In the Chips for the Coming Decade

MICROELECTRONICS permeate our lives. They are in our cars, our kitchen appliances, our computers, and thousands of other products that drive our modern-day existence. Now, researchers at Lawrence Livermore, Sandia, and Lawrence Berkeley national laboratories have developed a system that will keep microchips rolling off the line with ever-smaller features.

The extreme ultraviolet lithography (EUVL) full-field step-and-scan system is the first tool that demonstrates all of the key technologies needed for production of next-generation microprocessors. This fully integrated system prints 50-nanometer features—less than half the size of those made by current production tools—and it writes the full field size of the chip—24 by 32 millimeters. The projection optical system, which was developed at Livermore, is the first large-field diffraction-limited camera for extreme ultraviolet (EUV) wavelengths and may rank as the most accurate imaging system ever constructed.

Because it prints smaller features, the system produces chips that are higher in density. That is, they can "do more" in less space, which will dramatically improve the speed and memory capacity of computer systems. Microchips with features smaller than 50 nanometers may well lead to systems for facile speech recognition, improved weather prediction, enhanced medical diagnostics, three-dimensional image processing, microcontrollers for "intelligent" machinery, and more powerful supercomputers for scientific and defense research.

Physicist Regina Soufli, one of Livermore's principal investigators on the multilaboratory team, says such applications will be possible because the system embodies a set of groundbreaking technologies. In fact, until a few years ago, the science and technology community considered many of them impossible to develop.

Making the Jump for Moore's Law

For several decades, integrated circuits have steadily gotten faster, smaller, and cheaper. Circuit performance has basically doubled every two years—a pace of development referred to as Moore's Law. This rapid development rate is primarily responsible for the remarkable advances in computer technology that have occurred over the past few decades.

Unfortunately, fundamental physics laws on the diffraction of light are threatening to put the brakes on this progress. Photolithography uses light to print features onto a circuit substrate, which is usually silicon. The wavelike nature of light makes it extremely difficult to print images whose features have

Livermore team members (standing, from left): Eberhard Spiller, Russ Hudyma, Rick Levesque, Chris Walton, Regina Soufli, John Taylor, Sherry Baker, Mark Schmidt, Franklyn Snell, Layton Hale, Michael Johnson, Nhan Nguyen, Don Phillion, Henry Chapman, Butch Bradsher; (kneeling): Gary Sommargren, Ken Blaedel, Jim Folta, and Don Sweeney.

a resolution less than the wavelength of the light being used. To print 100-nanometer features—the current size for computer chips—manufacturers have had to add expensive enhancements to lithographic systems. The enhanced systems use light in the deep ultraviolet part of the spectrum with wavelengths of 193 to 248 nanometers.

The EUVL full-field step-and-scan system goes beyond deep ultraviolet into the EUV part of the spectrum, using light with wavelengths of about 13 nanometers—more than a factor of 10 shorter than the wavelength of even the most aggressive deep ultraviolet system. The current resolution for the EUVL system is 50 nanometers, but Soufli says that a resolution of 20 nanometers will ultimately be possible. She adds that such a fine resolution is not likely to be attained with other semiconductor technologies for high-volume manufacturing.

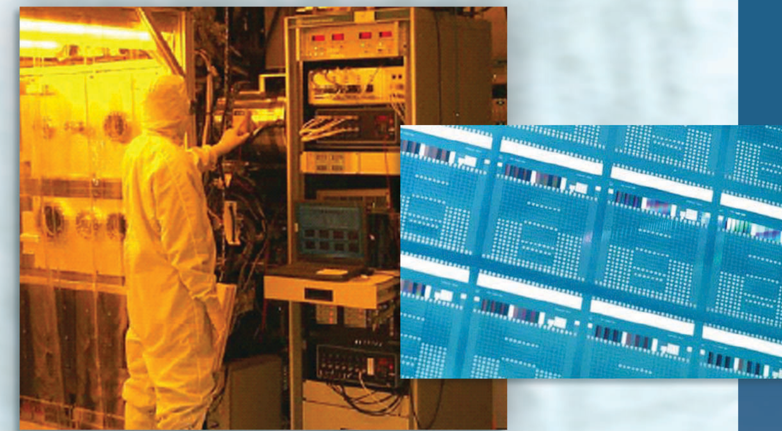
Because it uses EUV light, the new system will also have a greater depth of focus than systems using longer wavelengths, which will guarantee more robust processing capabilities. In addition, the mask patterns for imaging onto the silicon wafers can be relatively simple, which eliminates the complex and expensive pattern modifications that non-EUV systems use to enhance the resolution of the printing process.

Bringing the EUVL full-field step-and-scan system into reality for the next Moore's Law jump required the multilaboratory team to rapidly develop several technologies. Many of these technologies were thought to be too difficult or even impossible to develop in time for EUVL to play a role in manufacturing.

For example, the team developed highly accurate metrologies to fabricate and align the system's mirrors (see *S&TR*, October 1997, pp. 6–7) because no existing method came even close to measuring figure and smoothness with the accuracy required. With the new metrologies, these measurements are accurate down to atomic dimensions. The team also developed the world's most precise multilayer reflective coatings, which are necessary for EUVL optics (see *S&TR*, October 2002, pp. 10–11; October 1999, pp. 12–13), as well as a clean, 13-nanometer light source with a high-power laser-produced plasma. The source provides enough light for rapid scanning without creating contaminants that would damage the system.

Since EUV radiation is absorbed by gases, new controls were needed to ensure a suitable, ultrahigh-vacuum environment in which to operate the system. The team developed magnetically levitated precision stages compatible with the vacuum environment. Custom sensors were also created that could operate in the EUV environment, and control hardware and software were designed to provide full step-and-scan capabilities.

The EUVL full-field step-and-scan system is the central element of the largest Cooperative Research and Development Agreement (CRADA) between the U.S. national laboratories and private industry. This unprecedented CRADA is a 6-year, $250-million program, funded by the EUV LLC, a consortium of six semiconductor manufacturers. The system's development was key in convincing the microelectronics industry that EUV systems could follow deep ultraviolet systems as the next-generation lithography technology for producing microelectronics. In fact, Charles W. Gwyn, general manager of EUV LLC and a program director at Intel, noted that the success of this system led EUVL to be selected by international semiconductor organizations as the best candidate technology for use with circuit features below 50 nanometers.



Front view of the extreme ultraviolet lithography full-field step-and-scan system. Inset shows a close-up of the 24- by 32-millimeter fields that this technology can print on a silicon wafer.

The EUVL system also has potential applications outside the semiconductor manufacturing industry. Various nanotechnologies could benefit from the large surface area that can be imaged with features smaller than 50 nanometers. Possibilities include photonic crystals, surface-acoustic-wave detectors, and molecular electronic devices.

Set for the Future

With the success and acceptance of the system, EUVL now appears on the road maps of all the major semiconductor manufacturers. Soufli notes that subsequent versions of this system most likely will be used to fabricate microelectronics that are 100 times faster than those currently available. With Moore's Law now in good shape for well into the next decade, microelectronics will continue to advance at the pace we have all come to take for granted for nearly half a century.

—Ann Parker

Key Words: Cooperative Research and Development Agreement (CRADA), extreme ultraviolet lithography (EUVL) full-field step-and-scan system, EUV LLC, R&D 100 Award, semiconductor computer chips.

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