From AO to EUVL

From 31 May to 4 June 2010, the euspen 10th International Conference was held at Delft University of Technology, the Netherlands. The conference attracted over 400 participants and some 45 exhibitors from Europe, America and Asia. Keynotes were concerned with Extreme Ultra Violet Lithography (EUVL) and Adaptive Optics (AO). Besides, a large number of oral and poster presentations was delivered on the latest advances and market developments in precision processes and manufacturing, as well as fabrication, metrology, sensing applications and cutting-edge materials. The programme also included pre-conference tutorials, an international football match, a commercial session and exhibition, a conference dinner, and technical tours.

• *Raymond Knaapen and Hans van Eerden* •

The euspen 10th International Conference in the Aula congress centre (Figure 1) in Delft, the Netherlands, attracted over 400 participants. Naturally, the Dutch showed a strong performance with over 100 registrated participants, but Japan scored a remarkable second place with nearly 50 attendants. Euspen's strong links with industry were underlined by the number of 45 exhibitors, the majority comprising companies in the fields of precision engineering and nanotechnology.

Figure 1. The Aula congress centre on the Delft University of Technology campus.

Figure 1. Euspen president Dr Henny Spaan opened the euspen 10th International Conference in Delft. (Photo: Nicole Minneboo)

After pre-conference tutorials and a welcome barbeque in Delft Botanical Gardens on Monday, the conference was officially opened on Tuesday 1 June by euspen president Dr Henny Spaan, who elaborated on the history of Delft, the (scientific) 'Golden Age' of the Netherlands (Huygens, Van Leeuwenhoek, etc.), and 400 years of Dutch relations with Japan and with (the US of) America; see Figure 2. Following Dr Spaan's opening words, the participants were officially welcomed by vice president Karel Luyben of Delft University of Technology, a university with some 16,000 students and 4,500 employees and host of this year's euspen conference.

First keynote: EUVL

On conference day 1, the first keynote was delivered by Dr Jos Benschop, vice president Research of ASML, the world market leader in lithography machines, based in Veldhoven, the Netherlands. In his keynote on "Extreme Ultra Violet Lithography", Benschop discussed the EUVL roadmap, status and future. EUVL, using 13.5 nm wavelength, all-reflective optics and a vacuum environment, is a leading candidate to succeed immersion 193-nm lithography to print features of 22 nm and below. Several major programmes worldwide have matured this technology since the late 1980s. In 2006, ASML shipped its first two alpha demo tools, to Imec in Leuven (Belgium) and CSNE in Albany (New York, USA), respectively. Currently, early production tools are being assembled.

Benschop explained why EUVL is used to enable Moore's Law in a cost-effective way, presented some results obtained with the alpha demo tools, as well as an update of critical tool-related issues, including the EUV source, and the status of early production tool integration; see Figure 3. The EUVL roadmap, according to ASML's vice president

Euspen

Euspen is a European network organization devoted to promoting contacts between industry and research institutes in the areas of precision engineering and nanotechnology. Euspen was founded in 1999 with support from the European Commission's 'Competitive and Sustainable Growth'-programme. Now, euspen is an independent, not-for-profit organization counting over 550 individual members and 90 corporate members. Euspen collaborates with fellow organisations ASPE in the USA and JSPE in Japan; jointly they publish the Precision Engineering journal. Euspen headquarters is at the Cranfield University campus in the UK. Euspen's focus is on ultra/nano-precision manufacturing; design and build of ultra-precision machine systems; and characterization (metrology systems, instruments and techniques).
One of the highlights of euspen's activities is the annual conference, which was held this year in Delft.
Previous conferences were in Bremen (1999), Kopenhagen (2000), Eindhoven (2002), Glasgow (2004), Montpellier (2005), Baden (2006), Bremen (2007), Zürich (2008) and San Sebastian (2009). The next, eleventh euspen conference will be held on 23-26 May 2011 in Cernobbio, near Lake Como, Italy.

www.delft2010.euspen.eu
www.euspen.eu

Figure 3. The NXE 3100, ASML's EUVL pre-production tool.

Research, includes higher numerical aperture lenses, more powerful sources, and improved transmission and mechatronics, to achieve a resolution of 18 nm or better and a 150 wafers per hour productivity in 2013 – this productivity being comparable to state-of-the-art immersion lithography.

Patterning

Following the keynote, the first session of the day was devoted to "Emerging Patterning Technologies & Methods". S.V. Sreenivasan of Molecular Imprints (Austin, Texas, USA) talked about "UV Nanoimprint Lithography". Nanoimprint lithography techniques, he stated, possess remarkable replication capability with a resolution below 5 nm. In recent years, a form of UV imprint lithography knows as Jet and Flash Imprint Lithography (J-FIL) has seen significant progress in mask infrastructure, materials, critical dimension control, defect reduction, overlay, and throughput. This progress has opened up emerging nanomanufacturing applications for J-FIL, such as patterned media for hard disk drives, and as a complement to photolithography at sub-25nm half-pitch nodes for semiconductor ICs.

Sreenivasan presented the current state of J-FIL technology in applications such as terabit-density magnetic storage and advanced solid-state memory. He discussed both stepper tools as well as whole-substrate patterning tools developed using the J-FIL technology. Finally, he touched upon emerging applications in the biomedical and energy sectors.

Next, J.S. Faber of FEI Company (Eindhoven, the Netherlands) discussed "Novel FIB-SEM Based Methods for Nano-Patterning and Nano-Prototyping". Nano-patterning with a focussed ion or electron beam offers local deposition or removal of material in a process that is relatively slow, but has high spatial resolution, at the nanometer scale. Another advantage, as compared to optical lithography, is that no expensive masks are needed and that instanteneous changes to the design are allowed, giving a high turnover speed and offering a promising 3D nano-prototyping solution. Faber elaborated on the use of dual-beam FIB/SEM systems (Focussed Ion Beam/ Scanning Electron Microscope) for creating 3D nano-structures. Applications include, for example, photonics structures.

Figure 4. Snapshot of the audience attending one of the sessions. (Photo: Nicole Minneboo)

The final presentation in the "Patterning" session was delivered by P. Möller of RepliSaurus (Kista, Sweden), on "A High Precision System for Aligned Metal Printing on Wafers Using ECPR – Electro Chemical Pattern Replication". This new wafer metallization method, ECPR, is capable of printing patterned metal layers on 200- and 300-mm wafers. It combines the precision and resolution of advanced lithography with the efficiency of electrochemical deposition, by integrating the entire metallization sequence for top metal layers used in IC applications into one single electrochemical metal printing step, so Möller claimed. He presented a novel system architecture for a high-precision tool designed to perform aligned metal printing using the ECPR method. The alignment performance was shown to be better than 250 nm, as measured on 200-mm wafers.

Commercial session

The first conference day also comprised sessions on "Nano & Micro Metrology" and on "Ultra Precision Machines & Control". As an intermezzo, a commercial session was held in which some twenty companies seized the opportunity to present themselves and their product(s). Among the presenters were Moore Nanotech, IBS Precision Engineering, SIOS, MI-Partners, Klocke Nanotechnik, Cedrat, Attocube, Innophysics and Cranfield Precision. The day was concluded with a sporting event, a football match between a Dutch team and the International All Stars. In the game, the competitors lacked their professional precision, but they compensated with enthusiasm.

Second keynote: AO

The second conference day was opened by Prof. Rob Munnig Schmidt from Delft University of Technology with a keynote on "Adaptive Optics – Current International Status". In optics, shape and index of refraction of optical elements determine system properties, and disturbances in shape and index can therefore deteriorate optical performance. Well-known disturbances are thermal effects within optical components as well as atmospheric index variations. These disturbances can be corrected for by adapting shape or index of refraction of optical elements, the process of which is called Adaptive Optics (AO). The increasing demand for precision requires improvements in both hardware and software algorithms. In the keynote, some examples were presented with an explanation of the principles, as well as challenges and possible solutions.

The first example concerned terrestrial telescopes, the size of which is increasing for improved light-gathering capability as well as improved resolution. The European Extremely Large Telescope (E-ELT) of ESO (European Southern Observatory), which is planned to become operational in 2018, will have a main mirror diameter of 42 meters, which can only be realized by dividing it in 1,000 segments. Each segment is individually mounted and controlled to obtain the desired shape of the combined mirror. Additional to this shape correction, corrections must be made to compensate for atmospheric disturbance. Due to variations of atmospheric composition and density, the 'wavefront' of the incoming light is disturbed. This wavefront disturbance can be compensated for using feedback control of the mirror segments using, for example, a Shack-Hartmann wavefront sensor.

The number of actuators to be controlled in the E-ELT will be much more than 5,000, which poses an enormous constraint on control hardware and algorithms. A nice example of a very fast hardware configuration that can be stacked to large correctable mirrors had been presented on conference day 1 by R.F.M.M. Hamelinck (TNO Science and Industry): "Real-time Compensation of Dynamic Thermally Induced Optical Aberrations by a Deformable Mirror Based on Reluctance Actuators"; see Figure 5.

Another AO application can be found in lithographic projection systems for IC manufacturing with imaging resolution below 30 nm and image conformity better than

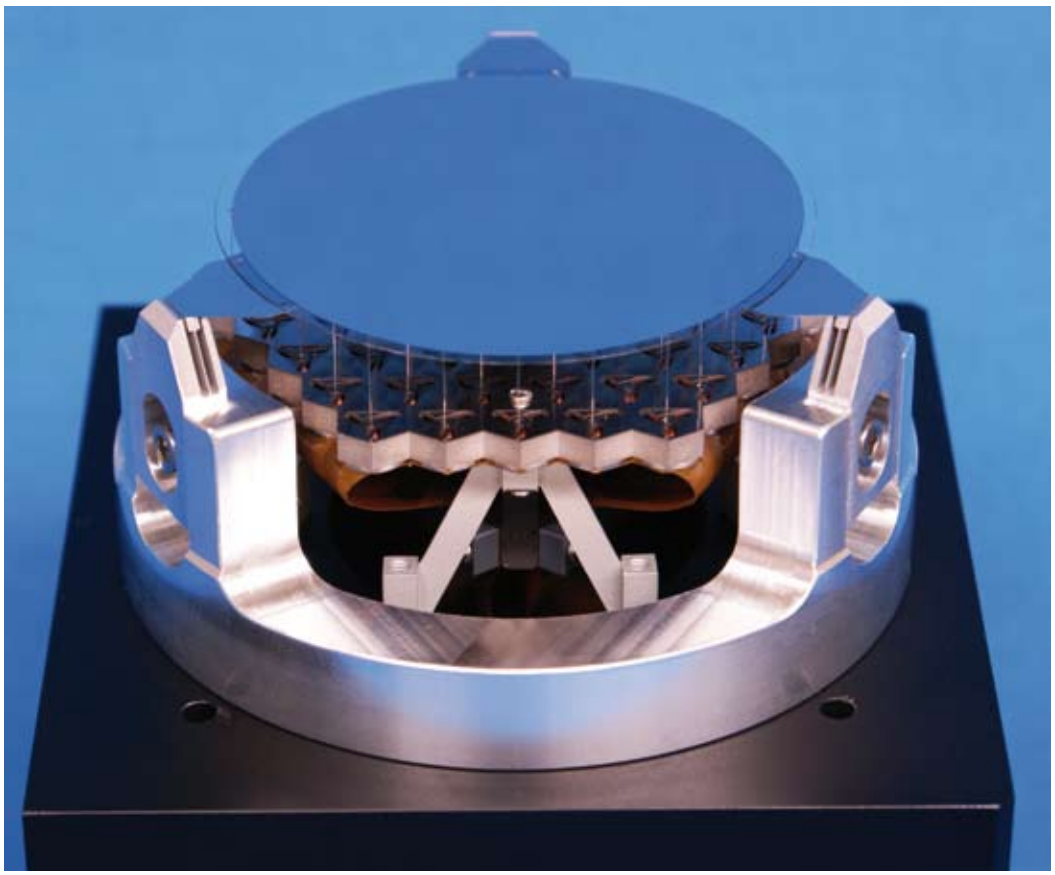

Figure 5. A deformable mirror comprising 61 actuators.

10 nm, although there is no long air path in lithography as compared to astronomy. In this case, the optical elements themselves are causing problems due to energy that is absorbed from incoming light. Additionally, other dissipative sources such as electronics and actuators impact optical performance. In EUVL, where the optical system operates in vacuum, similar AO approaches as used in telescopes are expected to be introduced. However, requirements on speed and accuracy are very different. Thermal effects are generally not as fast as atmospheric fluctuations, but accuracy levels in EUVL systems require surface accuracies down to 100 pm, which is a factor of 30 better than for the telescope example described above. This will provide the basis for a very interesting field of future research.

High Precision Mechatronics

Following this interesting keynote, J. Wesselingh, also from Delft University of Technology, opened the "High Precision Mechatronics" session with his presentation on "Contactless 6 DoF Planar Positioning System Utilizing an Active Air Film". A thin air film is used to directly position flat substrates, which can be used for production of, for example, integrated circuits, flat-panel displays and solar cells. Since no positioning stage is needed, the moving mass is reduced by two or three orders of magnitude compared to conventional positioning systems. Furthermore, the absence of mechanical contact reduces the chance of contamination and damage.

Then, S. Spiewak (University of Calgary, Canada) presented a paper on "Acceleration Based Evaluation of Motion Errors in a High Performance Translational Exciter". Position measurement errors that occur by double integration of acceleration are reduced by filtering of non-linear acceleration errors before integration. S.L. Paalvast (Delft University of Technology) talked about "Thermal Hard Disk Drive Micro Actuator for Improved Tracking Performance". His fine-stage thermal actuator enables increase in storage capacity of future drives by improving tracking accuracy. The design, fabrication and characterization of a thermal micro actuator for a hard disk drive were discussed by Paalvast.

The last presentation in this session was given by S. Henein (CSEM Centre Suisse d'Electronique et de Microtechnique, Neuchâtel, Switzerland): "Flexure-based Pointing Mechanism with Sub-microradian Resolution for the Laser Interferometer Space Antenna". Henein showed how a mirror mounted using flexures is actuated by two redundant linear piezo actuators in steps of 0.14 μrad up to a maximum stroke of 412 μrad. The mirror will compensate an out-of-plane point-ahead angle between three satellites flying 5 million kilometers apart.

Conference dinner

Other sessions on day 2 were on "Ultra-precision Manufacturing & Assembly Processes" and "Nano and Micro Metrology". The conference programme of this day was concluded by euspen presentations on the Co-Nanomet research programme activities, the forthcoming 11th conference, and the euspen Review by Prof. Pat McKeown. In the evening, the conference dinner was held in the Netherlands' smallest city, Madurodam. First, the conference participants could visit famous Dutch (architectural) highlights on a scale of 1:25. Then, they could seize the opportunity to make new business and social contacts and strengthen existing ones, while enjoying a delicious dinner.

Japan

The morning of the third conference day was dedicated to state-of-the-art developments in precision engineering & nanotechnology in Japan and the USA. The first session focused on Japan and was started by N. Moronuki (Tokyo Metropolitan University) on "Fabrication of Micro/nano-structures by Using Self Organizing Process". He explained about a self-organizing process of fine particles to produce micro- and nano-structures at lower costs compared to traditional top-down processes. Self-organizing behaviour is achieved by phenomena like surface tension in fluids, capillary forces and fluid evaporation.

W. Gao (Tohoku University, Sendai) presented a paper on "Micro and Nano Measurement Instruments". He described innovative optical sensors such as a grating-based encoder that can measure displacement along the encoder scale as well as perpendicular to the same encoder scale, by using positive and negative first diffraction orders in combination with a reference grating. Gao also reported about the same concept as used to perform 3D measurements.

The third and final Japanese presentation was by H. Yoshioka (Tokyo University of Technology), about "A Newly Developed Ultraprecision Machine Tool 'ANGEL'". ANGEL is a nano-pattern generator with a work area of 180 x 180 x 70 mm^3. The tool mechanism is fully suspended by air bearings and voice-coil actuator to prevent non-linear effects such as friction. Machining resolution of better than 50 nm has been shown in tests.

USA

The second morning session was about state-of-the-art developments in the USA. The first paper in this session, "Precision Equipment and Tools that Enable Practical Probe-based Nanomanufacturing" was presented by S.K. Saha (MIT, Cambridge, Massachusetts). He discussed process modeling for designing probe-based nanomanufacturing stations. Additionally, he addressed the design of a pilot probe-based manufacturing station which has a 6-axis nanopositioner moving the tool, kinematic couplings for workpiece alignment and a transfer line enabling sealed enclosure and work handling.

J.S. Taylor (Lawrence Livermore National Laboratory, Livermore, California) talked about "Precision Engineering within the National Ignition Campaign". He discussed several key precision engineering applications within the National Ignition Facility (NIF) at LLNL. This facility, which contains the world's largest and most energetic laser experimental system, contains a 192-beam, 1.8-MegaJoule, 500-TeraWatt, ultraviolet laser system that is used for ignition experiments. As Taylor explained, there are many precision engineering challenges in the constructing and manufacturing of the NIF system with its 75,000 optical elements.

The last presentation in the 'USA session' was given by V.K Badami of Zygo Corporation, Middlefield, Connecticut, on "High-accuracy short range displacement metrology". He gave an overview of precision measurement technologies of sub-millimeter displacement. Subsequently, he focused on a fiber-based, multi-channel interferometric sensor system that combines high-accuracy displacement measurement capability with absolute distance measurement over a range of 500 µm, with a displacement measurement uncertainty of 4 ppm.

Last session

In the afternoon, after a session on "Important / Novel Advances in Precision Engineering & Nanotechnologies", the last conference session was started. This second session on "Ultra-precision Manufacturing & Assembly Processes" was opened by G.P.H. Gubbels (TNO Science & Industry; see Figure 6) with a presentation on "Fabrication of Strongly Curved Aspheric Silicon Carbide Mirrors". His application was concerned with the GAIA spacecraft, which includes a Basic Angle Monitoring Opto-mechanical

Figure 6. TNO Science and Industry was one of the 45 (commercial) exhibitors at the euspen conference in Delft. TNO also contributed several presentations.

Assembly. In this assembly, two telescopes will measure the position of the stars with accuracy much higher than ever done before. This performance requires, as discussed by Gubbels, that the two telescopes have sub-µrad stability with respect to each other, and the telescope's off-axis parabolic mirrors have to be polished to a high shape accuracy of better than 25 nm rms.

In his presentation on "Lessons from Two Years of Building Fusion Ignition Targets with the Precision Robotic Assembly Machine", R.C. Montesanti of LLNL gave an overview of the design and function of a precision robotic assembly machine that is to manufacture the small and intricate laser-driven fusion ignition targets, which are to be used in the NIF (see above).

The last presentation, "Laser Cutting of Thin Gold Foils", was given by R. Meess (Physikalisch-Technische Bundesanstalt PTB, Braunschweig, Germany). He discussed a method for fabrication of gold foil absorber arrays of 50 um thickness by laser ablation. These foils are used in a device for the in-situ measurement of kinetic energy of micrometer-sized particles in space. Production challenges were found in thermal distortion, contamination and fixation, and handling of the gold foils.

Technical tours

The euspen 2010 International Conference was officially closed by Prof. Paul Shore of Cranfield University, UK. Prof. Shore is euspen's vice president and will succeed Dr Henny Spaan of IBS Precision Engineering as euspen president in 2011. On Friday, conference participants were offered the choice between two interesting technical tours in the Delft area. One option was the European Space Research and Technology Centre (ESTEC) in Noordwijk, the largest site and technical heart of the European Space Agency (ESA). The other tour was to the independent research organization, TNO Science and Industry, and to the Dutch metrology institute, VSL, both in Delft.

Authors' note

Raymond Knaapen works as a system architect in the Precision Motion Systems department of TNO Science and Industry in Eindhoven, the Netherlands. Hans van Eerden is editor of Mikroniek.