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From "**Micro**" to "**Nano**"

The technological race in the field of microelectronics is continuing at an undiminished pace. Schott Lithotec supplies materials for wafer steppers with which it is possible to produce still tinier chips.

The structure of the tracks printed on silicon wafers will become smaller and smaller in the future. This will not only increase performance, but will also reduce costs in chip production.

It seems that the prefix "micro" will soon be replaced by the prefix "nano." The branch working with bits and bytes is fast approaching the nanocosmos, where not millionths, but billionths of a meter (nanometer = nm) set the standard. The legendary Moore's Law says the complexity of chips doubles every 18 months because of the continual miniaturization of the structures mounted on silicon wafers, and this is still valid today.

Optical lithography is inseparably linked with the rapid progress generated by microelectronics in the entire technical world. Some say it is the engine driving the success story of miniaturization. Smaller and smaller mobile phones, increasingly faster and more powerful computers, safer cars, communications at the speed of light – all this and much more have only been made possible through the breakneck speed of innovation in the field of semiconductor chips.

High-tech optical materials from Jena

Over the years, German and other European companies have gained important expertise in this technology. This is particularly true of Schott Lithotec AG in Jena. "We are the only supplier worldwide that offers the full spectrum of high-tech optical materials for current and future applications in microlithography," says Dr. Martin Heming, CEO and Chairman of the Executive Board of Schott Lithotec AG. This includes special glasses for shortwave blue light, synthetic quartz glass and synthetic calcium fluoride crystals. And especially in today's 193-nm and next-generation 157-nm technology for high-performance wafer steppers, Schott Lithotec is the leading research and production company offering the necessary optical materials and the corresponding components and systems.

International recognition

Schott's subsidiary is gaining more and more international recognition for these achievements. "Schott Lithotec is a supplier of growing importance for us and the entire semiconductor industry. This is particularly true for the continued realization of Moore's Law, which means the imaging of increasingly smaller structures that require light sources for 157 nm, resulting in a greater demand for calcium fluoride crystals in lens production," stresses David Skinner, vice president of sales at Cymer Inc.'s Lithography Systems Solutions Unit in San Diego, California. The U.S.-based company is the world's leading producer of excimer light sources integrated into wafer steppers, and

Lithography equipment – Step by step

From their functional principle, wafer steppers and wafer scanners can be compared to oversized slide projectors, but in this case the structures of the "slides," i.e. the masks, are scaled down. These "exposure" or "printing" machines transmit the structures from the mask to silicon wafers that have been coated with a photoresist. This is how the pattern and design of the tracks are arranged on the semiconductor substrate. Up to 30 separate steps including coating, exposing and subsequent processing are necessary to produce the complete structure of an integrated circuit.

Lithography equipment generally consists of a radiation source, an optical beam control system for the light, an optical imaging system and photomasks. Excimer lasers with a wavelength of 248 nm are now used as radiation sources in the mass production of chips. Conversion to 193 nm with argon fluoride excimer lasers is currently underway. The next step to 157 nm with fluoride lasers has already begun at all the major producers of steppers, including the Dutch company ASML and the Japanese producers Canon and Nikon.

Due to its high resistance to radiation and absence of any compaction (local changes in density) when bombarded by lasers, the optical high-tech material calcium fluoride crystals are used for lens production in microlithography.

they have recently intensified their cooperation with Schott Lithotec.

"Our leading position in illumination sources is also due to the fact that we rely on a small group of particularly important suppliers who meet our quality requirements and work with modern processes. Schott Lithotec definitely belongs to this circle of key suppliers," says Skinner, full of praise for the German partner. Cymer recently introduced its innovative Master Oscillator Power Amplifier (MOPA) technology. A paradigm shift from current lithography technology, MOPA will enable next-generation light sources to deliver higher power, tighter bandwidths and lower operation costs for future optical lithography applications across all three deep ultraviolet (DUV) wavelengths – 248 nm, 193 nm and 157 nm. The first product in its new XL Series of performance-driven light sources for advanced lithography – the XLA 100, a 193-nm light source – was announced in July 2002. In addition to the introduction of this product, Cymer also announced that it received a volume purchase agreement with a value in excess of $130 million for the XLA 100, and the customer has agreed to take delivery of the light sources covered under the agreement from introduction through the year 2004.

A schematic drawing of an ASML wafer stepper (left). The U.S. company Cymer has recently developed even more efficient excimer lasers with its innovative XLA 100 system and so-called "MOPA technology."

EUVL – a radical change in technology

Although 157-nm technology, which will allow structure sizes of just 70 nm, will only be introduced in chip production beginning in 2006, the whole branch is already preparing for the next generation. This will be a giant leap forward, leading directly from 157 nm to EUV (short for Extreme Ultraviolet) wavelengths of 13.5 nm, (see Schott Info No. 99, page 6 ff). This advance into EUV is necessary because there is no complete value-added chain in between. The final drive into the world of dwarfs (nanos is Greek for dwarf) is a radical change because there is not any transparent material for 13.5 nm. This means that all optical imaging and beam transport systems must be converted to reflective optical systems (mirrors). A material composite that can be used to produce a system of reflective layers currently only exists for 13.5 nm technology.

The kind of light source is still uncertain. "It is fairly clear that we will use a plasma, but it is still open whether this will be produced by laser or gas discharge," explains Guido Schriever, Project Head EUV at Xtreme Technologies, a joint venture between Jenoptik and Lambda Physik with sites in Göttingen and Jena. Scientists use the term plasma to describe the fourth material state, which is clearly different from the well-known physical conditions solid, liquid and gaseous. Plasma is an electrically conductive, highly ionized gas composed of ions, electrons and neutral particles that are in different states of energy and excitation. The highly competitive race is on to develop next generation light sources, and both Cymer and Xtreme Technologies are involved.

Focusing on zero-expansion materials

Schott Lithotec is also preparing itself for such a technological leap. "With 'Zerodur' glass ceramic we have an excellent basis for the necessary mirror substrate. We have additional development projects for new materials, also for blank photomasks, so called mask blanks," explains Dr. Peter Rudakoff, Manager of Schott Lithotec's Business Unit Components. Special glasses and ceramics are required with extremely low thermal expansion coefficients. These are equipped with a highly reflective molybdenum-silicon (Mo/Si) coating system consisting of more than 100 layers, each only a few nanometers thick.

A highly sophisticated coating process is necessary to achieve the complex structure of EUV mask blanks, especially in terms of the homogeneity and flawlessness. The drastic reduction in structure sizes requires a further decrease in the maximum admissible defect density and thermal expansion. Particularly problematic are the imperfections that exceed a certain size and are then reproduced in the lithographic process. Current research is thus focused on reducing the defect density and minimizing mechanical tension in the layers. In addition, the EUV masks must be highly and uniformly reflective.

Until now, only very few research institutes around the world have succeeded in fulfilling one of the two prerequisites, i.e. flawlessness or high reflection, and only at a laboratory scale. One of them is the renowned Lawrence Livermore National Laboratory, near Oakley, California. Achieving both of these indispensable criteria for EUV lithography – and that on an industrial scale – has been the biggest challenge so far.

World leaders

As part of a technology transfer project, Schott Lithotec AG and the Fraunhofer Institute for Applied Optics and Fine Mechanics (IOF) in Jena have succeeded for the first time ever in developing a technology to produce highly reflective and flawless coatings for EUV mask blanks on an industrial scale. In this successful collaboration with Fraunhofer's scientists, Schott Lithotec came up with a process in just five months that complies with today's highest international standards. "With this development we have further strengthened the position of our Business Unit Components and verified our intention to become one of the world's leading suppliers of photomask blanks," says CEO Martin Heming enthusiastically. With a reflective capability of 64.6 percent from a 6" EUV mask blank that is free of imperfections, the Mo/Si coating system now already meets the requirements of the semiconductor industry that have been predicted for the years to come. ◂

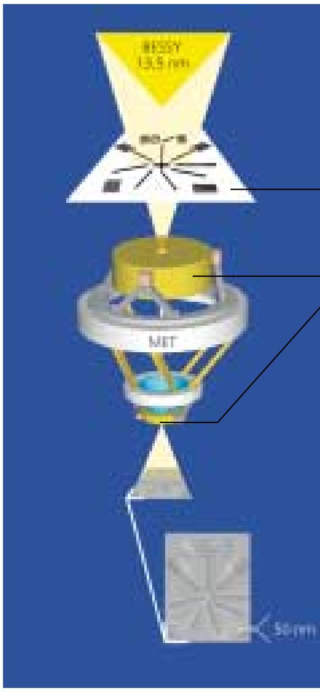
Exposure – a key technology

The "exposure" or "printing" process is of central importance because the ability of the objective in wafer steppers to reproduce the finest details and smallest structures has influenced the progress of microelectronics. The smaller the structures are, the faster the processes. In other words, the processor's tact rate increases, electricity consumption decreases, and productivity significantly improves because the single chip requires less room on the wafer.

One look at the objectives shows just how enormous progress has been from the beginnings of lithography at the end of the 1960s. In the early days they were based on simple photographic objectives. By the 1970s they were composed of a good dozen individual lenses weighing up to 50 kilograms. The latest product generations have up to 30 individual lenses and weigh up to 400 kilograms.

Improving the optical resolution can generally be achieved in two ways: either you increase the diameter of the lens, or you use light with shorter wavelengths. But both options have their limits. Once they reach a certain size, individual lenses begin to be awkward and unhandy. To use shortwave light you need light sources and optical materials that are transparent for this radiation.

For this reason, many experts already began predicting the end of optical lithography ten years ago. However, new developments such as the calcium fluoride crystals from Schott Lithotec that are transparent for 157 nanometers still outperform any alternative technologies.



The use of EUV radiation sources is a radical change in technology for chip production. All the imaging systems will have to be converted into reflective optical systems.

In cooperation with the Lawrence Livermore National Laboratory in California, Carl Zeiss SMT AG has developed a prototype for EUVL technology, the Micro Exposer Tool (MET), with highly precise mirrors instead of lenses. "Zerodur" from Schott is particularly well suited as a mirror substrate for this new technology because of its extremely low coefficient of thermal expansion.