Event report – DSPE Precision-in-Business day at ASML
March 29, 2018

ASML, a company to be proud of

Everybody knows ASML, but not everyone is familiar with the secrets of its success. The DSPE Precision-in-Business (PiB) day offered a good insight into the application of extremely short-wavelength radiation for the production of the chips that everyone uses in their computer, smartphone and washing machine. The ASML contribution to semiconductor production lies in the research and development of the lithography process and the manufacturing of the associated wafer steppers. These precision machines use lithography to project ultra-precise patterns onto silicon wafers.

On the well-attended PiB day, Cor Ottens from the ASML Opto-Mechanics department highlighted the latest trends in the dynamic world of integrated circuit manufacturing. The continuing race to fit more and more transistors onto a single chip is described by Moore's law: the doubling every two years of the number of transistors per surface area unit. From 500 transistors on one chip in 1970, to a nearly unimaginable estimated number of 10^{10} in 2020, the double-logarithmic representation of number of transistors vs. time can be depicted in an almost perfectly straight line. Keywords in the IC world are smaller, faster and cheaper.

Moore's milestones
Several milestones can be distinguished in the historical transition of specialisation in wafer steppers, beginning at Philips Electronics in Eindhoven and leading to ASML in Veldhoven, in what is known as the Brainport region. The author's own experience of this can be found in an article published in 1983 in *Philips Technical Review* describing the Silicon Repeater (see Figure 2). This research instrument worked with violet radiation of about 400 nm from a high-pressure mercury light source. The Silicon Repeater could project details of minimum 1.25 µm onto a 4-inch wafer, thanks to a high-precision telecentric objective.

Although the Silicon Repeater was an advanced instrument for its time, it could be upgraded successively by applying radiation with lower wavelengths. Why and how? The Rayleigh criterion states that the smallest distance between two features that can still be distinguished as separate – called optical resolution – is proportional to the wavelength of the used radiation and inversely proportional to the numerical aperture of the objective. As more functions on a chip demand smaller dimensions of the transistor, consequently the application of radiation with ever smaller wavelengths is required.

This brings us to a second milestone contributing to progress according to Moore's law: the ASML TWINSCAN NXE (see Figure 3). This wafer stepper applies EUV radiation, which is extreme ultra-violet with a wavelength of no more than 13.5 nm. This advanced instrument handles wafers with a diameter of 300 mm, three times larger than the wafers in the Silicon Repeater. The huge machine is provided with a wafer stage comprising two wafer tables to enhance its throughput by enabling the preparation of a second wafer while the first one undergoes the repeated-projection process. When comparing this TWINSCAN with its early predecessor, the Silicon Repeater, one difference is conspicuous: decreasing the applied wavelength results in a considerable enlargement of the machine.

How to make an IC?
During a tour of the ASML Experience Centre, the PiB attendants were able to watch the processes a wafer undergoes to become a large series of separate dies, each containing numerous integrated circuits (ICs), which then only have to be packaged. The silicon surface undergoes successive

treatments like vapour deposition, magnetron sputtering, ion implantation or etching. These treatments, however, only need to be processed locally with high-resolution details. That's why the wafer is covered repeatedly with a UV-light-sensitive photoresist, which is radiated locally according to patterns fixed in successively applied reticles.

Thus every chip production cycle involves:
- step-wise locally exposing the photoresist in the wafer stepper;
- removing the wafer from the wafer stepper;
- developing the photoresist;
- treating the free-coming silicon surface parts with one of the described processes;
- removing the photoresist from the wafer;
- covering the wafer with a new layer of photoresist;
- putting the wafer in the wafer stepper again for a new EUV exposure cycle.

Needless to say that subsequent illuminations have to match each other dimensionally with nanometer precision, thanks to ultra-precise aligning marks. It will have become clear that after each step-wise exposure, the wafer moves so that a new part of the silicon surface is illuminated. It is not only the precision stage in which the wafer moves, however; the reticle also moves, in the opposite direction to make optimal use of the optical beam trajectory. In the older models, these stages are designed with slides on air bearings, driven by linear motors. The even more sophisticated stages in the TWINSCAN NXE move on magnetic bearings with integrated electromagnetic drives.

EUV optics
The ASML wafer stepper TWINSCAN NXT works with a 193nm wavelength Deep UV light source and an immersion objective with a record numerical aperture of 1.35. This chip-making machine is equipped with lenses and a gas-discharge DUV light source. As mentioned earlier, its successor, the TWINSCAN NXE, works with Extreme UV radiation with a 13.5 nm wavelength. Unfortunately, such radiation cannot pass through 'conventional' optical lenses made from glass or other refractive materials. The only method to focus such optical beams is by using ultraflat mult-layer mirrors.

For a wavelength of 13.5 nm, ASML covers mirrors with a Mo-Si multilayer coating. This enables the reflection of 13.5 nm EUV, but nearly extinguishes the reflection of nearby wavelengths according to Brag's interference principle. The transmission efficiency of one coated mirror amounts to only 70%, obviously rather poor but still workable with a total transmission from the first focus to the wafer of only 1%. Figure 4 shows the principles of the EUV light path in the TWINSCAN NXE.

The EUV source
Yet how to generate 13.5 nm EUV light? ASML owns the Cymer Technologies division in San Diego, USA, which designed a highly sophisticated 13.5 nm EUV source. ASML housed this source in a thermostatically water-cooled and vibration-isolated vacuum vessel, designed in the Eindhoven Brainport area. A CO_2 laser beam hits droplets of liquid tin with some tens of μm diameter, thus heating the tin and eventually creating a plasma, consisting of tin ions and electrons. These tin ions emit all kinds of 'light', including 13.5 nm EUV photons. A first concave mirror concentrates the EUV beam in an intermediate point focus (Figure 4).

Lecture and tour
It is not only the EUV optical path itself that asks for intelligent alignment procedures. Bas van Dorp, system architect at ASML, explained the problems associated with the alignment of the CO_2 laser beam with respect to the centre of the EUV source. After his highly interesting lecture, the PiB day finished with a tour through the ASML test and measurement facilities. Here, several movement

assemblies from the TWINSCAN machines are tested for durability and dynamics, making use of advanced high-speed cameras, for example.

One remarkable test was for a reticle stage, on which a pellicle is deposed to protect the very sensitive reticle from contamination. During the high-acceleration movement of the stage, the pellicle is excitated in its natural frequencies, causing various oscillation patterns. The test is aimed at helping to design measures to avoid these oscillations. All of these experimental set-ups help to increase the reliability and lifetime of ASML products.

To conclude

The PiB day at ASML provided an excellent opportunity to make acquaintance with one the most prominent members of the Dutch precision engineering industry. It was also an extra stimulant for DSPE to organise more PiB days to show what the Dutch precision industry is bringing forth.