Stepping Up to Extreme Lithography

A revolutionary microprocessor technology developed by Lawrence Livermore and Veeco Instruments Inc. could increase the speed of personal computers by 10- to 20-fold and their memory capacity by 100- to 1,000-fold. The Production-Scale Thin-Film Coating Tool is a highly precise deposition system that opens the door to advanced, high-volume manufacturing of the next generation of microprocessors. It is one of this year's R&D 100 Award winners.

With the new technology, powerful desktop computers could be made that realize a wealth of exciting applications, including real-time multilanguage voice recognition, translation, and human interfaces. "Applications such as these are impossible on today's 1-gigahertz PCs," says Regina Soufli, Livermore physicist and leader of the team that developed the coating tool. "Technology enabled by the tool will allow tomorrow's PCs to approach the computing power of today's multimillion-dollar mainframe systems that presently only exist in laboratories."

Down the Optical Road

The semiconductor industry relies on optical lithography to manufacture computer chips. In the most advanced optical lithography in use today, light of 193-nanometer wavelength is projected through masks patterned with intricate circuit diagrams. The transmitted pattern is reduced by being relayed through a series of refractive lenses. In steppers (industry jargon for systems that repeat manufacturing steps over and over), the patterned image is reproduced onto thousands of silicon wafers, which are processed and developed into integrated circuits.

Presently, optical lithography can reduce circuit patterns to have features as small as 130 nanometers (the diameter of a human hair is 100,000 nanometers). This is approaching the limit of resolution, as dictated by the physics of light diffraction for the wavelengths used in current technology. But to increase the speed and power of computers, the semiconductor industry will need circuit patterns as small as 30 nanometers for computers operating at 10 gigahertz or faster. Thus, the industry has initiated a quest to find the next-generation lithographic technique that can further reduce feature size.

Extreme ultraviolet lithography (EUVL) has been recognized as the most feasible next step. It uses light of 13-nanometer wavelength, which is 15 times shorter than the wavelengths used by today's technologies. Adopting EUVL, however, represents a giant challenge.

Going Extreme

Radiation at the extreme ultraviolet wavelengths is strongly absorbed by matter such as air or the lens material. For this reason, the entire EUVL system has to be maintained under a vacuum, and the light that produces the circuit image must be reflected from mirrors rather than refracted through lenses. Furthermore, the mirrors must consist of precisely figured glass substrates that have been coated with alternating layers of molybdenum and silicon to a thickness of 280 nanometers.

Shown against a backdrop of the projection optics for the coating deposition system they co-developed with private industry, members of the Livermore team are, from left, Jim Folta, Rick Levesque, Claude Montcalm, Swie-In Tan, Mark Schmidt, Regina Soufli, Fred Grabner, Chris Walton, and Eberhard Spiller. Missing from the photo is Steve Vernon.

This thickness can only vary by less than 0.05 averaged over the entire optical surface; such a variance is equivalent to one-quarter the diameter of a silicon atom.

If this stringent specification is not met, the printed circuits will be blurred and will fail. The challenge of making precision-coated optics and doing so in a reproducible manner is daunting and thus an obstacle to implementing EUVL lithographic steppers. "There were doubts that such thickness precision could be achieved repeatably," says Soufli.

A daunting task to be sure, but Soufli and her team are receiving accolades for accomplishing it. Built on the basis of Livermore's expertise in thin-film technology, the coating tool can deliver commercial-quality multilayer coatings on the optics used in the camera and illuminator of EUVL semiconductor steppers. The tool has achieved the 0.05-nanometer-thickness precision required on camera optics. As a demonstration of success, the same optics have also been used to print integrated circuit patterns as small as 39 nanometers. This is the best imaging resolution ever achieved with optical lithography and foreshadows the ability to print circuits at the 30-nanometer resolution required for next-generation microprocessors.

The Way It Works

The new coating tool is based on the magnetron sputtering method widely used for thin-film deposition. The coating takes place inside a chamber where molybdenum and silicon sputter sources have been placed 180 degrees apart. The sources, called magnetrons, have a magnetic field attached to the back of their surface. With the chamber maintained under vacuum, the magnetrons are ignited, and a small amount of argon gas is introduced into the system. Argon ions, excited by the electromagnetic field, impinge on the sources and sputter atoms off the two materials. The atoms land on the optical substrate that sits atop a rotating deposition platter. The rotating platter passes alternately under the magnetrons, resulting in alternating layers of the two materials being deposited onto the optical surface. The platter is rotated under the sources at speeds of about 1 rotation per minute, while the individual substrates are simultaneously spinning fast around their centers at several hundred rotations per minute, thereby equalizing the spatial variations of the sources.

The tool's ability to control film thickness is based on a simple concept: The speed at which the optic passes under a sputtering source determines how much of that sputter material is deposited on the optical surface. Platter speed is modulated as the substrate passes under the silicon and molybdenum targets, depending on what thickness profile is desired.

The most critical step of the entire process is determining the right coating recipe for a given optic, and this is done with the help of computer simulation. First, using the substrate shape and desired coating thickness profile as input, a custom-designed computer model simulates the deposition process. The algorithm calculates the platter velocities and angles that should be applied and proposes a coating recipe that is tested on a surrogate optic. The resulting coating thickness on the surrogate optic is measured, compared with the desired profile, and fed back to the algorithm to adjust the recipe. The final recipe is arrived at after four or five iterations of simulation and adjustment. When put into use, the recipe must be calibrated only once for each set of optics and is stable enough to be repeatedly used for over a year.

Process engineer Mark Schmidt places an optical substrate in the coating deposition chamber.

The new coating deposition system can produce multiple sets of optics in a high-volume production mode with precisely identical thickness profile. This way of controlling coating thickness is accurate, quick, and inexpensive.

Riding the Wave of the Future

The coating tool represents a breakthrough in semiconductor equipment manufacturing. It enables the commercialization of EUVL. Beyond EUVL, the tool's capabilities can be applied in other areas where thin films with precision thickness control are needed, such as astrophysics, magnetics, and biological x-ray imaging.

"We achieved commercial-level thickness control for the first time ever on large multilayer optics," says Soufli. "By implementing a versatile design and a unique deposition algorithm, the tool has enabled commercialization of EUVL as the next-generation technology for highly advanced computers of the future." The first EUVL-fabricated computer chips are scheduled to be developed in 2007. Expect to be able to buy your very own "supercomputer" shortly thereafter.

—Whitney Lacy

Key Words: extreme ultraviolet lithography (EUVL), magnetron sputtering deposition, production-scale thin-film coating tool, R&D 100 Award, semiconductor computer chips.

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