect), so that the width of the exposed region is much larger than the diameter of the electron beam. The proximity effect ordinarily restricts feature sizes to about 0.1 micrometer and above.

Benjamin Siegel, a Cornell professor of applied and engineering physics, heads a group that is building an ion beam lithography system. Ions, being much heavier than electrons, do not bounce around so easily, and the proximity effect is much reduced. Feature sizes of 0.01 micrometer (100 angstroms) are said to be feasible with ion beams. In fact, Charles Lee, a Cornell electrical engineer, and his co-workers demonstrated 2 years ago that ion beam lithography with protons could make patterns with lines only 400 angstroms wide. At about the same time, Siegel and his co-workers devised an intense source of molecular hydrogen ions, thereby overcoming one of the main problems with the technique, the lack of an ion beam bright enough to write patterns in a reasonable time. The source is 10 times brighter than previous liquid metal field ion sources. If it could be made to work with heavier atoms, the source could also be used in systems to selectively etch surfaces or directly implant dopants (impurity atoms) in microcircuits, thereby simplifying the fabrication process greatly.

The work of Lester Eastman's group falls into the second category of applications. Eastman, who is on the electrical engineering faculty at Cornell, and his co-workers are constructing artificial materials by means of molecular beam epitaxy, a process that allows building up thin crystalline films one atomic layer at a time. With certain restrictions, the composition of each layer can be different, so that materials with quite unusual properties are possible. The main restriction is that, for epitaxial growth, the crystal structures of the layers must be nearly the same.

The group is using molecular beam epitaxy to advance the state of the art of gallium arsenide microwave devices. Each atomic layer of the epitaxial material is primarily gallium arsenide, but the concentrations of the dopants that determine the electrical properties of the semiconductor are abruptly changed at certain times. The internal electric fields caused by the changing dopant profile accelerate free electrons in the gallium arsenide to velocities 10 or more times higher than normal, thus giving rise to the possibility of very high speed devices such as oscillators and switches. Test structures have been made but not yet actual devices.

The submicron facility made this work feasible because it is equipped with a

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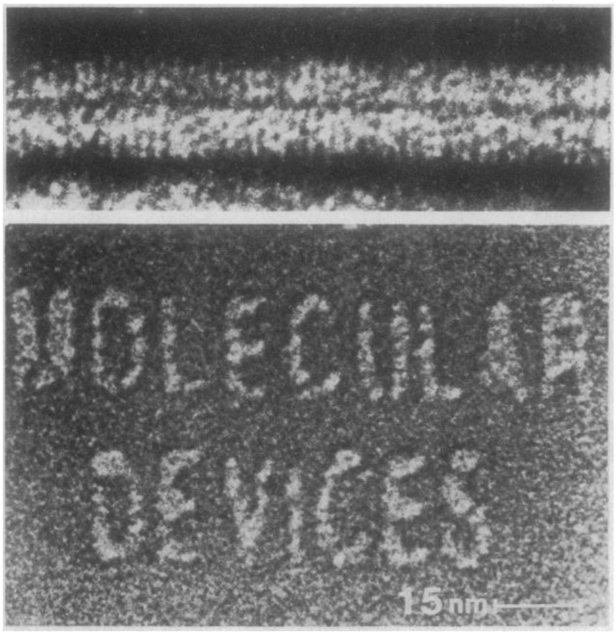

Nanometer lithography

Electron micrographs by Michael Isaacson and Andrew Murray of Cornell University of a tobacco-mosaic virus and of letters etched into a sodium chloride film by an electron beam 5 angstroms in diameter. The repeat distance of the helical virus molecule is about the same as the thickness of the letters (20 angstroms). The magnification is ×760,000.

half-million-dollar molecular beam epitaxy machine. Eastman's group has been one of the main users of this particular piece of equipment. The successful investigation of new ideas, made possible by access to the machine, has contributed to a fivefold growth in Cornell's gallium arsenide semiconductor research program, including large Department of Defense and industry contracts. The group is now affluent enough to purchase its own molecular beam machine.

Similarly, Siegel's group developed the ion beam source idea as part of research funded by the submicron facility, but the construction of the ion beam lithography system, which when completed will be part of the facility, is being underwritten by the Defense Advanced Research Projects Agency. Ronald Gutmann, who oversees the submicron facility for NSF, takes a favorable view of the expansion of the gallium arsenide and ion beam lithography programs. "NSF prefers to view itself as providing seed money that catalyzes the growth of independent programs," says Gutmann.

The submicron facility has also catalyzed the growth of Cornell's faculty. Thomas Everhart, former chairman of electrical engineering and computer science at the University of California at Berkeley, is now the dean of Cornell's college of engineering, partly because "I wanted to make the submicron facility succeed." Michael Isaacson, well known for his studies of high-resolution imaging with the scanning transmission electron microscope at the University of Chicago, has come to Cornell to try his hand at making structures on the 10-angstrom size scale. And James Mayer, a semiconductor materials specialist from the California Institute of Technology, has joined the Cornell faculty. Finally, the electrical engineering school is launching a very large scale integrated (VLSI) circuit initiative, which involves some hiring.

Among the new acquisitions, Isaacson is already well into his high-resolution electron beam lithography project. His idea is that, even if there were no proximity effect, the minimum size feature obtainable would be 50 angstroms or so because that is the effective size of the polymer molecules in resists. So part of the research includes looking into inorganic materials consisting of much smaller molecules. In one investigation with a scanning transmission electron microscope, Isaacson and his colleagues have etched simple patterns, such as alphabetic characters, in sodium chloride. The width of the lines in the patterns is only 20 angstroms. The proximity effect is greatly reduced because the exposure mechanism in sodium chloride is different from that in polymers.

A second part of the research is directed toward the eventual construction of a high-resolution electron beam lithography system. Just as commercial electron beam lithography machines can trace their ancestry to scanning electron microscopes that were modified in the laboratory, future higher-resolution lithography systems may be the descendants of today's scanning transmission electron microscopes.

To continue this and other kinds of research, the submicron facility needs to have its grant renewed. Wolf has prepared a plan for the next 5 years of operation and a budget sufficient to finance it. Cornell has submitted a proposal to NSF for about three-quarters of this amount, the rest to be raised elsewhere. About half of the total budget would go to running the facility, and the remainder would be divided between capital equipment and research of a type such as Siegel's and Isaacson's that Wolf calls facilities development.

Despite the acknowledged quality of the research that has come out of the submicron facility, NSF will be weighting heavily the effectiveness of the outside user program in its grant renewal deliberations—a fact well appreciated at Cornell. "We will have to develop our user capability even more to justify the next 5 years of funding, even though we have already exceeded our original commitment," says Wolf. The balance between Cornell and outside users is very close to 50:50. There is also concern at Cornell that outside users have tended to come for short periods, a week or two. As a result, they have not had time to master the more sophisticated instruments and have in some instances relied on submicron facility staff to accomplish their goals.

For its part, NSF claims to be interested in both quantity and quality. Gutmann says the question is how much of the electrical engineering–materials science–applied physics community finds the capabilities offered at Cornell so intriguing as to be willing to travel there to work, and how good is the research that results. He admits, however, that this community is not used to working at national facilities the way high energy physicists are and that this factor has to be folded into any judgment as to the submicron facility's cost-effectiveness.

For its dedication ceremonies, Cornell set up an all-day program that included two symposia on topics of great current interest: issues facing the semiconductor industry and issues facing engineering schools. By itself, the submicron facility can neither develop the technology for the next generation of microcircuits nor can it train all the engineers industry needs to make them. But Jay Harris of San Diego State University, who was Gutmann's predecessor at NSF, reminds that the submicron facility was the first of a now growing number of research programs that address these issues, including the Department of Defense's VHSIC (very high speed integrated circuit) program and several VLSI centers at universities. To the extent that the establishment of the submicron facility stimulated the subsequent development of microstructures research, NSF's money has been more than well spent.

—Arthur L. Robinson