PROGRESS FROM PELLICLES TO PATHOLOGY

Last month, the DSPE Optomechatronics Week 2023 was a great success. Preceded by a fully booked three-day Optomechanical System Design course, the DSPE Optomechatronics Symposium on Thursday 30 March attracted about 100 participants. They were treated to fascinating presentations about the progress in optomechatronics, ranging from EUV mirror metrology and pellicle qualification to digital pathology system design and photonics assembly platform development. In addition, there was ample room for networking and visiting the lively exhibition.

The Symposium was organised by DSPE in collaboration with the German photonics cluster Optence and the independent high-tech knowledge institute Mikrocentrum, which acted as the host at its premises in Veldhoven (NL). The event was targeted at engineers and architects who are closely involved in designing and building optomechatronic systems; youth was well represented among the approximately 100 participants. Chairman of the day Frank Schuurmans, vice president Research at ASML, ensured the smooth running of the lecture programme, which comprised multiple showcases of progress in optomechatronics.

Impressions of the symposium.
(a) The well-filled lecture hall.
(b) The lively exhibition.

High-NA EUV lithography

Lithography is one of the main applications that are driving progress in optomechatronics. Now that extreme ultraviolet (EUV) lithography as incorporated in ASML machines has been established in semiconductor mass production, the next logical step on the path to further shrinkage of semiconductor features, following Moore's Law, is to increase the numerical aperture (NA) of the optics in use. To that end, ASML and the world-leading German optics technology company ZEISS are developing a new generation of high-NA EUV tools to enable even smaller feature sizes than currently produced.

The increased NA inevitably leads to larger and more extreme aspheric mirrors in the optical path and thus to tightened requirements for the necessary manufacturing steps. A central aspect of this process is the surface metrology. For this purpose, ZEISS and ASML jointly developed a completely new, interferometry-based measuring tool to meet the stringent requirements in accuracy, precision, throughput and reliability.

Stefan Obermaier, key functional systems engineer at ZEISS High-NA Mirror Metrology, part of ZEISS Semiconductor Manufacturing Technology, talked about the design of this advanced tool. It was based on Fizeau interferometry, which has the advantage over other interferometry principles that the reference surface is close to the object (mirror) under test, thus reducing the potential for environmental perturbations of the measurements. Still, a lot of attention was to devoted to optimising the test set-up – placed in a vacuum chamber to prevent air perturbations – with respect to mechanical drift, thermal expansion and dynamics.

Ultimately, ZEISS demonstrated a measurement reproducibility of 5 pm rms, well below the specified 8 pm. Obermaier also discussed the advanced calibration procedures and the measures that were taken to achieve long-term stability and high availability of the tool, to meet the demanding throughput requirements in semiconductor production.

EUV pellicle qualification

ASML's introduction of EUV (13.5 nm wavelength) in lithography has had very diverse and far-reaching consequences. One example is the EUV pellicle, a thin film (≈ 50 nm thick) that is placed above the patterned surface of the EUV reticle to prevent particles from landing on the surface. As the particles retained by the reticle are out of focus, their impact on the imaged pattern is strongly reduced. This thin-film reticle has to be qualified in various aspects before it can be put into service. In particular, the EUV transmission and reflectance at 13.5 nm have to be quantified over the entire pellicle area.

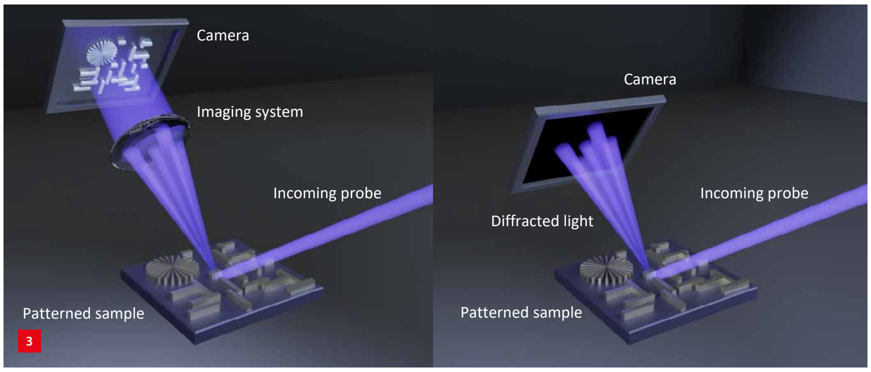
Andreas Biermanns-Föth, head of the business section Photon Instrumentation, EUV/XUV Systems at RI Research Instruments GmbH (RI), located in Bergisch Gladbach (Germany), talked about metrology tools and solutions for actinic EUV pellicle qualification. Based on RI's actinic EUV inband metrology concept (AIMER™), the EUV Pellicle Reflection and Transmission Tool (EUV-PRTT) was co-developed with ASML.
Biermanns-Föth presented the main building blocks of the tool and explained the working principle that allows to simultaneously measure EUV transmittance values above 90% and reflectance values as low as 0.002% with high spatial resolution and accuracy. See also RI's company presentation in this issue (page 21).

Lensless imaging

Measuring semiconductor features produced by short-wavelength EUV lithography requires correspondingly short-wavelength tools such as microscopy using EUV or soft X-rays. This kind of short-wavelength microscopy is however not compatible with conventional imaging optics. Within the NWO-TTW Perspective Program on Lensless Imaging of 3D Nanostructures with Soft X-Rays (LINX), an EUV beamline for measuring semiconductor samples was designed and constructed at Delft University of Technology.


2

RI's EUV pellicle qualification tool in a cleanroom environment.



3

Conventional imaging (left), using imaging optics (lenses) to create an image on a camera, compared to lensless imaging (right): the imaging optics has been removed and the diffracted light is captured directly.

For this lensless microscope that uses coherent EUV light, the algorithmic concept of lensless imaging (or ptychography) has been developed in order to image nanostructures by reconstruction from far-field diffraction patterns. Wim Coene, parttime professor in Delft and director of Research at ASML, presented the design of this beamline. He started with showing the cover of the Mikroniek 2022, nr. 4 issue, which featured an article on lensless imaging by Sven Weerdenburg, who is currently doing his Ph.D. research on this topic with Prof. Coene.

In the beamline, EUV light, as generated by a table-top high-harmonic generation source, is focused on the sample, scattered by the nanostructures at the sample surface, and reflected towards a camera, where a far-field diffraction pattern is recorded. A data set comprising a multitude of these diffraction patterns is generated for multiple partially overlapping positions of the focused coherent probe on the sample, which is mounted on a well-controlled stage. Such a data set provides the necessary redundancy to transfer the acquired diffraction patterns into a computer-generated image of the sample by means of very specific algorithms.

Coene concluded his presentation with discussing the multiple challenges that have been and are being addressed to improve the imaging resolution of the EUV beamline.

Design principles

The aforementioned pellicle is a small, yet critical component of ASML's latest machines. The wider perspective of the optomechanical design of the various generations of lithography machines was taken by Cor Ottens, system architect at the Veldhoven-based company. He identified overlay as one of the main design drivers: with the number of layers

Cor Ottens, system architect at ASML, talked about the optomechanical design of the various generations of ASML's lithography machines. In his capacity of chairman of the DSPE Special Interest Group Optics, he was also the chairman of the organising committee for the symposium.

on a wafer going up to 200, the optical alignment of these layers, and the patterns therein, with respect to each other is crucial for creating vertical contacts.

For example, at linewidths of 20 nm the alignment error must be around 2 nm. Alignment and reference sensors are used to ensure this and their accuracy then has to better than this 2 nm. To a large extent this is determined by the stability of the mechanics, under the influence of thermal drift (the biggest disturbance contributor), forces, vibrations and shocks, and stresses and creep. To achieve the tight stability specifications, the correct mechanical design principles have to applied in order to keep the optical elements in position even under extreme influences.

Ottens gave an overview of the various design principles that have been applied, such as kinematic mounting in six degrees of freedom, applying a thermal centre, using a fixed reference, flexible surface mounting, CTE (coefficient of thermal expansion) matching, thermal conditioning, force compensation, and symmetrical mounting. To conclude, he showed how to align a wafer to the reticle on a single-stage and a dual-stage machine, and how the optomechanical design principles have been applied to realise a stable and accurate machine that serves as the basis for reaching the tight overlay specification.

Adaptive wafer table

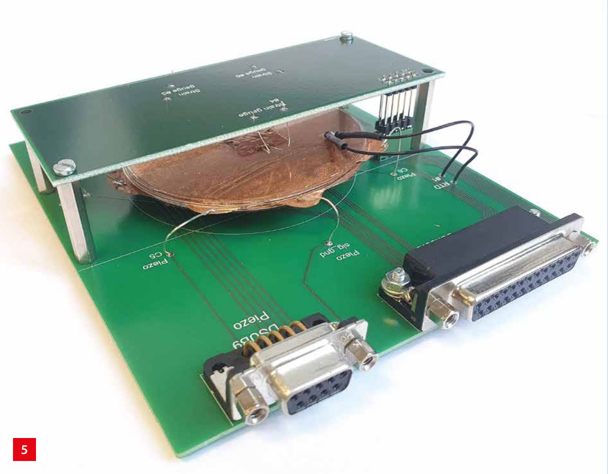
The evermore exacting requirements not only apply to the projecting optics of a lithography system, but also to the wafer table that positions the wafer for exposure. Sander Hermanussen, Ph.D. candidate in the Control Systems Technology group at Eindhoven University of Technology presented the design of a deformable wafer table that can achieve enhanced image plane conformity to both aerial image and wafer load geometry.
In his design, a set of multilayer piezo-electric actuators are mounted at the back of the adaptive wafer table. Both curvature as well as in-plane strain can be controlled by using different electrode patterns. To verify the functionality of the adaptive wafer table, he manufactured a prototype actuator in collaboration with Penn State University.

Besides compensating for mismatch between the aerial image and the wafer surface, a deformable wafer table can be used for damping dynamic excitations from the wafer-positioning system and mitigating friction during wafer load. In current systems, microscopic sliding between the wafer and the table causes irreproducible overlay errors and degrades the tribological properties of the wafer table. By deforming the table conformally to the wafer before loading, overlay position can be predicted in advance, and wear is reduced.

Deformable mirror

Hermanussen's adaptive wafer table extends the application of active/adaptive optics (AO) to the wafer level. A more mature AO application is deformable mirror (DM) technology, which has been used for years for aberration correction in the field of astronomy, space telescopes, and laser communication. Stefan Kuiper, mechatronic system architect at TNO, gave a presentation on DM development.

At the heart of TNO's DM technology is the unique hybrid-variable-reluctance actuator principle. Its main advantages are the inherent high reliability, high linearity (> 99%), and high efficiency in terms of force per volume and unit power. Based on this actuator technology, TNO has built and tested



Manufactured by Sander Hermanussen: a functional prototype (not the Penn State collaboration) of a deformable wafer table fitted with lithium-niobate piezo-electric actuators.

a number of DMs as well as a highly compact fine steering mirror for use in laser-communication systems onboard satellites. The next step on the development roadmap is the realisation of large adaptive secondary mirrors (ASMs) that have to improve the imaging performance of large astronomical telescopes.

Kuiper talked about the design of an ASM that contains up to several thousands of actuators and optically powered (concave/convex) mirror shells of up to Ø1.4 m. He covered aspects such as dynamics and control, mirror-shell manufacturing and the surface form error budget. After showing recent experimental results, he concluded with an outlook on the future development plans regarding this DM technology.

Alignment turning

Christian Buß, head of R&D Alignment Turning Systems at Trioptics in Wedel (Germany), talked about innovations in alignment turning for high-precision optomechanical systems to address the need for increasing imaging performance. Alignment turning has proven to be a very versatile technology for the efficient and accurate assembly of optomechanical systems, from small lenses in mass-produced microscope objectives to large lenses for semiconductor equipment.

Today, the main technical challenges for alignment turning of objective lenses with the highest precision are imposed by asphericity, large diameters and single-micron tolerances. These often require additional pre- and post-processing to make efficient use of the alignment turning technology in mid- to large-scale production. A solution is provided by Trioptics through the integration of smart measurement techniques and turning technology in its alignment turning machines.

Buß discussed the benefits and limitations of the alignment turning process, comparing the chuck-based method with CNC-based methods of alignment turning. With CNC-based alignment turning the optical axis does not have to be aligned with the spindle axis of the turning machine, as the optical metrology is used to correct for the off-axis orientation during turning. To conclude, Buß presented specific results and gave suggestions for individual applications. In a forthcoming issue of Mikroniek, CNC-based alignment turning will be presented in more detail.

6

Render of the adaptive secondary mirror of the NASA Infrared Telescope Facility, located at Mauna Kea, Hawaii. (Image: TNO)

Gradient-index optics

Another innovative manufacturing technology, based on a unique design capability, was presented by Andrew Boyd. He is the optical design capability lead at Qioptiq St Asaph, the UK-based defence and aerospace optics subsidiary of US photonics company Excelitas Technologies. Boyd has performed extensive research into the optical design of gradient-index (GRIN) optical systems. GRIN optics have a spatially varying refractive index, which for example can cause light rays to follow a curved trajectory, produce curved wavefronts or enable lenses with flat surfaces.

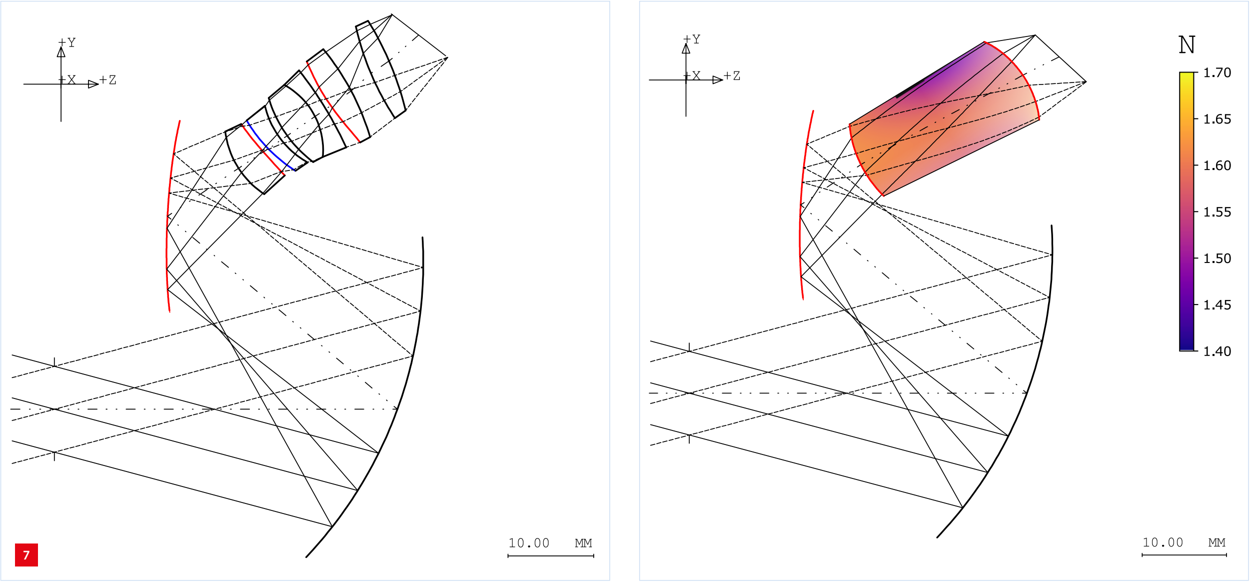
Boyd dwelled upon the various benefits GRIN optics have to offer when compared to conventional optics. For example, continuous optical systems can be designed to replace multi-element lens systems, thus at least reducing the number of lenses required for a complex optical system and hence facilitating its assembly. GRIN optics can also be designed to offer intrinsic chromatic aberration correction or to replace harmful materials in multispectral infrared optics.

Over the years, GRIN optics have evolved from radially and axially symmetric systems to freeform optics consisting of multi-material GRIN components of arbitrary distribution. They can be produced from glass or polymer materials, e.g. by diffusion or additive manufacturing (inkjet printing).

To conclude, Boyd gave a brief overview of the main GRIN challenges, in design, manufacturing, metrology, quality control and environmental robustness. One of the issues is degradation of optical performance, caused by thermo-mechanical stress due to the spatially varying CTE (coefficient of thermal expansion). In a forthcoming issue of Mikroniek, these challenges will be discussed in more detail.

Medical devices

And then for something completely different, the focus briefly shifted to medical technology. In line with the general trend, the field of pathology, including structural and molecular analysis, is transforming from analogue to digital. This calls for mechanisation and automation of visual and manual functions previously performed by human operators. System design of the new digital medical devices not only involves optical and mechatronic design, but also advanced image processing as well as significant effort for quality assurance including tolerancing, calibration and regulatory aspects.



7

On the left, a multi-element lens system for a head-mounted display optic, as compared to the corresponding gradient-index optical system on the right, where the colour coding represents the index variation.

Michiel van Beek, senior group lead physics & optics at Sioux Technologies in Eindhoven, presented the case of the XYALL Tissector HT as an example of Sioux's holistic approach of system design of optomechatronic medical devices. He focused on aspects that were relevant for the multidisciplinary design and realisation of the XYALL system for automated tissue dissection. Among the tools that Sioux employed for this system design were its proprietary Supermodels, SAXCS and Holodeck platforms.

Supermodels is a platform for visual state modelling and automatic code generation. It provides visual models in a design language understood by engineers from different backgrounds. Combined with the SAXCS platform for advanced motion control and the CAD drawings of the various modules, it enables the creation of a digital twin in Holodeck. The generic visual design languages of Supermodels and Holodeck foster interdisciplinary knowledge sharing and collaboration, enabling early alignment with the customer and feedback loops (reviews) that play a critical role in holistic systems engineering.

8

The XYALL Tissector HT for automated tissue dissection.

In a forthcoming issue of Mikroniek, the system design will be presented in more technical detail.

Photonics assembly

To conclude the symposium, Gordon Saunders, process development engineer at Aixemtec, located in Aachen (Germany), talked about the challenges in photonics assembly. For this, Aixemtec has developed a highly flexible machine platform and control software. Saunders presented the case of the automated attachment of single fibres and fibre arrays to PICs (photonic integrated circuits) for test or assembly purposes, which require high precision of fibre-to-waveguide alignment down to submicron level. Coupled with a broad component and product spectrum, this results in a high complexity for test and assembly machines.

With this, Saunders once again underlined a common thread of the presentations at the successful DSPE Optomechatronics Symposium 2023: challenging system requirements that have been translated into complex optomechatronics solutions.

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