Beam work

The success of the world's leading lithography company is based on close collaboration with its suppliers. **David Ridsdale** reports on how **ASML** and **Carl Zeiss SMT** have transformed lithography.

One might assume, given the way some people in this industry speak about it, that "collaboration" was a brand new concept invented by the semiconductor sector. Of course, collaborative efforts have been around since the industry started. It is just that now they are vital.

Chip making has become such a complicated business that no single company can be an expert in every area. Companies therefore have to rely on the expertise of others to ensure that their products remain at the cutting edge,

Nowhere is this more evident than in lithography. In the last few years Dutch firm ASML has become the number one lithography supplier for semiconductor fabrication.

Just over a decade ago it would have been unfathomable for Europe to have any semiconductor manufacturers in the top ten companies, let alone the world's most successfully supplier of the most significant enabling tool.

ASML has also had to compete in a cut-throat market with two ferocious Japanese companies. Nikon and Canon had ruled the lithography roost for some time and they were not expected to be challenged.

It is clear that much of ASML's success has been due to the collaborative way in which it operates. Much of technical work involved in making the company's lithography tools is outsourced to companies all over Europe. Possibly the most important collaboration ASML has is with Carl Zeiss SMT, a Germany-based maker of lenses for lithography tools.

To understand how important this relationship is to both companies, you only need to take a trip to Oberkochen in the south of Germany and see the new factory that Carl Zeiss is building for its lithography optics division.

By the time the building is completed, Zeiss will have more than 45,000m² of extra space. More than half of this will be dedicated to production space with 4,000m² of clean rooms. The development will cost more than euro 280 million. The new factory is a massive site with state-of-the-art facilities for manufacturing some of the world's most advanced optics lenses. What makes the whole venture more remarkable is the fact that the whole factory is being built to manufacture products just for ASML.

Optical lithography remains the dominant technology for forming transistors on silicon wafers

During my visit to the site I was accompanied by journalists from the financial community. It seemed implausible to them that a company would invest so much capital when relying on another company's product. It took some time to convince one journalist that the companies were not mad and had solid reasons to invest and trust so much in each other.

The truth is that ASML cannot make lithography tools without the expertise of Carl Zeiss. In fact 90% of the cost of ASML's tools comes from components supplied by external companies. This amounted to almost euro 1.4 billion in 2004. Of the 512 suppliers ASML uses, 445 are within the European Union.

Whereas the two Japanese suppliers of lithography equipment belong to huge Japanese companies and are mostly serviced internally, ASML is a spin out of a European chip manufacturer and has built its business on creating partnerships with its suppliers.

ASML was founded in 1984 as a spin off of Philips Semiconductor. The two companies

ASML's lithography tools are widely considered to be the best in the industry

continue to share a close partnership but ASML has grown to a global company with over 5,000 employees and serving every major semiconductor manufacturer.

The business model ASML chose from the start is one that is now embraced throughout the industry. Outsourcing and subletting all the component work has allowed ASML to let the "experts" deal with the segments they are best at while leaving ASML to focus on the bigger picture of customer needs.

Despite the range of suppliers that ASML uses, there is no doubt that Carl Zeiss is the most visible. Founded as a workshop for precision mechanics and optics in the German city of Jena in 1846, Carl Zeiss is today a global leader in the optical and opto-electronic industries.

After the Second World War, the headquarters were moved to the Western German town of Oberkochen. Zeiss has maintained its leadership in global optics ever since.

To give an idea of how well known the company is in the field of optics, a comparison can be made to bikes and cameras. When a bike enthusiast goes to buy a bike they will look for Shimano gears. When a camera enthusiast looks to buy a camera, he wants a Zeiss lens.

The company is renowned for the inventiveness of its engineers, who love nothing more than to get their teeth into a new technical challenge.

For example, while it was working on developing products for a twinscan lithography tool and undertaking research into extreme ultra violet (EUV) and immersion lithography, Carl Zeiss realised some of the tools it needed did not exist.

This was especially true for the metrology section of the lens making process. But rather than seeing this as a problem, the company simply invented and built the tools that were required.

The ASML/Carl Zeiss partnership has paid big dividends in the last few years and it has all been achieved thanks to new technological approaches.

ASML's twinscan tool, released a few years ago, was the first sign the company was approaching the lithography process in a novel manner by implementing two scanners in the same device.

The aim of the pioneering tool was to reduce footprint while at the same time increasing production output. Semiconductor makers were smitten and are increasingly buying the tool when they make the crossover from 200mm to 300mm fabs. When the industry was ready to move to 193nm lithography, ASML was able to present another improvement to the twinscan, thanks to the work of one of the company's major partners.

The updated tool featured a revolutionary lens – the Starlith 1400 – made by Carl Zeiss SMT. What made the lens and tool so special was that they allowed light with a 193nm illumination to volume produce feature sizes at a resolution of just 65nm.

This amounted to a size reduction of almost 10% over previous systems and was made possible by the lens's numerical aperture (NA) of 0.93 (variable from 0.65-0.93) and the image quality. Carl Zeiss has refined the lens for further technology nodes.

The semiconductor industry has announced its intentions to its community via the ITRS roadmap. With production requirements below 65nm on the horizon, the lithography community was planning to introduce 157nm lithography and then a form of lithography other than optical was supposed to take over. As is common with industry roadmaps, what was desired did not come to pass.

It was expected the transition to 157nm lithography would be smooth and technical problems such as birefringence from calcium fluoride lens would be solved. Then in 2002 the Carl Zeiss group made an announcement that was to change the roadmap completely. By using an old optics trick – inserting fluid between the lens and the specimen – the company was able to extend the resolution of current 193nm tools beyond what had previously been thought possible. Suddenly everyone was talking about immersion lithography.

Immersion lithography has its roots in the proven technology of immersion microscopy. Developed by the Italian physicist Giovanni Battista Amici (1786-1863), immersion microscopy works by placing a thin liquid film between the final microscope lens and the specimen to improve depth of focus and improve the numerical aperture value to higher than 1, thus increasing resolution.

The first lithography lens based on this concept – the Starlith 1150i – was developed by Carl Zeiss. It has a numerical aperture of 0.75 and a resolution of 90nm.

Development work on the lens started in the summer of 2002 and within just a few months Carl Zeiss had a working prototype that boasted identical technical data to the "dry" version of the lens. The lens was then put in an ASML pilot tool tested over the 2003 summer. Feasibility of immersion lithography was demonstrated during the following months.

The encouraging results led to an unforeseen change in the roadmap of optical lithography. While only two years earlier, 157nm lithography was the technology of choice to close the resolution gap between 193nm "dry" lithography and EUV lithography, 193nm immersion lithography is now considered the only feasible option and is expected to reach resolutions as low 32nm over coming years.

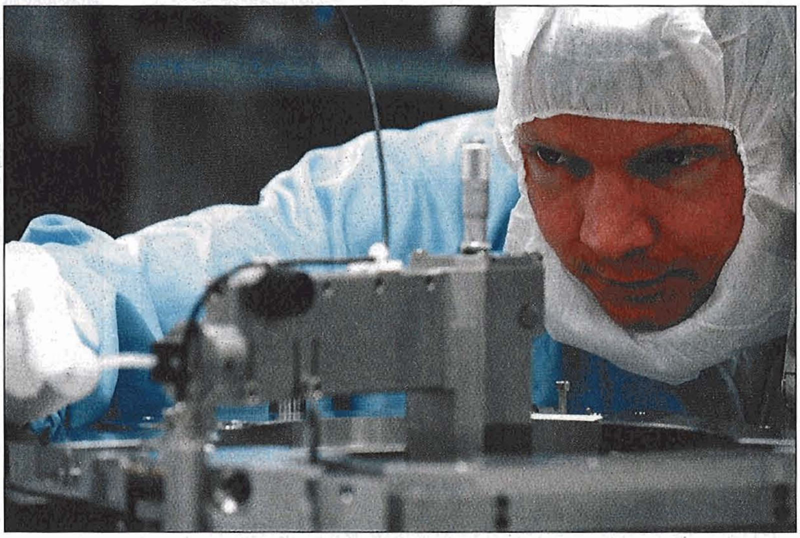
At present, the ITRS roadmap envisages that EUV will be the next lithography node. Both ASML and Carl Zeiss SMT are actively working to this goal, although they are aware that EUV might ultimately not be adopted.

This is because there are huge technical challenges that must be overcome before EUV can become a mainstream technology.

One of the big problems is that refractive optics cannot be used because EUV radiation (13.5nm) is strongly absorbed by all known materials. Therefore, at present, the only option is to use mirrors. In addition EUV exposure tools must be operated under extreme vacuum conditions to avoid absorption of EUV light by gases.

Three optical components are required for an EUV exposure tool: the collector which captures as much radiation from the source as possible, the illumination system which homogeneously illuminates the used field on the mask, and finally the imaging optics which demagnifies the structures from the mask to the wafer.

Within the framework of the European EUCLIDES project, the first development work on



EUV lithography was started at Carl Zeiss SMT in the mid-1990s. Further funding was given by the joint European MEDEA project and the Federal Ministry of Education and Research (BMBF) in Germany.

The initial focus was the development of the technology required to produce extremely precise mirrors. Neither the figure errors nor the roughness of mirrors for the imaging system must exceed a few angstroms (one angstrom corresponds to the diameter of a hydrogen atom).

For the production of mirrors for the illumination system, Carl Zeiss already had the required know-how from the production of synchrotron optics and various X-ray satellite projects such as ROSAT and XMM.

Further challenges facing optical systems for EUV lithography lie both in the measuring technology needed for testing the surface structure of the mirrors and in the coating technology used for the reflective coatings.

The mechanical construction must also meet extremely stringent requirements, as no transfer of machine vibrations to the optics is permitted during the exposure process. A further focus of attention is the long-term stability of the optical systems. A long service life is an absolute must for a successful EUV production tool.

Although there are still huge obstacles in the way of EUV lithography, if anyone can make it work, it will be ASML in collaboration with ingenious suppliers such as Carl Zeiss.

Indeed, Carl Zeiss's Oberkochen facility in Germany is already making the first giant lenses for EUV lithography and ASML has begun placing tools containing the lenses in pilot lines in customers' fabs.