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- THEME: GREEN PRECISION
- MANUFACTURING TECHNIQUES FOR CO_2-CAPTURING MATERIALS PRODUCTION
- NEXT LEVEL IN LASER GUIDE STAR CREATION
- PRECISION FAIR 2022 REPORT – GROWING HIGH-TECH AMBITIONS

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The cover illustration (source: Shutterstock) depicts the contribution (precision) engineering can make to solving the energy and climate-change challenges. See the articles on the pages 5 ff, 8 ff, and 14 ff.

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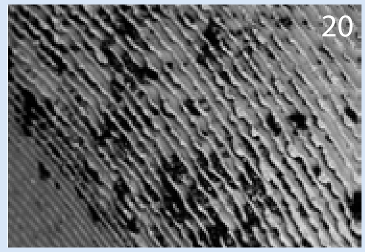

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CLIMATE CHANGE SELLS HORRIBLY!

We all know it: we need to fly less, take the bike more often, eat less meat and turn down the thermostat in our homes... We know we should do it, but most of us take only tiny steps in the right direction, if any at all. Why is it so difficult to change for the sake of our planet?

Climate change sells horribly: if you do everything 'wrong', there are no direct consequences for you personally and if you do everything 'right', there is no direct reward either, only your own morals that might be slightly satisfied. Every political party knows that we need to act, but if they include tax increases for the 'finer things in life' into their political agenda, they will lose many votes.

Earlier this year, I attended a congress on the energy transition at the PSV stadium in Eindhoven (NL). Heleen de Coninck, Professor of Socio-Technical Innovation and Climate Change at Eindhoven University of Technology, had the opening statement and her conclusion was clear: the window is rapidly closing, but we might still pull it off if we achieve a series of daunting targets on time. The energy in the room was tangible; the challenge is huge, but we'll step up!

The next presentation was about a centralised heat pump project in a district in Den Bosch (NL). Technically very promising. The questions from the audience at the end, however, revealed a couple of weaknesses: despite a return-on-investment of just a few years, only about 20% of all households could afford to participate, the project would take 12 years to complete (far exceeding all deadlines that De Coninck had mentioned), and moreover, the project might not continue at all because the district is a protected city view...

Are we really going to allow such a great initiative to fail due to reasons like that?! I don't know about the rest of the audience, but I personally felt a bit defeated. Are we going to stand around in a circle, pointing to each other that they are the reason we cannot move forward?

Of course not! We are engineers and we solve problems. The number of technical solutions being developed for the energy transition is insane and seems to increase by the day. Electric vehicles, PV and heat pumps in more and more homes, development of energy-storage solutions (both electrical and thermal, both for home use and on industrial scale), green hydrogen and synthetic fuels. As ETS (Emissions Trading System) exemptions are coming to an end, we are also seeing the big players like Tata steel coming in motion.

So, I think mankind will be able to come up with excellent new technologies to face the massive challenge of climate change. If you ask me, it will not depend on technology whether or not we will succeed at turning things around on time, but on policy and changing the behaviour of all of us.

The world needs a global PR campaign to 'sell' climate change. Make it attractive to do the 'right thing'. Not just because the gas bill is so high, but because it matters and because it cannot wait!

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BYE BYE PRIMARY BATTERIES, HELLO ENERGY HARVESTERS

Harvesting vibration energy from the environment and storing it in a capacitor or a rechargeable battery provides a solution for powering devices such as sensors in an Internet-of-Things network. Kinergizer develops state-of-the-art motion energy harvesting solutions that ensure uninterrupted operation of these low-power devices, making primary batteries unnecessary. Predictive maintenance is one of the promising applications.

ERIK VAN DE WETERING

Introduction

Over the last couple of years, large steps have been taken in implementing sustainable and green alternatives for energy production. Think of renewable energy solutions such as wind turbines, solar farms, hydropower plants and tidal energy. These technologies are all examples of energy harvesting: extracting a part of the ambient energy and converting it into electrical energy. For instance, in a hydro-power plant, part of the kinetic energy of the water is converted into useful electrical energy, while a photovoltaic panel converts a part of the radiant energy of the incident light.

The previous examples are all on the megawatt scale. On the milliwatt scale, however, innovations for green energy can be made as well. These are based on another type of ambient energy that has a lot of undiscovered potential: vibration energy harvesting. Although vibration energy harvesting does not have the same impact in terms of generated electrical power as the examples mentioned above, it can play an instrumental role in the development of key Internet-of-Things (IoT) applications, which will impact everyone on a daily basis.

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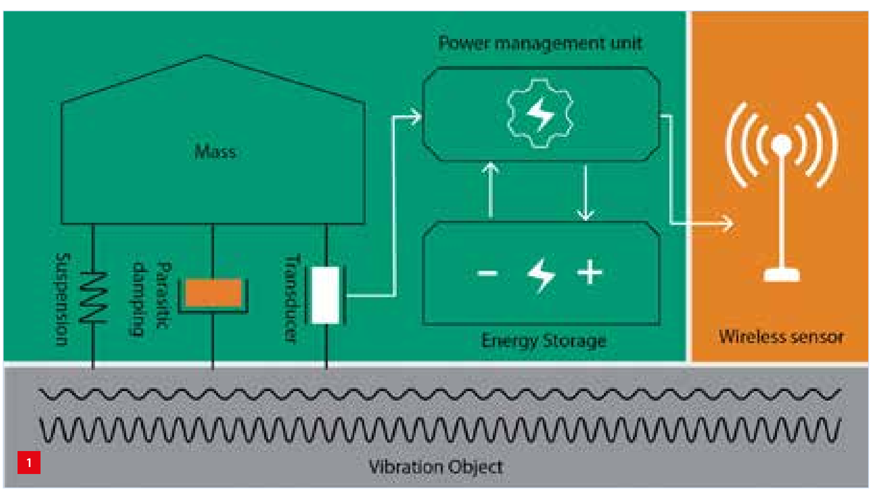
For example, by implementing vibration energy harvesters, the lifetime of wireless sensor networks in vibration-heavy environments can be greatly extended by eliminating the need of early replacement of their batteries. This saves costs and makes wireless sensor networks a more sustainable solution. But how can a vibration energy harvester enable such a benefit?



1 *Schematic representation of a vibration energy harvester unit.*

Basic working principle

With vibration energy harvesters, a part of the energy present in ambient vibrations is scavenged and transduced into electrical energy. Figure 1 shows the basic working principle of a vibration energy harvester (for confidentiality reasons, no more details can be shared). A vibrating object to which the harvester has been mounted transfers energy to the energy harvester. A mass suspended in the harvester then starts to build up kinetic energy. Part of the energy of the mass is inevitably dissipated into some parasitic damping, which is always present. Another part of the kinetic energy is intentionally extracted from the mass by a transducer. This component transduces the mechanical kinetic energy into electrical energy. The power management unit then makes sure that the energy storage, which can be a supercapacitor or a rechargeable battery, can be charged and that a sensor unit can draw power from it.

Predictive maintenance

An interesting use case for energy harvesting devices is predictive maintenance. No machine will last forever. At a certain point, parts have reached their end of life and failure

Application example of Kinergizer's energy-harvesting solution.
(a) The Hiper-D energy harvester (ø35 mm, 75 mm height, 90 g mass, 1-5 mW power).
(b) Mounted to a train bogie axle box.

of the machine will occur. Of course, nowadays the lifetime of components can be accurately predicted, but a premature failure of components does still happen. The consequences of such failure can be severe and, in some cases, can even endanger lives.

Mitigation of machine failure is therefore of great importance. Several known methods exist, the oldest of which being reactive maintenance: when a part fails, it is replaced. Of course, this does not prevent machine failure and is therefore not very effective. A better version is preventive maintenance. Parts are checked periodically and replaced based on a schedule. Using this maintenance scheme, parts could be replaced too early, increasing waste and costs. Next to that, periodical checks rapidly become expensive due to the involved man hours and potential machine downtime.

This has led to the principle of predictive maintenance: using wireless sensor nodes to track changes in e.g. temperature and vibrations, the health of a machine can be monitored. An accurate prediction of the required service interval can then be made, saving costs and minimising downtime. Advanced sensors do not only determine that a failure is imminent, but can also pinpoint the component that is close to failure.

The sensors used are mainly powered by primary batteries and just like machines, primary batteries do not last forever. Depending on the capacity of the battery, the number of variables to process and the measurement interval, the power consumption of the sensor node can quickly become too large. The batteries are then likely to be depleted before the service life of the component that the sensor is meant to monitor. As a result, the battery must be replaced to continue the monitoring and this is often a costly process. It is important to note that, although batteries might not be expensive, replacing them actually is. The batteries are often placed together with the sensor in a sealed package, making it infeasible to replace the battery only; the entire unit must be replaced. The sensor nodes are also often located at places that are hard to reach, which leads to more downtime of the equipment and more required labour for replacement. Therefore, although batteries are not expensive, the additional factors escalate the operational costs quite rapidly. Taking all this into consideration, predictive maintenance fails to serve its purpose in this way.

Fortunately, this is a problem that can be solved. As vibrations and reduced service life of components often go hand in hand, vibration energy harvesting forms a perfect solution to this issue, by utilising an energy harvester and a rechargeable battery to power the sensor. A good example where this principle can be applied is the railway sector.

Railway sector

Railway transport is deemed to be one of the greenest ways of transport and is on its way to achieving net-zero carbon emission. To make travelling by train appealing to the traveller, train arrival times must be accurate and precise, so the system needs to be reliable with minimum downtime. The high reliability of the train bogies (chassis) plays an important part in achieving that goal.

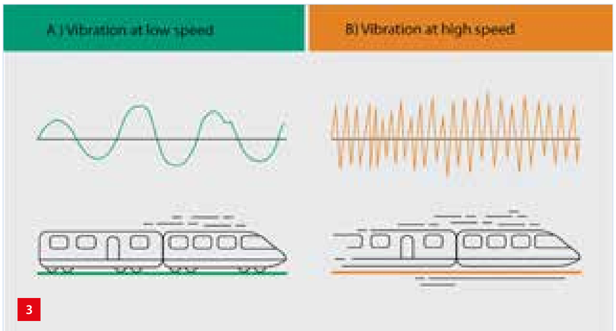
Currently, wireless sensor nodes powered by primary batteries are already being used to monitor the health of the bogie. However, the lifetime of those batteries is a limiting factor to the sensor. Either the power consumption of the sensor must be budgeted, limiting its capabilities, or the sensor's lifetime is only limited to a few years, increasing the operating costs by an imminent need for early sensor replacement.

Kinergizer aims to provide an energy harvester solution that increases the power budget of the mounted sensor while ensuring that the sensor can operate reliably for at least ten years or more. Figure 2 shows an energy harvester mounted to a train bogie axle box.

Train bogies are subject to a harsh vibration environment with large vibration amplitudes. Depending on the speed and other conditions of the train, large variations in amplitude and frequency content can be expected. To guarantee a reliable output power, the energy harvester must not be too dependent on a specific input vibration: it needs to be robust to varying input conditions.

Kinergizer's energy harvester solutions are therefore engineered in such a way that they supply a sufficient amount of power to the sensor for all foreseeable vibration conditions. Figure 3 illustrates this concept: whether the signal's frequency or amplitude is low or high, or whether the signal is wideband, ideally the energy harvester can scavenge a sufficient amount of energy in all cases.

To power a wireless sensor node, energy harvesters need to deliver a fair amount of power, sometimes up to several tens of milliwatts. Size greatly favours the output power, yet is often limited due to geometrical constraints of the application. So, to ensure a high power density, meaning high power from a small volume, components must be tightly packed. The precision of components must therefore be high and must be precisely assembled to prevent moving parts from rubbing against each other. At the same time, those closely-packed moving parts must be resistant to acceleration levels that could exceed several tens of g's and must be able to resist shocks that can exceed 100 g. To ensure that the energy harvesters can deliver power in such an environment, the products are thoroughly lab-tested



Kinergizer's energy harvesters are designed to extract power from a wide variety of input vibrations.

to experimentally validate the shock resistance. Additionally, to meet railway standards, 25 years of service life is simulated in an accelerated life test, in combination with an operational temperature range of –40 °C to +85 °C. In this way, the energy harvester is certified to reliably power the wireless sensor nodes on the train.

The future of wireless sensing is green

Utilising a wireless sensor network brings several merits. The performance of machines and their components or static structures such as bridges can be continuously monitored. This enables the operator to predict service intervals accurately and helps to prevent structural failure of components. The catch is that when a sensor node is installed, it should be an install-and-forget solution. Furthermore, due to the growing market in wireless sensor networks, it is not desirable to make this market a battery-devouring enterprise.

The continuous effort of lowering the power consumption of chips has enabled energy harvesting to become a feasible alternative to primary batteries as a power supply, creating the possibility of having green and sustainable wireless sensor networks. Therefore, we at Kinergizer believe that the future of wireless sensing in vibrating environments is to those who harvest energy.

MEASURING A FUSION PLASMA WITH CAMERAS

One of the biggest challenges of operating a nuclear-fusion reactor is preventing the scorching heat from damaging the reactor wall. A Swiss-Dutch team is heavily engaged in investigating solutions to this challenge. They use camera images to measure how the reactor exhaust is behaving, and use this information to keep the reactor wall alive.

MATTHIJS VAN BERKEL, JESSE KOENDERS AND ARTUR PEREK

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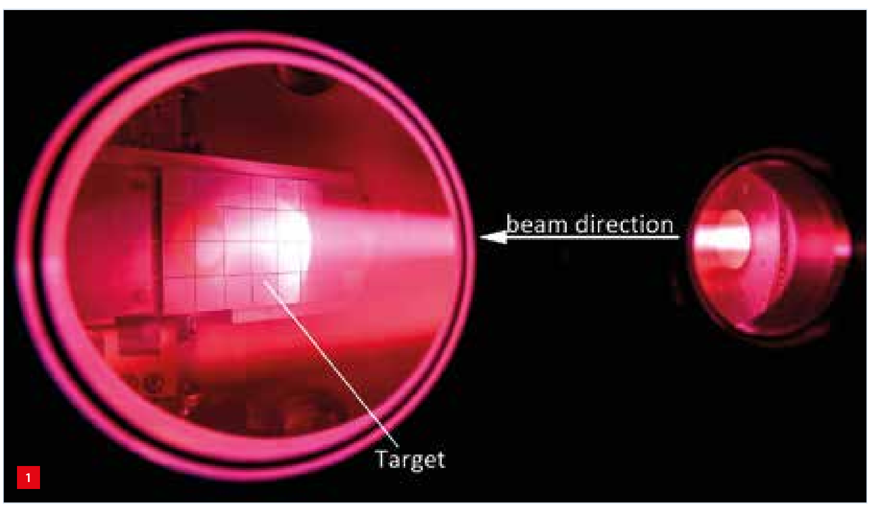
Introduction

When two hydrogen isotopes are fused together, a huge amount of energy is released. In order to harvest this energy, a nuclear-fusion reactor design called a tokamak has been under heavy research for the last 70 years. In such a reactor, hydrogen isotopes are magnetically confined in the form of a plasma, creating the right conditions for their fusion.

Unlike nuclear fission, fusion produces only short-lived radioactive products, making it a very safe and reliable energy source. However, important steps still need to be taken in this 21st century to achieve commercial fusion. Next to creating and sustaining energy-producing fusion reactions, an important challenge is the exhaust of the resulting helium byproduct and the energy it contains.

At DIFFER, we research and develop the technology to analyse and safely control this exhaust. For example, DIFFER hosts one of the largest linear plasma generators in the world, called MAGNUM-PSI [1]. This machine is used to test wall materials for future fusion reactors, such as ITER, which is presently being built in France. Figure 1 shows a snapshot of wall material exposure to a hot plasma during an experiment at DIFFER.



A look inside the linear plasma generator MAGNUM-PSI. The highly energetic plasma beam enters the chamber from the right, and hits the wall material (or simply target) at the left. The target can be exposed to different conditions and loading, resulting in deformation, melting and recrystallisation.

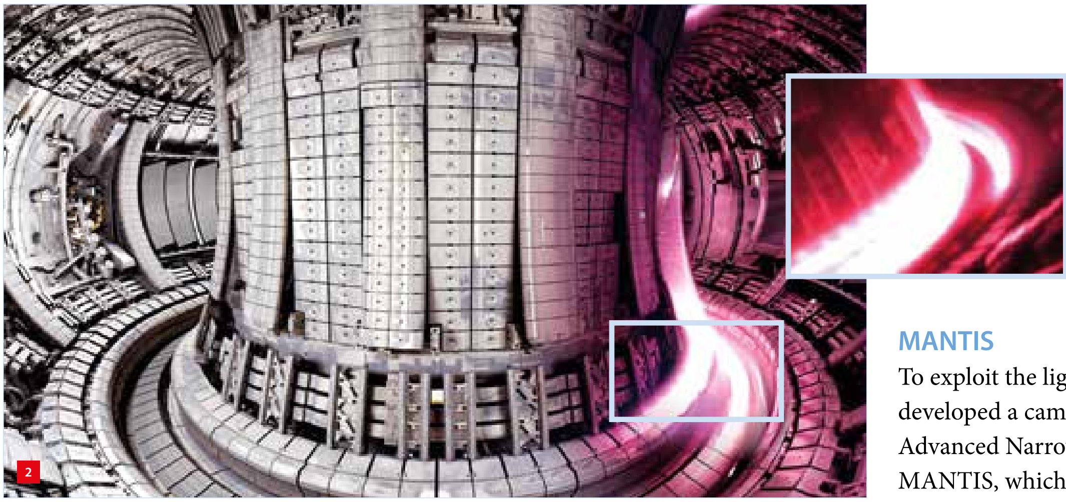
Moreover, DIFFER develops diagnostics for fusion reactors, to which the most recent addition is a tangential camera system. This camera system is called the Multispectral Advanced Narrowband Tokamak Imaging System or MANTIS [2] [3]. It is used for the analysis and feedback control of the plasma exhaust, exploiting the specific light emitted by the reactor exhaust plasma. So, why is this reactor exhaust so challenging?

The exhaust of a fusion reactor

The reaction of fusing the hydrogen isotopes deuterium and tritium (the reactor fuel) produces a neutron and a helium particle. The neutron is not charged, and will escape the magnetic fields used to confine the fuel, and hit the reactor wall. The main wall of the reactor is sufficiently protected by water cooling.

However, the helium byproduct and impurities contained in the core of the reactor are charged, and will therefore not escape the magnetic fields. But they do need to be exhausted in order to avoid choking the fusion process by diluting the plasma with fuel that has already reacted. Therefore, the magnetic configuration is designed to allow these burning products to be exhausted to a specific wall region on the bottom of the reactor. This specific wall region is known as the divertor, and must sustain a plasma flow containing helium particles.

The helium particles carry 1/5th of the energy produced in a fusion reaction, and must be safely exhausted. This means their energy must be dissipated to prevent damage of the divertor region. Two (or more) so-called 'divertor legs' are formed where the plasma is cooled before interacting with the wall. A continuous injection of neutral gas is required to control the level of mitigation in the divertor legs to protect the divertor area. Actively adjusting this injection (actuation) in real-time is done by a control system, which



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The Joint European Torus (JET) is the largest tokamak (type of fusion reactor) in the world, located in Oxfordshire, UK, with a plasma radius of 2.96 m, a volume of 79 m^3 and a magnetic field strength of 3.45 T [4]. On the left, the torus without plasma, and on the right, with plasma (pink haze). The zoom-in shows specifically the divertor region where the emitted light is brightest. (JET Image: EUROfusion)

requires millisecond-range observation of the relevant mitigation processes. Here is where light emitted by the plasma plays a key role.

Light emitted by the plasma

Inside the JET reactor (Figure 2), a fusion plasma emits light, in this case depicted in pink. This light is brightest near the wall elements at the bottom, in the vicinity of the divertor. The reason is that plasma only emits light at relatively low temperatures and such conditions are only attained at the periphery near the wall. This light is most intense near the divertor, where a lot of cooling plasma-wall interaction is taking place, making it an ideal diagnostic to analyse what is happening with the exhaust.

The idea is as follows: in the analysis of stars, their emitted light is used to determine age, distance and composition. For the plasma near the divertor, it is possible to use the intensity and spectral distribution of its emission to estimate temperature, density and reactions taking place. As most of the particles in the exhaust are hydrogen, in particular we analyse the relevant spectral content originating from the hydrogen atoms. This is known as Balmer lines, which originate from the hydrogen-plasma interaction, reflecting the (electron) temperature, density and formation of molecules when atoms and electrons cool down.

To perform this kind of analysis, we also need information from other atoms, such as helium. Figure 3 shows a few of these spectral lines, which correspond to different lines (wavelengths) in the visible spectrum, such as red (656.279 nm), ultraviolet (397.0075 nm), blue (434.0472 nm), aqua (486.135 nm) and violet (410.1734 nm). Similar spectral lines for helium can be identified, as Figure 3 shows. By now using filters, we can isolate certain atomic processes and analyse the edge plasma.

MANTIS

To exploit the light emitted from the plasma, we have developed a camera-based diagnostic: the Multispectral Advanced Narrowband Tokamak Imaging System, or MANTIS, which name is inspired by the high visual acuity and high resolution the eyes of mantis insects can achieve necessary to examine potential prey and hunt.

The main goal of this diagnostic is to analyse the exhaust plasma in the divertor with ten cameras (Figure 4), each looking at a specific emission line. This image is transformed to a 2D cross-section employing tomographic inversion techniques, and then analysed to interpret the physical quantities. These quantities are for example the electron temperature and density, but also more complex quantities, such as particle sources and sinks due to several atomic and plasma-molecule interactions.

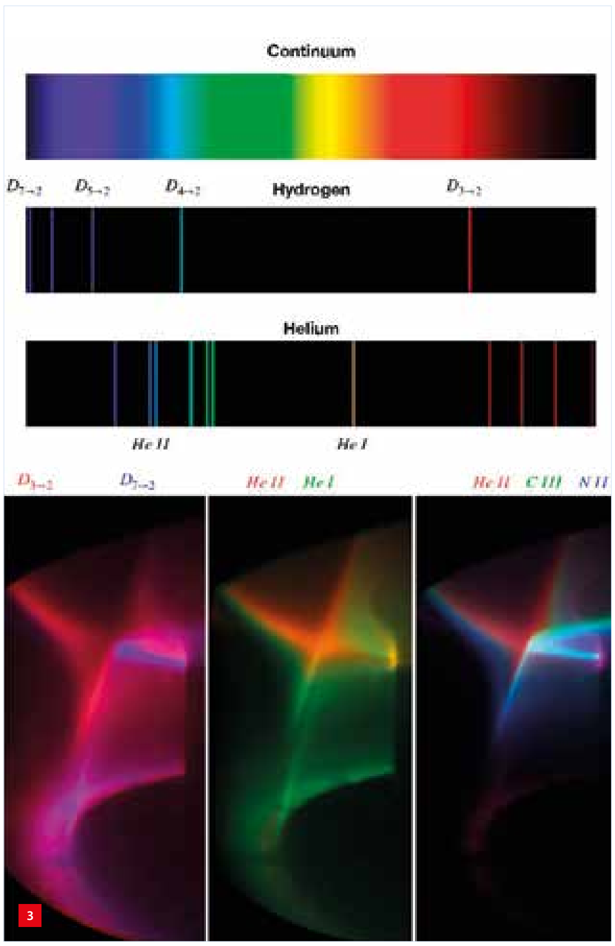
The design, construction and calibration of such a system presents considerable precision engineering challenges. First, the concave mirrors reflecting incoming light must be held in machined slots with micrometer precision to maintain the image quality. The light is reflected to the other side (see Figure 5), where ultra-narrow bandpass interference filters are housed in 3-axis Thorlabs kinematic mounts allowing for adjustments in pitch and yaw, as well as forward and backward. These filters are a crucial part of the system and determine the final image quality.

The filters pass a nanometer-range-wide spectral band of light to the cameras, while reflecting the remaining light to the next channel of the system. The quality of the reflection is just as important as the quality of the transmission; when unfolded, the optical path the light needs to travel through the system is approximately 15 meters long. Any optical aberrations the filters introduce will accumulate through the remaining reflections and deteriorate the image quality.

In order to reach the required specifications, each filter must provide an exceptionally good reflection, with a surface flatness of approximately 80 nm peak-to-valley variation per inch. Normally this is achieved by splitting the spectrally active coatings forming the filter's bandpass cavity between the front and back surfaces, balancing the coating-induced stresses.

However, this standard solution cannot be used, as it causes reflections on multiple surfaces of the filter, ruining the image with a reflection resembling that of a double-glazed window. Instead, a low-stress coating process was introduced, while the resulting stresses were countered with a thicker filter substrate and an extra-thick anti-reflective coating at the back side to balance the remaining stresses. This ensures both a good image quality and a good reflective quality to reflect the light to the next filter.

Apart from maintaining the image quality, the filters must also be easily interchangeable without misaligning the channels downstream in the cavity (Figure 4). To ensure that realignment is not needed when changing a filter, the kinematic mounts were modified with a custom filter-holder mechanism with a spring-loaded retention system to ensure constant contact with the reference surface. As a result, an exchange of the first filter can be done in seconds



Example of line filtering from the electromagnetic spectrum.
Top: The continuum of electromagnetic light, ranging from ultraviolet (left) to infrared (right).
Middle: Indication of emission lines from hydrogen and helium, each located at a discrete point along the continuum. The MANTIS filters only allow light near these spectral lines to pass, and reflect all other light.
Bottom: An overlayed camera image taken of a plasma inside the TCV (tokamak à configuration variable) at EPFL, depicting scaled emission line intensities encoded into red, green and blue channels. (Figures adapted from [4])

and will result in a displacement of the multiply reflected beam by only a millimeter at the end of the cavity, which is well within the requirements.

This development is part of a European Horizon project and was done together with the Swiss Plasma Center of EPFL, and MIT. The resulting MANTIS diagnostic is heavily used for the TCV tokamak at EPFL [5]. It can process incoming images to estimate the plasma state up to 1,000 frames per second with a feature-tracking algorithm (Figure 6), which next to physics studies is an important application of the real-time exhaust control system [6] [7]. Below, we give some insight into this system.

Real-time plasma exhaust control

The expected heat load impacting the divertor targets is approximately 1/5th of the power generation by fusion reactions in the core plasma. To protect the divertor area active local mitigation of this incoming heat load is required. In order to control the level of mitigation local cooling of the plasma is achieved by injecting neutral gas into the divertor area. This neutral gas interacts with the plasma, taking away momentum and energy, thus mitigating the load being endured by the divertor area.

The question now is: how much neutral gas should be injected to protect the divertor? With too much gas injection, the fusion-generating core plasma will cool down as well, stopping the fusion reactions. However, too little injection will cause the divertor target to melt away, as the plasma will hit the wall with too much energy and momentum. This trade-off can be perfectly controlled by a real-time control system. Such a system consists of a sensor and an actuator linked to the process to be controlled. A control loop is created by means of feedback from measurements, in this case obtained from the MANTIS system. The final performance of the control algorithm is a trade-off between tracking behaviour (is the desired reference reached?) and robustness (will the controller continue to operate in different conditions?).

In our application, one of the MANTIS cameras looks at the light of twice-ionised carbon ions, C^{2+}, inherently present in the TCV due to its carbon wall. This emission is measured by filtering the spectral line CIII (carbon III), which provides insight into the status of the plasma: the amount of light is strongly dependent on the local temperature.

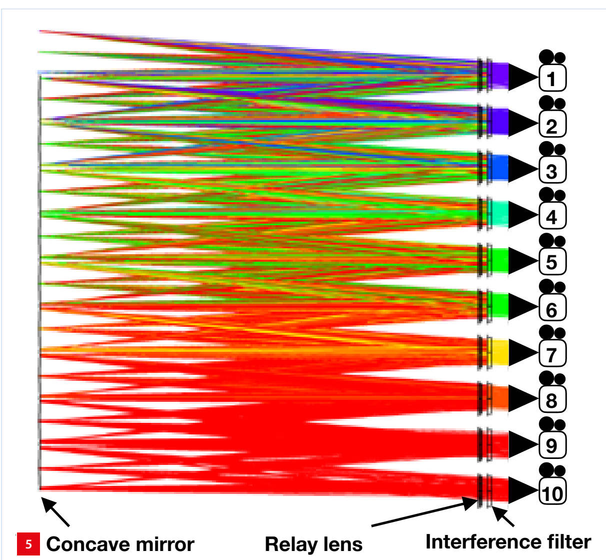
The decrease of light in a certain direction can be used to make a temperature estimate. Specifically, the 50% decrease from a hot region to a cold region corresponds to a temperature of around 80,000 °C, which is significantly colder than the core plasma. This can be seen as the 'cold front'. The position of this front gives an idea of the

MANTIS set-up and components.
(a) Set-up with the ten cameras with the lenses; in front, the spectral filters, and opposite, the mirrors, which reflect the light to the next spectral filter.
(b) From right to left: the camera, the spectral filter and its holder. (Photo: Curdin Wüthrich)

temperature of the divertor plasma. The farther the front is from the divertor target, the colder the plasma hitting the target. We define the position of this front by the variable L_{pol}, which is determined 800 times per second by means of an image processing algorithm applied to the CIII-filtered images taken by MANTIS [8].

Figure 6 gives an overview of this image processing. The processing and its output information are handled with a real-time accuracy of 50 ms and passed to the control system. The image-processing algorithms have been developed in the Matlab-Simulink environment and compiled into shared object libraries that are dynamically linked at runtime. This allows for rapid development and testing.

The MANTIS system has provided the capability to control this front position in real-time by specifically designing control algorithms based on earlier measurements to



Schematic of the MANTIS set-up with the ten cameras, showing the propagation of light through the relay lenses and concave mirrors.

identify the plasma response to neutral gas injection. Presently implemented control algorithms range from simple PI controllers to more advanced multiple-input multiple-output (MIMO) control schemes, all based on models obtained through system identification experiments. Extensive work is being done to extend this to model-predictive control, which employs a model to look ahead in time allowing for pre-emptive action against disturbances.

Outlook

In this article, we have shown the use of only one of the cameras of the MANTIS system to obtain an active measure of mitigation in the divertor. However, the MANTIS system consists of ten cameras. By combining the information in all ten images, a better measurement of the plasma can be obtained.

In future reactors, more than one type of gas will also be injected, each with its own effect on the divertor plasma. The use of multiple gases and cameras can be used in a MIMO control configuration to achieve even better results. The continuation of the collaboration between DIFFER and EPFL focuses on the use of multiple gases and cameras at the same time and is currently in full swing.

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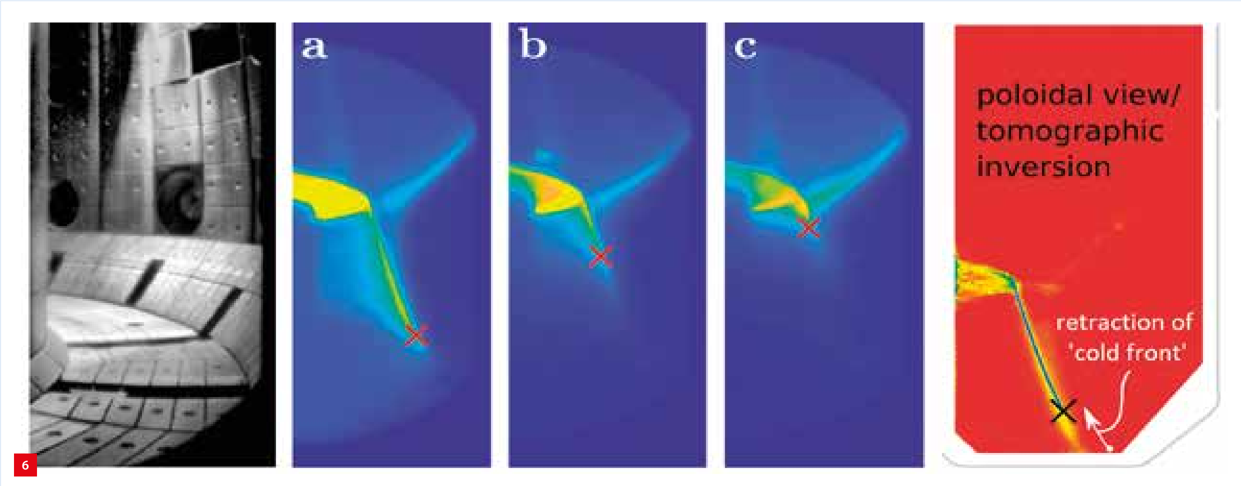

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Depiction of the image-processing algorithm applied to CIII-filtered images and used for real-time exhaust control.
Left: *The camera view from the MANTIS system inside the TCV tokamak.*
Middle: *Retraction of CIII emission with the cold front defined at 50% emission extinction; retraction of this emission from the target as shown from left to right (a to c) indicates cooling of the divertor area.*
Right: *Tomographically inverted image showing the retracted distance of the cold front used as a control parameter (adapted from [6]).*

[6] T. Ravensbergen, *et al.*, "Real-time feedback control of the impurity emission front in tokamak divertor plasmas, *Nat. Commun.*, 12(1), pp. 1-9, 2021.
[7] J. Koenders, *et al.*, "Systematic extraction of a control-oriented model from perturbative experiments and SOLPS-ITER for emission front control in TCV", *Nucl. Fusion*, 62(6), 066025, 2022.
[8] T. Ravenbergen, *et al.*, "Development of a real-time algorithm for detection of the divertor detachment radiation front using multi-spectral imaging", *Nucl. Fusion*, 60, 066017, 2020.


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TOWARDS NEGATIVE EMISSIONS THROUGH DIRECT AIR CAPTURE

Every day, the news has some mention of climate change. A flood, a forest fire, a climate summit, climate protestors,... Climate change is real and it is happening faster and faster. The world needs solutions with a real impact to tackle climate change. Carbyon is an Eindhoven-based start-up company, developing novel equipment to help solve the biggest challenge humanity has ever faced. To make use of Carbyon's USPs, advanced manufacturing techniques are needed for the production of CO_2-capturing materials. Carbyon is developing their own dedicated set-up for this, which will be explained in detail.

JASPER SIMONS

Carbyon's mission

Carbyon's founder and CEO Hans de Neve was working on novel thin-film materials for solar applications at Solliance. The idea arose to apply these materials for capturing CO_2 directly from the atmosphere (direct air capture, DAC). Some 'Friday-afternoon' experiments were done and results looked great. The principles were patented by TNO shortly after. Because TNO did not want to pursue DAC at the time, De Neve decided to spin out and found his own company, fortunately supported fully by TNO. Carbyon joined the programme of Eindhoven-based venture builder HighTechXL and made great progress in acquiring essential testing equipment and proving the fundaments of the technology in lab-based experiments (technology readiness level TRL 4).

Early 2021, Elon Musk tweeted, "Am donating $100M towards a prize for best carbon capture technology", and engaged in a cooperation with X-prize, an independent international organisation with the goal to accelerate innovation through competition. With Musk's $100M as the biggest prize-pot in X-prize's history, the 4-year contest started in April 2021. The challenge is to present a carbon-capture solution that can be scaled to gigaton scale. As this contest fits Carbyon perfectly, we joined right away.

The competition consists of two parts; after the first year (in April 2022) it was possible (not obligated) to participate in the 'Milestone Award' and the big final will take place in April 2025. The Milestone Award consisted of a sizeable submission on paper, comprising a description, calculations and hard evidence from lab measurements. On Earth Day 2022, we received the news that we had won one of the 15 $1M prizes from the hundreds of submissions worldwide. To be able to compete in the final, the challenge is to capture and store 1,000 tons of CO_2 within the timespan between 1 February 2024 and 1 February 2025.

Today, the team has grown to about 20 people in house and dozens more in external cooperations with companies and academics in the region. The mission of Carbyon is to slow down, stop and eventually reverse climate change by restoring the carbon balance in the atmosphere.

AUTHOR'S NOTE

Jasper Simons studied Mechanical Engineering at Eindhoven University of Technology (TU/e) and graduated from the Constructions and Mechanisms group. He worked at CCM (now Sioux) and MI-Partners, in the field of high-tech mechatronics, and in 2020 became the CTO of Carbyon in Eindhoven (NL).

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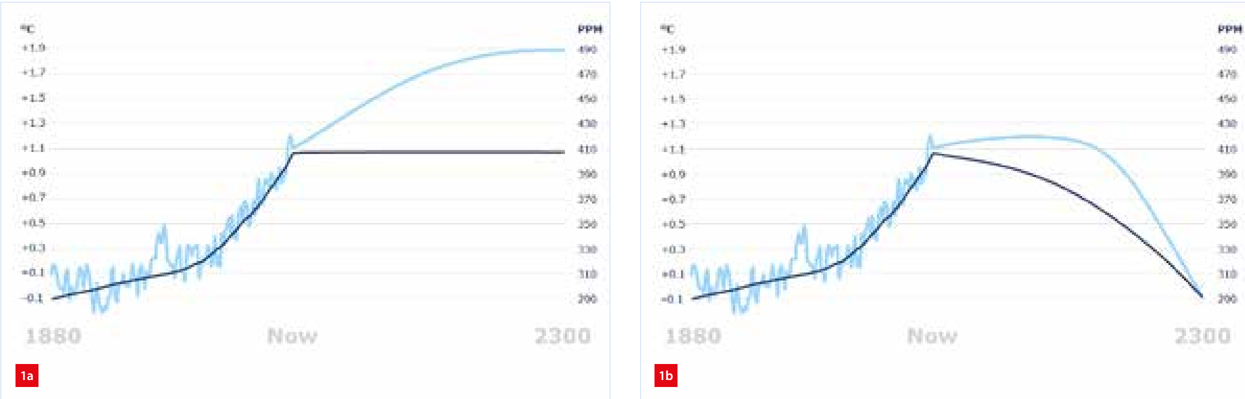
Climate change

Luckily, by now, most people understand that climate change is real, that it is moving faster than ever, that it is caused by human behaviour and that it has devasting effects on our own environment. The CO_2 in our atmosphere allows energy from the sun to reach the earth's surface, but keeps the energy within the atmosphere. The higher the CO_2 concentration in the atmosphere becomes, the more energy is 'kept' in our atmosphere.



To stop global warming (blue) due to rising CO_2 concentrations in the atmosphere (black), CO_2 emissions have to decrease.
(a) With net-zero emissions, temperature will still rise.
(b) Negative emissions are required to bring back the global temperature to an acceptable level.

The vast amount of thermal mass in the earth's surface and atmosphere causes the response of our 'system' to be rather slow. As a result, the temperature on earth is presently not in equilibrium with the CO_2 concentration in the atmosphere. This means the following: Even if we would stop emitting CO_2 tomorrow completely, reaching true net-zero emissions worldwide, even then climate change will not stop. Because we are not at equilibrium yet, the IPCC (Intergovernmental Panel on Climate Change) concludes that climate change would continue for another three hundred years before levelling off. It is this realisation that stresses the need for negative emissions (Figure 1). This requires the removal of all the CO_2 we emitted over the past 150-200 years, cleaning up our own mess. And then, hopefully, climate change would indeed slow down, stop and even reverse...

Carbon balance

All the CO_2 we emit, comes from carbon that was already on earth in a different form. Strongly simplified, carbon occurs on earth in three 'forms':

- Biosphere: in plants and trees, in the oceans, in animals and also in our own bodies.
- Atmosphere: CO_2 gas.
- Underground: mineralised in rocks and sediments, but for the sake of this story, predominantly in the form of fossil fuels.

Many processes occur naturally that exchange carbon between these different forms. Starting from the industrial revolution, humanity started burning vast amounts of fossil fuels, taking large quantities of carbon from underground and emitting it into the atmosphere. In doing so, we strongly unbalanced the naturally occurring carbon cycles. We need to undo this by removing the CO_2 from the atmosphere again and this is exactly what Carbyon's equipment is being designed for.

What to do with all that CO_2?

The captured CO_2 can go in two directions: Carbon Capture and Utilization (CCU), and Carbon Capture and Sequestration (CCS)

CCU

There are many industries that use CO_2 as a feedstock. Examples are the chemical industry, merchant gas suppliers (such as Air Liquide or Linde gas), greenhouses (will be addressed later) and the beverage industry (e.g. Coca-Cola). An additional market that is presently still small but is expected to grow to huge proportions is the synthetic fuel market, which uses CO_2 and green hydrogen to synthesise fuels such as kerosine.

The CO_2 these markets use, often comes from fossil sources and ends up in the atmosphere sooner or later. The shortest imaginable cycle is the beverage industry. They put CO_2 in their products and after a shelf life of a couple of weeks, a consumer will drink it, burp and the CO_2 goes into the atmosphere. The same happens in greenhouses. They use CO_2 to help crops such as tomatoes grow. After a few weeks of growing, consumers eat them, burn the fuel they supply and exhale the CO_2 into the atmosphere.

In each of these industries, fossil CO_2 sources could be replaced by CO_2 captured from air. As mentioned, all of these industries have in common that the CO_2 will eventually end up back in the atmosphere, which is where it came from with DAC, making this a CO_2-neutral cycle.

CCS

Contrary to utilization (CCU), sequestration (or storage; CCS) means that CO_2 is taken out of the cycle permanently (or at least for several centuries). There are two major 'sinks' for CO_2: ironically (or beautifully) underground, or locked in building materials such as concrete. Underground storage can be done in depleted natural gas fields. There are not many sites operational yet, but scientists agree that this is a safe and sustainable way of storage and the available capacity is huge.

Alternatively, CO_2 can be mineralized in certain rock formations, such as olivine and basalt. For example, the captured CO_2 can be dissolved in water and pumped into underground porous basalt layers where the CO_2 mineralises and stays there forever. This mineralisation can also be done above ground (sometimes called enhanced weathering). The resulting minerals can be used as a replacement for cement, storing the CO_2 inside concrete from which it will also never be released, not even if the concrete is later demolished. This solution really cuts both ways as it reduces cement production, which is a huge emitter of CO_2, and it sequesters CO_2 from the atmosphere.

Summary

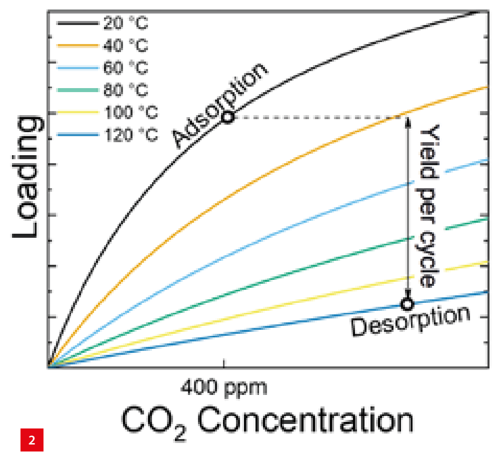
Although CCU applications are 'only' net zero, they actually support Carbyon's mission. To get to net negative emissions worldwide, we first need to get to net zero. This means reducing the use of all fossil fuels as quickly as possible and replacing the old-fashioned processes with renewable processes based on CO_2 from air. On top of that, we need to ramp up as much CCS as we can. The negative emissions we create there will first serve to compensate hard-to-abate CO_2 emissions (such as commercial aviation, which cannot easily be electrified). As emissions are reduced and CCS is scaled up, actual net negative emissions will be achieved as well.

Direct Air Capture

Recently, the concentration of CO_2 in the atmosphere has exceeded 420 ppm, which is 150% of the 280 ppm before the industrial revolution, but even then, 99.958% of the atmosphere is not CO_2... Removing CO_2 from the atmosphere is therefore like finding a needle in a haystack over and over again; only one in every 2,500 molecules is CO_2. Hence, we need a way to specifically target the CO_2 and let everything else pass. This is achieved by a thermal- and pressure-swing chemisorption process.

There are two main groups of chemicals that can capture CO_2 molecules by forming a covalent bond; amines and carbonates. These chemicals cannot be used as stand-alone materials, so they have to be coated onto a carrier structure. The combination of the carrier structure and the active chemicals is called the sorbent, which is exposed to the air at ambient pressure and temperature. CO_2 molecules will hit the surface and some of them will stick to it (forming the aforementioned covalent bond). This is called adsorption and it is an exothermic reaction, which results in a relatively stable bond.

Adsorption and desorption are continuously taking place side-by-side. The net amount of CO_2 on the sorbent is influenced by temperature and partial CO_2 pressure. Higher temperature results in more desorption, so less CO_2 on the sorbent, and vice versa, and higher partial pressure of CO_2 results in more adsorption, so more CO_2 on the sorbent and vice versa. The influence of temperature is stronger in our case. The relation between CO_2 loading on the sorbent, temperature and partial CO_2 pressure is described by isotherms (Figure 2).



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Isotherms showing the relation between CO_2 loading on the sorbent, temperature and partial CO_2 pressure.

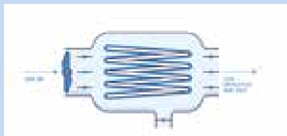
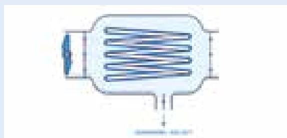
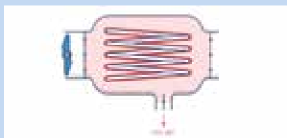
After a certain adsorption time, the sorbent reaches sufficient loading to be desorbed. Because the sorbent is heated, the equilibrium shifts towards desorption and the CO_2 is released again. As mentioned, adsorption takes place under atmospheric conditions, but obviously, desorption cannot. The CO_2 would be released back into the atmosphere then, making the entire process useless. Ad- and desorption phases therefore have to be separated in place (spatial) or in time (temporal). Carbyon has chosen the latter, which results in a batch process where ad- and desorption are separate steps, carried out sequentially. The resulting machine and process layout is presented in Table 1. Upon completion of the desorption step, the vessel is vented to atmospheric pressure again and the cycle can start over.

Carbyon's USP

Carbyon is not the only entity pursuing DAC and most of our fellow climate-change-fighters use very similar processes: temperature (and pressure) swing of amines or carbonates. Carbyon's USP is speed. For any DAC process, one of the biggest challenges is mass transport; how do the CO_2 molecules from the bulk airflow find their way to a 'binding site' on the sorbent?

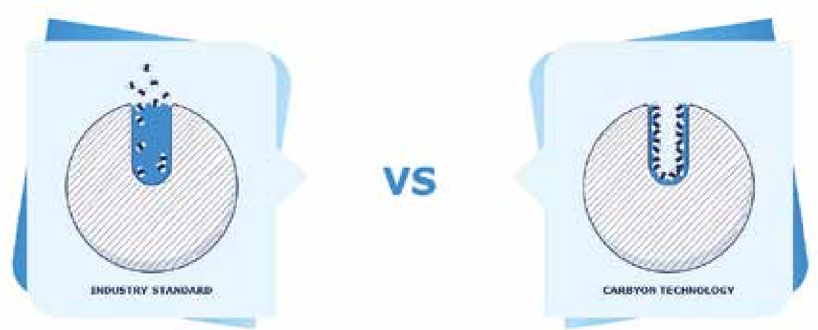
The biggest difference here is illustrated in Figure 3, showing a generic cross-section of a carrier material, which is porous to enlarge the surface area and available volume for the sorbent. The left image shows how most competitors coat their carriers; the pores are completely filled up with sorbent. This results in a high mass percentage of the active chemicals, which is good for the capturing capacity. But all gas-to-solid interactions can only take place on the surface area of the coated carrier structure, resulting in rapid saturation of the outer layer. To reach the deeper binding sites, the already adsorbed CO_2 molecules have to 'move over' to free up binding sites on the surface again. This 'moving over'

Table 1
Carbyon's machine and process layout.

The sorbent is structured in high-aspect ratio panels; the panels are placed in a filter-like configuration, resulting in a high surface area for airflow through thepanels.	
The panels are placed inside a reactor-vessel with large openings allowing high flow rates of ambient air at a low pressure drop. The air is blown through with a fan.	
After adsorption is finished, the fan is shut down and the large valves are closed, enclosing the panels. A vacuum pump is used to remove the remaining ambient air between the panels.	
In parallel, the panels are heated up. Both the high temperature as well as the low pressure ensure rapid desorption. The CO_2 is also transported out of the vessel by the vacuum pump.	

happens based on solid-state diffusion, which is a rather slow process.

On the right, Carbyon's sorbent is shown schematically. The difference is that the pores are not fully filled up, but rather a thin layer of active chemicals is 'coated' on the walls of each pore. This results in a sorbent with 'only' surface area and no volume. All binding sites can be reached by gas-phase rather than solid-state diffusion, which is three to five orders of magnitude faster. Yes, the transition from a '3D sorbent' to a '2D sorbent' results in a lower capacity, but this can be made up for by using materials with a very large internal surface area. Carbyon uses activated carbon materials with ~1,000-3,000 m²/g, due to the presence of many tiny pore structures with nanometer-scale diameters (typically between 0.5 and 5 nm). The challenge then becomes: how to 'paint' the walls of nanometer-scale pores without clogging them?



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Schematic of the adsorption process: the '3D sorbent' of competitors (left) versus Carbyon's '2D sorbent'.

Introduction into ALD

To the initiated, pursuing a thin, conformal, self-limiting coating screams for Atomic Layer Deposition (ALD).
For those who are new to ALD, some introduction might be needed. ALD and the closely related Molecular Layer Deposition (MLD) are special cases of chemical vapour deposition (CVD). In classic (temporal) ALD, a substrate is placed inside a vacuum reactor. The reactor is evacuated to ~0.1 mbar or (much) lower pressure. Then, a controlled amount of a gas-phase chemical is dispensed into the reactor; this 'precursor' contains a specific atom, or group or atoms, that is to be deposited. The remaining atoms present in the molecule act as a sacrificial scaffold that is used to protect and transport this atom to the substrate.

The molecules of this precursor are designed such that they can attach to the surface exactly once, making the reaction self-limiting. This means that – in theory – a perfect monolayer of these molecules is formed on the surface after sufficient waiting time and assuming sufficient amounts of molecules are dispensed in the first place.
After this, the remaining precursor, and any byproducts from the reaction between the precursor and the surface, are evacuated from the reactor using the vacuum system. Then the second chemical, typically called the 'co-reactant', is dispensed. It reacts with the precursor on the surface, forming the desired coating. If the precursor and the co-reactant were dispensed into the reactor simultaneously, the self-limiting nature of the ALD process would be lost and uncontrolled, and CVD-like growth would take place on the surface and potentially even in the gas phase.

By repeating the cycles mentioned above, multiple layers can be built up, accurately controlling the thickness of the coating. Alternatively, it is also possible to apply multiple pulses of theprecursor before ever dispensing any co-reactant. This so-called multi-pulse strategy is sometimes needed to ensure full coating of larger surface areas.
ALD is presently typically used in the semiconductor industry, display technology, and solar. TNO has done a lot of technology development on this topic in the past and presently, two Eindhoven-based companies (SALD, formerly SoLayTech, and Spark Nano, formerly SALDTech) develop ALD equipment industrially.
One can imagine that this technique can be quite suitable for coating the carrier materials to create Carbyon's sorbents. This is indeed the case and in close cooperation with the group of Professor Adriana Creator (Applied Physics, TU/e), a multitude of samples have been produced, inspected and tested. This joint research effort quickly ran into some limitations of the existing equipment, however.
In most present-day use-cases of ALD/MLD, depositions are done on silicon wafers or other fairly flat materials. These materials have a specific surface area of ~1 m²

internal surface area for every 'real' m² of surface area. Coating a monolayer on such a flat surface therefore also results in ~10^{-9} m³ and ~10^{-6} kg deposition amounts per m² of substrate. Carbyon's carrier materials have much higher specific surface areas of ~100.000-200.000 m²/m², resulting in deposition amounts that are also that much higher.

Aladdin

Operating at the low pressures described above for these large surface areas results in processing times of days or even weeks, even for very small samples quantities. To overcome these productivity issues, several orders of magnitude of improvement are needed. This cannot be achieved by minor process modifications, but requires an entirely new set-up.

Carbyon decided to develop – in cooperation with the TU/e and supported by several suppliers and SALD – their own ALD set-up: Atomic Layer Deposition Device Innovation Necessity (Aladdin). The major differences with existing equipment are:

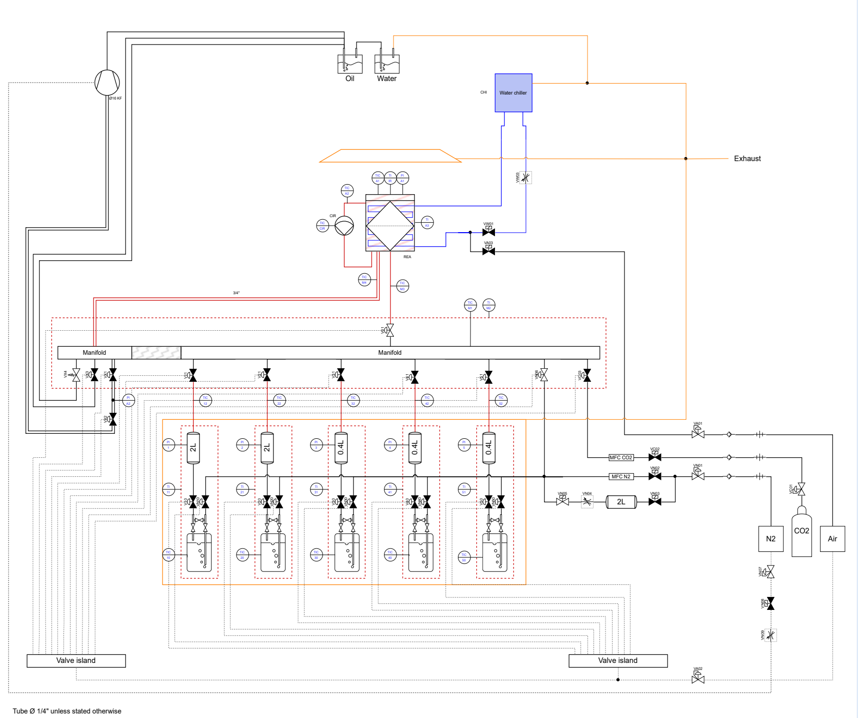
- Instead of operating at ~0.1 mbar or lower, much larger vapour pressures of the precursors are used. The target is 250 mbar.
- Similar to the adsorption process, mass transport of the precursor is also a determining factor. The byproducts mentioned above also need to be removed from the carrier at the same time. Both are achieved by recirculating the gas inside the reactor through the carrier material.

Another challenge is to supply the gas-phase chemicals to the reactor. This is done using 'bubblers'; airtight stainless-steel vessels that contain a liquid or solid precursor. These vessels need to be heated to create vapour pressure of the chemicals inside. They are called bubblers because they are generally also equipped with a 'dip-tube'; a tube that leads to the bottom of the vessel, allowing a carrier gas such as nitrogen to be dispensed into the liquid chemical. The bubbles that come up, will carry some of the chemical vapours. They can also be operated without a carrier gas; this method is called 'vapour-drawn'. The vapour pressure is then directly related to the temperature and varies between the different chemicals.
To be able to supply the desired vapour pressure levels of ~250 mbar, temperatures up to 250 °C are required. This is far from straightforward as component availability (such as manual and pilot valves) becomes limited to only a few suppliers worldwide. Furthermore, the entire path from the bubbler up to the reactor cannot contain any cold spots as this would result in condensation of the precursors.

Figure 4 shows the piping and instrumentation diagram (P&ID) of Aladdin. In the lower middle, five identical bubblers can be seen. These contain the different precursors and co-reactants needed. Each bubbler has three manual valves to open, close and flush them. A nitrogen supply from the wall is connected to all the dip tubes to be able to use the bubbler functionality if needed. This can also be used to flush the tubes for cleaning.
Each bubbler is placed inside its own custom-built oven (Figure 5). This is the best way to heat the bubbler and the five valves on top and the vessel above uniformly. Each oven has a thermocouple on the 'load' (the bubbler) and on the heating element to protect against overheating. All five ovens are placed inside a cabinet with active ventilation for safety.

If the vapour would be dispensed directly into the reactor, the deposition reaction would start immediately; especially since the reactor is designed for high productivity. As mentioned before, most precursor molecules release one or more groups as byproducts when they attach to the surface. If the number of separate molecules coming off of each deposited molecule is larger than one, this means that more molecules are 'created' inside the reactor. This results in an increase in pressure, which is actually a really nice way to monitor the progress of the reaction. But the fact that this pressure increase starts immediately, makes it very difficult to accurately dose the amount of vapour dispensed into the reactor. Accurate flow measurement devices do not exist for 250 °C, so an alternative solution was needed.

The vessel above each bubbler is called the 'dosing vessel', a passive tank that acts like a 'waiting room' for the vapour. The volume of the tank is known accurately from calibration.



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Piping and instrumentation diagram (P&ID) of Aladdin; see text for explanation.

Combined with an accurate pressure sensor, the amount of precursor inside the dosing vessels can be calculated. When the valve between the dosing vessel and the reactor is opened, the pressure will equilibrate rapidly. The volume of the reactor and the tubing leading there, is also calibrated. Therefore, the amount of vapour dispensed into the reactor can be calculated with sufficient accuracy.

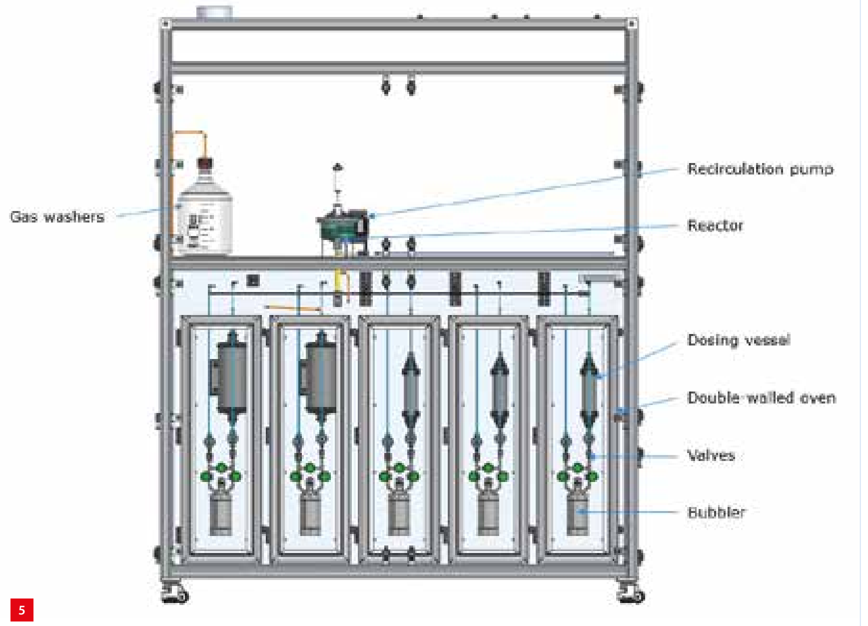
The precursors from each bubbler (always operated one at the time) enter the reactor through a manifold. The reactor is then closed off and the recirculation pump is activated. This is a membrane pump with a temperature-controlled heated head that can operate up to 250 °C. All the gases in the reactor (precursor and byproducts) are recirculated through the porous samples while the pressure is monitored. As the pressure levels off, everything can be flushed out using nitrogen and the next step can start.

Flushing is also not entirely straight-forward. Some precursors are pyrophoric (they will burn in contact with air), which is a safety concern. To solve this, all gases that come from the reactor need to pass through a gas washer. As this particular precursor reacts with the water in the air, the gas washer in this case is the water vessel shown at the top of the P&ID. By 'bubbling' the gases through this water tank, any remaining precursor that did not react inside the reactor, will react with the water in the tank in a controlled way. The reaction product will simply sink to the bottom of the tank.

If only the water gas washer were present, water vapour from this tank could diffuse into the tubing towards the reactor. In that case, the reaction product would form inside the tubes and valves, potentially clogging them. To prevent this, an additional gas washer with oil is added upstream. The precursor does not react with the oil, but the oil acts as an 'oil-lock', keeping the water vapour out of the tubes.

The reactor is heated electrically, but active cooling is also added; cooling water is pumped through channels in the reactor to cool it down in ~15 minutes instead of 2-3 hours. This allows faster changing of samples and therefore more productivity. Introducing room temperature water into a 250-°C reactor would result in steam generation and rapid pressure build-up. This is a safety concern as well, and therefore, the initial cooling from 250 °C down to ~100 °C is done with compressed air. This compressed air is also used to flush out any remaining cooling water before heating starts again, to prevent boiling water in the cooling channels.

The set-up (see Figure 5 for a partial overview) is presently being assembled by LT Technology, which designed and built multiple components of the system. After completing the mechanical assembly and the 'plumbing', the set-up will come back to Carbyon, where VHE industrial automation will install the electronics and complete field wiring. Next, ICT will come to integrate the PLC software and the Python-based user interface. After integration testing in Carbyon's labs, the set-up will be transported to the TU/e Applied Physics PMP (Plasma & Materials Processing) labs, where joint research will be conducted with Carbyon's scientists and researchers. The set-up is planned to be operational in January 2023.



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Partial overview of the Aladdin design.

Conclusions and outlook

Presently, we are at TRL 4, based on lab-scale measurements of our sorbents. In Q1 2023, our first 'integrated prototypes' will become available in our labs, bringing us to TRL 5. We call these integrated prototypes because these will be the first set-ups that include all elements of the process in a single set-up. These prototypes will have a small reactor (roughly 1% reactor volume compared to the size we envision for the commercial products) and much more diagnostics to enable us to learn a lot from these set-ups.

Parallel to product development, Carbyon's technology research group will continuously improve the sorbent to obtain higher capacity, faster kinetics and lower energy use, for which Aladdin is a key part. Development of first full-scale systems is already ongoing, in collaboration with Demcon in Best (NL). These systems will roughly have the volume of a 20-ft shipping container and can capture 100 tons of CO_2 every year; we are aiming to have the first systems operational by the end of 2023. Pilot testing will be done in all major market segments and we hope to achieve our first commercial sales by mid-2025, scaling up to gigaton deployment worldwide in the decades after that.

ENABLING THE 'BIG ENABLER' – VACUUM

Chemical or molecular contaminants are harmful in vacuum applications because they disturb the operation, which can lead to lower production yield or faulty measurements, for example. Molecular contamination can be prevented by using suitable materials and clean gases, and by ensuring that parts are properly cleaned, manufactured, assembled and inspected. These issues were the focus of the DSPE Knowledge Day Molecular Contamination Control, hosted by TNO in early November. The event featured presentations from the semicon, space and analytical industries, as well as a tour of TNO research facilities, including the advanced EBL2 (EUV Beam Line 2).

Since 2019, DSPE has been organising knowledge days on precision engineering for vacuum and the related issue of contamination control. Molecular contamination control was the topic of a DSPE Knowledge Day hosted by TNO in Delft (NL) in early November. DSPE board member Kasper van den Broek, contamination control architect at VDL ETG, kicked off the day by welcoming the over 40, mostly young, participants and briefly introducing DSPE and its Knowledge Day format.

Rising star

The host of this event was TNO, the Dutch organisation for applied research that aims to act as a catalyst for open innovation in public-private partnerships and supports many high-tech companies in confidential projects. It was introduced to the participants by Rogier Verberk, director of TNO Semicon & Quantum, and Medical Photonics. He described how contamination control is critical for two of TNO's high-tech industry roadmaps: Semicon & Quantum and Space & Scientific Equipment.

Verberk underscored the relevance of contamination control by presenting TNO's track record in these areas, including instrumentation for atmospheric chemistry, astronomy and gravitational-wave detection, as well as extreme-ultraviolet (EUV) lithography equipment and particle-detection technologies. EUV lithography (EUVL) for realising the smallest semiconductor features requires an ultra-clean vacuum because of the high absorption of EUV in non-vacuum. Another important focus of TNO is quantum technology, which is the rising star in Delft. It involves the quantum computer and networked communication, centred around QuTech, the joint research centre established by Delft University of Technology and TNO in 2014.

EDITORIAL NOTE

This report was based on the presentations given at the DSPE Knowledge Day on 3 November 2022 at TNO in Delft.

No perfect vacuum

Freek Molkenboer, senior systems engineer at TNO in the department of Nano-instrumentation and vice president of NEVAC (see the text box on the next page), described vacuum as the 'big enabler' of big science, particularly in areas such as nuclear fusion and research into elementary particles, gravitational waves and space. However, there is no such thing as a perfect vacuum. Even the best man-made vacuum, an extremely high vacuum of 10^{-12} mbar (= 10^{-10} Pa) pressure, contains some 10^5 molecules per cubic centimeter. Thus contamination, i.e. unwanted matter at an unwanted location, can never be fully eliminated, and each application has its own level of allowed contamination and requires its own specific contamination control measures.

Forbidden elements

After a tour of TNO's research facilities (see the text box on page 23), Paul de Heij, cleanliness specialist at VDL ETG, was the first presenter from industry. He talked about molecular contamination control during the manufacturing of the frames for ASML's EUVL machines, focusing on the prevention of 'forbidden' elements on the surface of grade-1 EUVL parts, in particular the contamination-sensitive EUVL optics, and demonstrated the urgency with a few numbers. Under atmospheric pressure it takes only 3 nanoseconds for a monolayer of contamination to build up, while under high vacuum (10^{-6} mbar) this increases to a mere 3 seconds. It requires extremely high vacuum (10^{-12} mbar) to achieve an acceptable period of about a month.

Even this, however, may be not enough. When highly reactive hydrogen plasma is used to remove hydrocarbons from sensitive surfaces, hydrogen radicals can form molecular acids with phosphorus or sulphur, for example, or form volatile metal hydrides which can redeposit onto

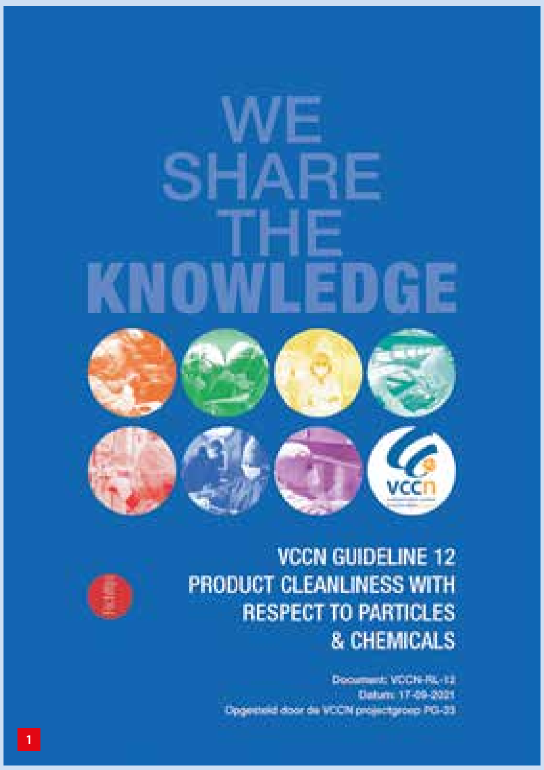
NEVAC, VCCN and Guideline 12

There are two Dutch organisations dedicated to vacuum technology and contamination control in this field. One is NEVAC, the Dutch Vacuum Society, founded in 1962 to promote the exchange of knowledge in the field of vacuum technology and areas in which vacuum plays a major role. The society does this by organising scientific meetings (NEVAC Days), excursions, an extensive course programme and publishing a magazine. The next NEVAC Day will take place on 12 May 2023 at ASML in Veldhoven (NL).

Under the auspices of NEVAC, three vacuum books were written, which can be considered as 'must-haves' for everyone working in vacuum-based research, development, instrumentation, production or business; see the NEVAC website.

The other organisation is VCCN (Dutch Association for Contamination Control), a professional platform for knowledge sharing and knowledge transfer in the field of contamination control, optimising expertise and contributing to the development of this field. It publishes the quarterly C2MGZN magazine, offers a wide range of training courses, and organises various congresses as well as the National Contamination Symposium and the Cleanroom Day. A new VCCN initiative is the Cleanliness & Contamination Control Circle for knowledge sharing; the first meeting will be held in January 2023.

VCCN also recently developed an important contribution to this field: the VCCN Guideline 12: Product Cleanliness (Figure 1). Rather than prescribing solutions for achieving product cleanliness in manufacturing with respect to particles and chemicals, for example through contamination control or cleaning, the guideline describes what should be considered when dealing with product cleanliness. This information should, among other things, enable and align the communication (about specification and qualification) between suppliers and customers, in order to help industries to realise and improve product cleanliness.



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VCCN Guideline 12: Product Cleanliness, published in 2021.

WWW.NEVAC.NL
WWW.VCCN.NL

the surfaces. Minimising this hydrogen-induced outgassing requires both an ultra-clean vacuum (for which a low hydrogen flow is used to continuously clean critical surfaces) and the reduction of the presence of forbidden materials, following the philosophy that what is not on a surface does not have to be cleaned off, and what is not in a material does not have to be baked out. These forbidden materials range from Zn and Sn to Mg and Ca, and further to N and Si; they are the 'byproducts' of the materials (alloy elements) and processes such as soldering, greasing and cleaning with water and other solvents, as well as the general environment (human beings, buildings, etc.).

Large frames

With the increasing frame size of EUVL machines, the challenges are only getting bigger. Firstly, this has to do with the quality of available materials. For example, cast materials applied in large structures have a higher porosity than wrought materials, and their corrosion resistance is lower, leading to increased outgassing and surface contamination. Naturally, processing times – for manufacturing, cleaning (the large thermal mass complicating matters) and assembly – increase with frame size, and hence the risk and the degree of contamination (for example, due to the exposure to coolants). In addition, options such as ultrasonic cleaning are not feasible at these length scales. De Heij's conclusion was, "Size matters! Scaling up affects cleanliness and contamination control in many ways, and many of the associated problems compound each other."

Clean and dry

Rients de Groot, senior system design engineer at Thermo Fisher Scientific, talked about cleanliness for (transmission) electron microscopy, or (T)EM. Vacuum is everywhere in a TEM system, comprising the electron source area (10^{-10} - < 10^{-12} mbar), the column area (10^{-6} - 10^{-8} mbar) and the projection chamber (10^{-5} - 10^{-6} mbar). Hence, optimal performance requires a very high cleanliness level, especially of all the parts and modules in contact with the high- to extremely-high-vacuum environments.

The vacuum is important, besides ensuring a sufficiently long (> 60 mm) 'mean free path' for the electrons, also for minimising oxidation (caused by oxygen from air or water) and contamination (carbon growth) on the sample or the electron source; and preventing particles from 'igniting' electrical discharge, and deflecting or blocking the electron beam. In addition, the trend in EM is towards lower accelerating voltages, making the microscopy even more sensitive to contamination. De Groot's conclusion was, "We need a clean and dry vacuum." Here, 'dry' also refers to reducing the water content in the vacuum to prevent ice growth on cryogenic (biological) samples.

From grades to levels

In Thermo Fisher Scientific's outsourcing relationship with its suppliers, its requirements for the parts involved are specified via Technical Product Documentation, while the required cleanliness is specified via the Quality of Electron Optics (QEO) documents. The cleanliness grades are related to the application in which the parts are used and cover the range from no cleaning, general cleanliness, and pre-cleaning for final cleaning (by Thermo Fisher Scientific), to low- and high-vacuum cleaning (by the suppliers).

De Groot announced that a QEO upgrade is needed for modules and ultra- to extremely-high-vacuum cleaning/treatment, as well as for alignment with ISO standards. In the new QEO standard under construction, the specifications are in terms of particle and chemical cleanliness levels, PCLs and CCLs, respectively. These are defined for the various types of contamination in a more detailed fashion as compared to the current cleanliness grades. This enables Thermo Fisher Scientific to specify higher cleanliness levels and provides suppliers with a more detailed insight into the cleanliness required for their parts.

The weakest link

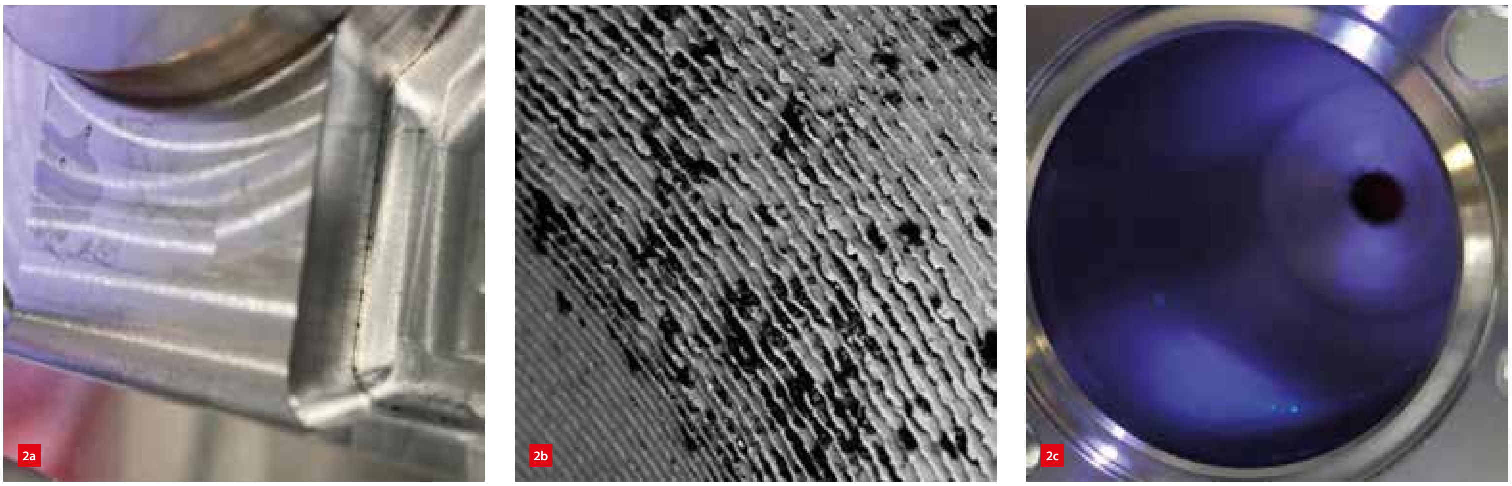
To conclude, De Groot illustrated the broad scope and complexity of the cleanliness and contamination control challenge. After showing the company's clean lab, featuring RGA (residual gas analysis) tools, a scanning electron microscope and a flow cabinet in which an optical microscope is used for inspection, he presented measurement and inspection examples of the various contamination types (Figure 2). These included: particles, dirt and burrs from (threaded) holes, corrosion of and cleaning stains on stainless steel, and powder blasting residues on parts; organic contamination in ploughing tracks on turned titanium surfaces; and many more potential EM error sources. This once again underscored De Groot's motto of "A vacuum is as good as the weakest link".

"Reflect before you begin"

Gabby Aitink-Kroes, senior opto-mechanical system engineer at SRON (Netherlands Institute for Space Research), talked about the practical difference between cleanliness and contamination. To clarify matters, she started by defining the two key concepts. Contamination is the process or fact of making a substance or place dirty or no longer pure by adding a substance that is dangerous or carries disease. Cleanliness is the state of being clean or the habit of keeping things clean.

For contamination control, it is customary to define requirements in terms of cleanliness, but ultimately it is about achieving an acceptable level of contamination. So, when a critical system has to be assembled, there are several factors that determine the outcome. It is not only the (input) cleanliness of the parts that have to be assembled and the cleanliness (ISO class) of the cleanroom in which assembly will take place, but the duration of the assembly process also matters, as it determines the available time for build-up of contamination on the system.

Hence, contamination control is not just about cleaning parts and ensuring the appropriate cleanroom class, but also about developing efficient assembly procedures, in order to reduce exposure to the environment, giving things less time to become dirty. Aitink-Kroes illustrated this for the Dutch contribution to the Mid Infrared Instrument for the James Webb Space Telescope, of which the assembly could be carried out so quickly that an ISO-5 flow cabinet inside an ISO-7 cleanroom was sufficient, eliminating the need for a complete ISO-5 cleanroom (with its tighter rules and regulations). And taking efficiency one step further,



Measurement and inspection examples of the various contamination types.
(a) Contamination of a stainless-steel part, including local corrosion (at the inner edge), particles and stains; UV-A-light inspection.
(b) Organic contamination in ploughing tracks on a turned titanium surface (R_a < 0.6 μm); SEM image.
(c) Organic particles (white luminescence) in a vacuum transport container; bare-eye (with protective goggles) UV-A-light inspection.

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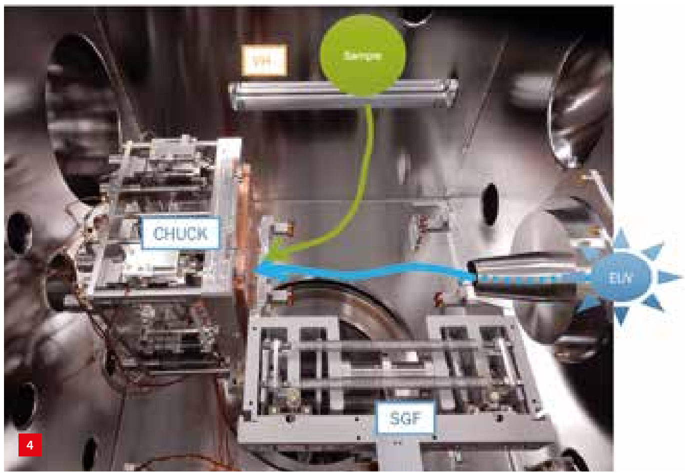
Working in a cleanroom environment is not much fun.



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Overview of the EBL2 exposure chamber with the various components. VH is the central vacuum handling chamber, SGF is the sample gripper flipper.

she said, "Cleaning things is difficult, so don't make them dirty!" This may help to relieve cleanliness requirements further down the contamination chain. "So," she added, "reflect before you begin."

Aitink-Kroes also drew attention to the human factor (Figure 3). People are the most 'burdened' by the required clean way of working and are at the same time the biggest contaminator of a cleanroom. Working in a cleanroom is difficult because of the gowning (including the face mask), the tiring environment (temperature, noise), the strict procedures, the extensive run-up and wrap-up, and the disastrous effects of 'little pleasures' (smoking, make-up, hair gel). So, everything that can help to reduce cleanroom time is welcome.

Sample gripper flipper design

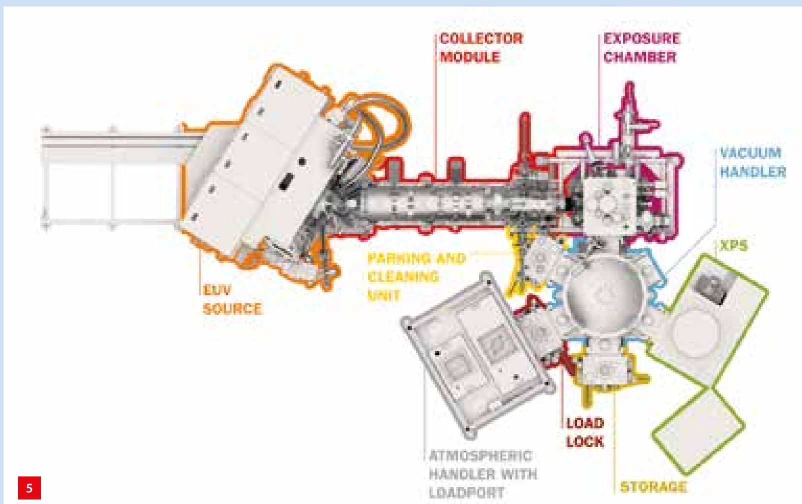
As the final speaker, Peter Kerkhof, optomechatronic design engineer at TNO, presented the design of a sample gripper flipper for TNO's EBL2 research facility (see the text box). The function of this gripper flipper is to change the orientation of the sample that is fed into the exposure chamber horizontally and has to be flipped to a vertical direction for EUV illumination. The sample can be either a bare reticle or a multi-layer mask, quartz plate or wafer contained in a holder (a square aluminium plate, basically).

Design challenges for the sample holder included the integration of different sets of handling interfaces, for EBL2's various vacuum regimes. These range from the ambient handling chamber to the central vacuum handling chamber to the ultra-high-vacuum exposure chamber, which comprises the sample gripper flipper and a chuck onto which the sample holder is mounted. The complete design (Figure 4) was successfully completed and realised, as evidenced by the five years of 'clean' running of the EBL2 facility.

TNO research facilities

At the DSPE Knowledge Day in Delft, three TNO research facilities for semicon (in particular EUVL) applications were included in a tour for the participants:

- ATOM: Advanced Tool for Outgassing Measurement, for measuring the outgassing rates of various molecular constituents from vacuum equipment components.
- DGL: Dynamic Gas Lock, for measuring contamination levels and studying mitigation strategies.
- EBL2: EUV Beam Line 2 (Figure 5), for simulating the environment of, for example, an EUVL machine to determine the effect of high EUV dose on specific samples and the degree of contamination that occurs.



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Overview of the EBL2.

INFORMATION
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NEXT LEVEL IN LASER GUIDE STAR CREATION

In order to meet the ever-increasing demands of large telescopes, laser guide stars are being used for adaptive optics correction. These artificial reference stars are created by a Laser Projection System (LPS), which has a Beam Conditioning and Diagnostics System (BCDS) as one of its critical subsystems. Building on its works for the Very Large Telescope (VLT), TNO recently won the tender for the Extremely Large Telescope's LPS. Demcon focal was challenged to design a BCDS that combines easy maintainability with strict optical requirements concerning laser beam quality and pointing stability, taking into account large thermal and mechanical load variations.

RALPH POHL AND SANNEKE BRINKERS

AUTHORS' NOTE

Ralph Pohl is a senior optical system engineer and Sanneke Brinkers is a senior project manager. They both work at Demcon focal, located in Enschede (NL) and Delft (NL), part of the Demcon group, a developer and supplier of high-end technology and innovative products. Group members Demcon advanced mechatronics and Demcon multiphysics also contributed to the BCDS and Control Electronics development.

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Introduction

Large ground-based telescopes are equipped with adaptive optics (AO) to correct for atmospheric disturbances. The AO input can be provided by either bright reference stars or – in the absence of such stars within the actual field of view – bright artificial stars, which can greatly increase the telescope's sky coverage. Laser guide stars are created by using a Laser Projection System (LPS) to excite the sodium atoms (at λ = 589 nm) that originate from the ablation of micrometeorites in the Earth's mesosphere at an altitude of ~90 km.

For example, one of the four telescopes of the VLT, operated by the European Southern Observatory (ESO) at Cerro Paranal in Chile, is fitted with four LPS systems, for which Dutch applied research organisation TNO designed and realised the Optical Tube Assembly (OTA) [1]. Combined with other instruments in VLT's AO facility, these LPS systems enable the correction of the blurring effect (wavefront degradation resulting in decreased optical resolution) of the Earth's atmosphere in real time and aid in the creation of images that show astonishing sharpness.

1

Artist's impression of ESO's Extremely Large Telescope (ELT), which will be the world's biggest 'eye on the sky' when it achieves 'first light' later this decade. Eight LPS systems will create artificial guide stars for measuring how distorted light is due to turbulence in the Earth's atmosphere. ELT's deformable M4 mirror will adjust its shape in real time to compensate for these changes in the atmosphere, helping to produce images that are 16 times sharper than those of the Hubble Space Telescope. (Image credit: ESO)

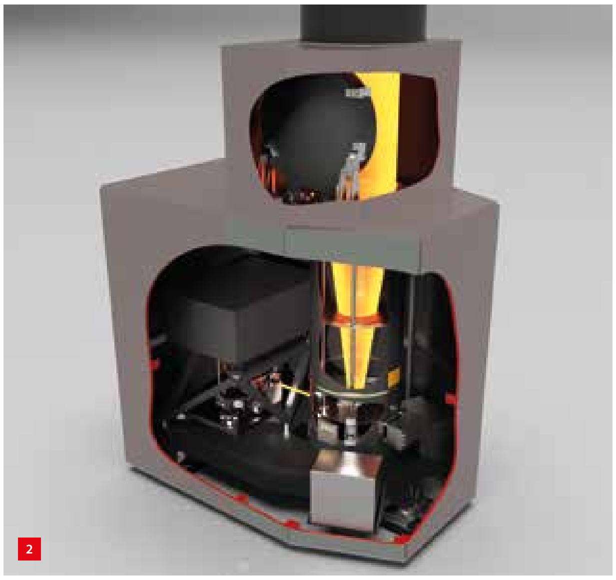
Currently, ESO is developing the next in line: the 39-meter Extremely Large Telescope (ELT). This is currently under construction at Cerro Armazones in Chile and is designed to be the largest visible- and infrared-light telescope in the world: the world's biggest eye on the sky [2]. The ELT can be equipped with up to eight LPS systems (Figure 1) to cover the atmospheric variations in its large field of view.

Building on its experience with VLT, TNO won ESO's tender for the ELT LPS (Figure 2) and partnered with Demcon focal as the subcontractor for the design and realisation of the Beam Conditioning and Diagnostics System (BCDS) and Control Electronics. Since early 2021, TNO and Demcon focal have been working on the development of the ELT LPS [3] [4], which includes the control electronics and software, as well as dedicated tooling for beam quality measurement, maintenance and verification (test tooling).

Optomechanical layout

Figure 3 shows the functional overview of the LPS. As well as the baseplate (fixed to the tilting part of the ELT) and the cover, the optomechanical layout comprises the laser head (for Toptica's 589-nm, 50-W continuous-wave SodiumStar laser source), the BCDS (designed by Demcon focal) and the OTA (designed by TNO). The laser head is mounted on top of the BCDS, subjecting it to a large mechanical load due the head's mass of 80 kg. The cover encloses the complete LPS to protect it from heavy wind loads and to ensure the high optical quality of the transmitted laser beam.

The BCDS directs the laser beam from the laser head to the OTA, where a Field Selector Mirror controls the pointing of the output beam. The function of the BCDS is to manage beam conditioning and diagnostics, ultimately to support the control of optical beam quality.



Artist's impression of the ELT LPS. (Image credit: TNO)

Beam conditioning is provided by the remotely controlled Beam Expander Unit (BEU), which expands the beam – with a factor of 3.6, from Ø4.2 mm to Ø15 mm – and controls its focus. Refocusing the beam is required because the optical distance travelled by the laser beam can vary due to the thermal (day-night) cycling the system undergoes and the changes in the elevation angle of the telescope platform. In addition, the Jitter Loop Mirror acts as a highly dynamic tip-tilt mirror to correct for high-frequency laser jitter.

Beam diagnostics involves measurement of beam stability by the Periscope and of optical beam power by the water-cooled Bolometer, when the Beam Propagation Shutter steers the beam in that direction.

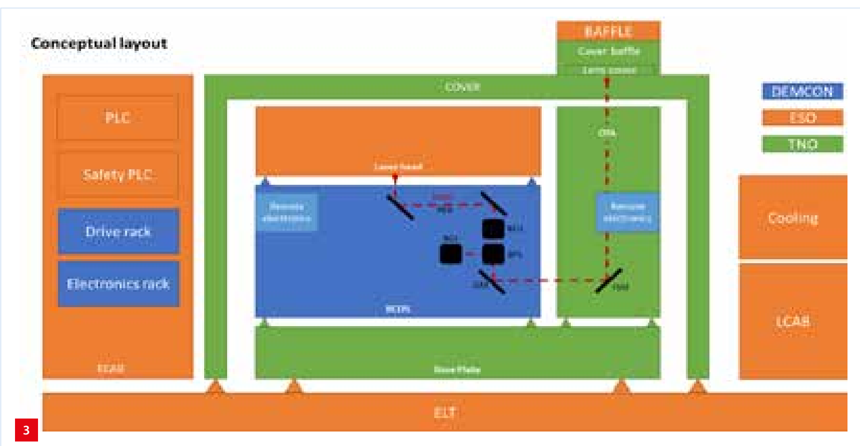
Design

The main design challenge was to provide high optical beam quality in terms of wavefront error, degree of linear polarisation and high optical throughput, as well as high pointing accuracy and stability, while the BCDS is being exposed to varying environmental conditions, including thermal (day-night) cycling and a changing gravitational vector due to tilting of the ELT. As a consequence of the optical design, any pointing-angle variations at the LPS input are demagnified by a factor of 72 (the BCDS and OTA contributing a factor of 3.6 and 20, respectively); lateral offsets, however, are magnified by the same factor. This required an LPS system-level approach for handling the thermal and mechanical (gravity) loads.

The design of the BCDS (Figure 4a) involved the custom design of various submodules combined with the selection of the appropriate off-the-shelf components, such as actuators, mirrors, lenses and their coatings, providing the right properties in terms of throughput, polarisation and optical tolerances. All submodules were designed as Line-Replaceable Units (LRUs) that are placed on the BCDS baseplate (Figure 4b) and provided with kinematic mounts for easy exchangeability during maintenance and high repeatability in mounting.

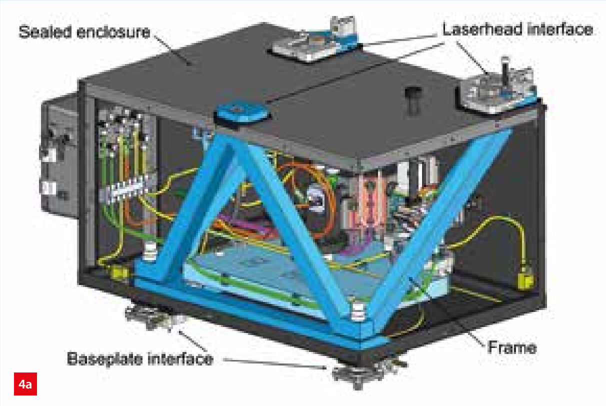
Athermalised and stiff

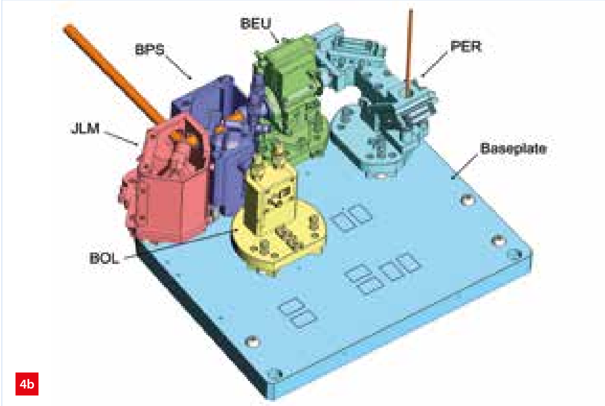
During operation, the LPS will experience temperature gradients of up to 0.55 °C/hr. Therefore, an athermalisation strategy was applied to the BCDS design, to match the thermal time constants of BCDS components with each other and with those of the OTA. One the design choices was to select inox steel (AISI 304 and 316L) as the material



Design of the LPS.
The Periscope comprises a dichroic mirror (for beam polarisation purposes) and a second mirror, as well as two locations where an interferometer can be inserted for beam diagnostics (during verification or maintenance), such as measuring the wavefront error.
The Beam Expander Unit has three lenses, L1 to L3, of which L2 is actuated for focus control.
(Image credit: Demcon focal)
Legend:

PER = Periscope	*BOL = Bolometer*	*ECAB = Electronics Cabinet*
BEU = Beam Expander Unit	*JLM = Jitter Loop Mirror*	*LCAB = Laser Cabinet*
BPS = Beam Propagation Shutter	*FSM = Field Selector Mirror*	





CAD design of the BCDS and its interior; see Figure 3 for the legend.
(a) The complete system with the cover removed.
(b) The individual Line-Replaceable Units (LRUs) mounted on the BCDS baseplate.

for most components, as this is also the prevalent material in critical parts of the ELT structure.

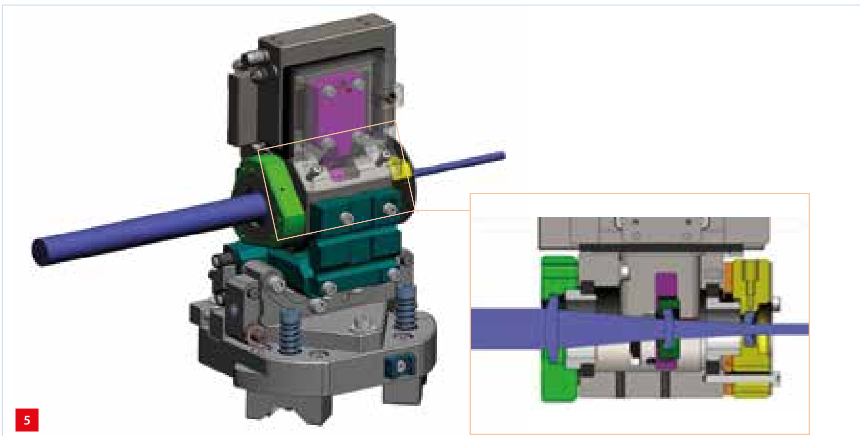
In addition, the BCDS was given a high stiffness to ensure structural stability, thus minimising deformations due to the varying thermal and mechanical loads. The stiffness of the frame derives from its construction with triangular elements made out of steel beams that have a cross-section of 40 mm x 40 mm. This design also enables easy access to all submodules inside. According to ESO's design review, it was the most stable structure that could have been designed.

BEU design
To illustrate the custom design of submodules, the BEU design is presented here (Figure 5). It comprises two major components, namely the optical barrel and the adjustable BEU frame.
The optical barrel consists of subcells, with each lens mounted in a separate subcell. Optical feedback is used to align the lenses to the required accuracies of ±10 µm in lateral displacement and ±50 µrad in tip/tilt rotation. After alignment, the lenses are fastened using an epoxy adhesive. Focus control in the optical barrel is realised by moving the second lens of the BEU (L2) along the optical axis of the BEU, while keeping L1 and L3 fixed in place. This is achieved by using a commercially available linear stage L-505 from PI. Its resolution and range enable a focus control of ±5, with 0.01 resolution, both in terms of wavelengths (peak-to-valley).

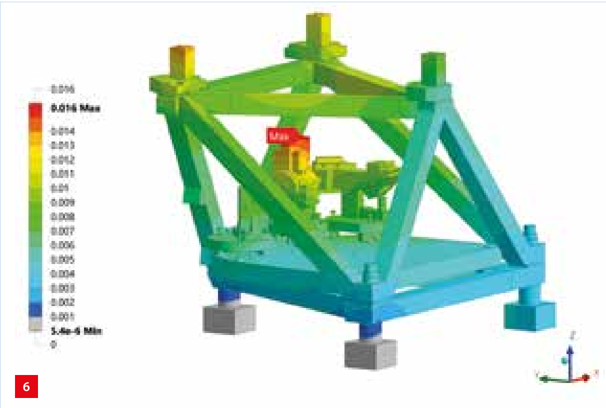
The BEU frame allows for adjustments of the optical barrel in four degrees of freedom (DoFs) – Tx, Ty, Rx and Ry, where the optical axis of the optical barrel forms the z-axis. The translations and rotations are achieved with fine-threaded differential screws. The minimum range of motion was determined to be ±725 µm and ±2.63 mrad, with corresponding resolutions of ±5 µm and ±25 µrad. After adjustment, the system is locked by fastening dedicated locking screws.

Control
Overall control of the LPS pointing direction is done by ESO, which provides separate setpoints for the BEU, JLM and FSM. The control electronics that translate these setpoints into appropriate actuator actions for the BEU and JLM were designed by Demcon focal, while TNO designed the one for the FSM. Due to the strict requirements, quite some effort had to be put in controller tuning. For the JLM, for example, this resulted in excellent dynamic performance of its piezo stage: 240 µs rise time; 480 µs settling time (10% margin); and 3% maximum overshoot. This was better than the nominal specifications provided by the supplier (PI).

Analysis
Critical performance parameters were studied by extensive analysis of the thermal and structural behaviour of the BCDS, a few results of which concerning laser beam quality and stability will be highlighted here. The quality of the laser beam output was determined using optical analysis. It was concluded that the degree of linear polarisation was above 95%, while transmission was nearly 95%. The BCDS wavefront error (excluding tip/tilt and defocus errors)



Design of one of the LRUs, the Beam Expander Unit, showing the adjustment features for alignment in four DoFs, and the kinematic mounts for easy exchangeability and high repeatability.
The inset on the right shows the three lenses, of which the middle one (L2) is actuated for focus control.



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FEM analysis of BCDS deformation due to a tilt of –90° around the x-axis; the maximum deformation (in red) of the structure is 16 μm.

was found to be under 40 nm RMS, below the requirement of 41 nm RMS.

The stability of the laser beam at the BCDS output can be affected by multiple error sources, in particular thermal effects, changing elevation and the L2 lens motion during focus actuation of the BEU. The impact of these error sources was studied using optical ray tracing combined with finite-element method (FEM) analysis.

Thermal

Concerning the thermal effects, the athermalisation strategy had been aimed at matching the thermal time scales (and associated coefficients of thermal expansion) of the individual BCDS components to prevent significant thermal gradients and transients in the system. A lumped-mass model was used to justify the assumption of equal thermal time scales and the subsequent performance of a static thermal analysis, using a uniform temperature distribution. From this analysis, the displacements and rotations of the optical components and their interface points were determined and used to calculate the resulting deviations in the transmitted laser beam. For the temperature range of 0-15 °C, the beam position error due to temperature was found to be limited to 15 μm.

Mechanical

During operation, the ELT – and hence each BCDS system – will be tilted from 0° to 60° zenith angle (i.e. from 90° to 30° elevation angle) and consequently the direction of the gravitational vector with respect to the system will change. As a result, the frame and the internal components of the BCDS, with the 80-kg laser head on top, will deform under a varying load, affecting the position and the pointing direction of the laser beam. From a FEM analysis of the BCDS tilting performance, it was concluded that the total laser beam pointing error remained below 1 μrad and was almost unaffected by the tilt of the system. Taking the 0°-tilt configuration as reference, the deviation of the laser beam position was also found to be barely affected and the calculated beam position change due to system tilt was less than 15 μm.

BEU error

The BEU error contribution derives from the linear stage that actuates L2, in particular its motion stability and the alignment accuracy of its motion axis with respect to the optical BEU axis. Based on specifications concerning the straightness, flatness and rotational errors of the BEU stage, and an alignment accuracy of better than ±1 mrad, a pointing error of less than 5 arcsec was calculated.

Summary

The summary of performance specifications at the BCDS output (Table 1) gives an indication of the optical beam quality and the stability of the laser beam pointing and position under varying environmental conditions.

Table 1 Performance specifications at the output of the BCDS.

Laser wavelength λ	589.159 nm
Laser beam magnification	3.6
Optical throughput	94.8%
RMS wavefront error	39.5 nm
Focus adjustment range	±5 λ peak-to-valley
Focus adjustment resolution	0.01 λ peak-to-valley
Pointing control range	±1,000 μrad
Pointing control resolution	0.08 μrad
Pointing control settling time (10%)	0.48 ms
Beam position stability (combined)	±30 μm
Beam pointing stability (combined)	±15 μrad

First light

This summer, Demcon focal passed the final review for its BCDS design and the first system is already under construction. Next spring, the system will be integrated with TNO's OTA for LPS system verification to reach provisional acceptance by ESO at the end of 2023. The testing procedure covers the extreme mechanical and thermal conditions the LPS will be subjected to. For example, a dedicated tip-tilt trolley was designed for the mechanical testing, while final testing will take place in a climate chamber to simulate the temperature regime on the Cerro Armazones mountain-top.

The first new LPS will be installed on one of the VLT telescopes (three of them do not have any LPS at the moment). After that, LPS systems for the ELT will be built, for which Demcon focal is planning to commission a new assembly facility in Delft. By 2027, the new TNO/Demcon LPS systems will have been installed on the ELT to provide reference to the world's biggest eye on the sky, which is then expected to achieve technical 'first light'.

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GROWING ALONG WITH THE AMBITIONS OF THE HIGH-TECH INDUSTRY

The Dutch high-tech sector has serious growth ambitions. This was proved once again by the Precision Fair being bigger than ever this year. To further strengthen the Precision Fair as the place to be for the entire precision engineering value chain, various improvements and additions to the fair set-up were successfully introduced for this 2022 edition. The network hall was expanded and the meeting areas were centralised on the exhibition floor. Another addition was the Live Stage Arena, where (keynote) presentations, panel discussions, pitches and award ceremonies took place. Overall winner: the precision engineering community.

The recent financial injection of more than 450 million euros by the Dutch government into the investment programme NXTGEN HIGHTECH has sent a clear signal. The Netherlands wants to further strengthen its position as a front-runner in high-tech, aiming to make the Dutch high-tech equipment ecosystem one of Europe's leading high-tech clusters by 2030. A logical step for a country that is big in micro- and nanotechnology and in which the high-tech sector is responsible for about 50 per cent of all R&D investments.

EDITORIAL NOTE

This report is in part based on a press release by Precision Fair organiser Mikrocentrum.

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However, more is needed to strengthen that pioneering role. It requires even more sharing of knowledge and connecting parties from the entire (international) high-tech value chain. This was also confirmed during the 21st edition of the Precision Fair, which Mikrocentrum organised on 16 and 17 November in the Brabanthallen in Den Bosch (NL). The fact that the high-tech sector has serious growth ambitions is also evident from the fact that the Precision Fair was bigger than ever this year. Over 5,000 visitors, 330 exhibitors and 50 speakers met on the exhibition floor over two days. "We see now more than ever that the entire precision engineering value chain needs to meet, share knowledge and innovate together," says Bart Kooijmans, Precision Fair programme manager at Mikrocentrum. "That is extremely important, because by visiting and helping each other, you arrive at new, groundbreaking innovations and solutions for the current major challenges. In addition, we see that the Precision Fair also attracts new visitors and also manages to attract the next generation of precision engineers."

One of the exhibitions halls, with a presentation area on the front. (Photos: Mikrocentrum)

Live Stage Arena

In order to strengthen and even further facilitate networking and knowledge sharing, the Precision Fair was expanded with new elements. Kooijmans says, "For example, the network hall where industry associations, universities of technology and of applied sciences, knowledge institutions, start-ups and high-tech projects can meet was expanded, the meeting areas were centralised on the exhibition floor so that visitors and exhibitors could easily explore a first collaboration with each other, and we added the Live Stage Arena."

This Live Stage Arena was also where prominent industry figures and experts shared their views on the current challenges. One example is a panel discussion that was held on the impact of the National Growth Fund investment

One of the panel discussions in the Live Stage Arena.

Impressions from the exhibition floor.

programmes NXTGEN HIGHTECH, PhotonDelta (integrated photonics) and Katapult (public-private partnership between the vocational education community and industry). During the Precision Fair edition of the Techcafé, the joint DSPE-Mikrocentrum initiative, the challenges in the supply chain were on the agenda, illustrated by questions such as "How do we ensure that we work together even better as a chain?" and "How can I, as an SME, better support the OEM?"

Young tech talent

The high-tech industry's growth ambition entails another major challenge: finding young tech talents. To put these talents in the spotlight, the Precision Fair offered a solid Young Talent programme this year. Students, Ph.D. students and start-ups could pitch their projects here, allowing them to further develop their power skills and make new contacts. A student tour of the exhibition floor was organised for the first time and DSPE took the initiative to organise bus trips (see the text box) to the fair.

Talking about talents, awards were handed out in the Live Stage Arena. Mikrocentrum presented two Boost Your Talent Awards in collaboration with KIVI (the Dutch Royal Institute of Engineers) and international engineering platform & community Wevolver. Lieke de Visscher of the Eindhoven-based Force Fusion team won a €5,000 training check from Mikrocentrum with her team, and Tijmen Seignette won a marketing check worth €5,000 from Wevolver for his M.Sc. research at Delft University of Technology into ground reaction forces in running-specific prostheses. Under the auspices of DSPE, the Rien Koster Award (for a senior talent) and Wim van der Hoek Award were presented; see page 30 ff.

Keynote by MIT professor

David Trumper, MIT Professor of Mechanical Engineering. (Photo: MIT)

At the first fair day, David Trumper, Professor of Mechanical Engineering at the renowned MIT (Cambridge, MA, USA), presented a keynote on the physical foundation of precision engineering. The many challenges we face as a world also require knowledge of physical phenomena, Trumper said, underlining the importance of precision mechatronics and the proper training of mechatronics.

"We are extremely proud that David wanted to share his experience and vision with the audience at the Precision Fair," says event manager Bart Kooijmans. "It also shows that we as Dutch high-tech not only face certain challenges, but that we can also work together and learn from each other beyond our borders." It was Trumper's pleasure to visit the Netherlands, which he sees as one of the most important countries when it comes to precision mechatronics. "The technical universities in Delft, Eindhoven and Twente and companies like Philips and ASML make the Netherlands a strong proposition."

By bus to the fair

In an era when the Netherlands plays a key role in the global high-tech industry, connecting well-educated engineers of the future with leading companies is more important than ever. That is exactly what DSPE aimed to do during the second day of the Precision Fair. Buses were arranged to accommodate transportation to the fair for students from the student associations Dispuut Taylor (Delft University of Technology) and Isaac Newton (University of Twente). Approximately 110 students visited the fair through this initiative.
The buses were sponsored by specialist in low-flow fluidics handling technology Bronkhorst (Twente) and high-end technology developer and producer Demcon (Delft and Twente). Their representatives had ample opportunity to talk to the students and get them enthused about the kind of career a mechanical engineer can expect in this field. Lunch for the students was also provided by the two companies and VDL ETG, which gave them the opportunity to show their stand demonstrators to the students.

DSPE would like to thank the sponsors and the students for taking part in this activity with great enthusiasm and interest.

RIEN KOSTER AWARD TO ENTHUSIASTIC INSPIRER AND TEAM PLAYER

During the 21st edition of the Precision Fair, the Rien Koster Award was presented under the auspices of DSPE. Hans Vermeulen, senior principal architect at ASML and part-time professor at TU/e, received the prize for his tireless efforts in promoting and innovating in the field of mechatronics and precision engineering.

The Rien Koster Award is given to a mechatronics engineer/designer who has made a significant contribution to the field of mechatronics and precision engineering. The jury, now chaired by Ton Peijnenburg, deputy general manager and manager Systems Engineering at VDL ETG, uses four criteria in the assessment: oeuvre, creativity, relevance (social and commercial) and professional appearance. Also, the winner must have been working in the profession for at least fifteen years, have put theory into practice, contributed to the promotion of the profession, and know how to enthuse colleagues. He/she needs to have demonstrated exceptional competence and creativity, and achieved appealing results, which are recognised and acknowledged internally and externally.

The award was presented for the ninth time on the first day of the Precision Fair 2022, 16th November. On behalf of the jury, Rien Koster, after whom the prize is named, presented the award to prof.dr.ir. Hans Vermeulen, senior principal architect EUV Optics System at ASML, part-time professor of Mechatronic System Design at Eindhoven University of Technology (TU/e), and lecturer at the High Tech Institute.

Precision mechanics and mechatronics

Vermeulen has built up an enormous track record by successfully applying well-known design principles for precision mechanics and mechatronics on the one hand, and training and enthusing a new generation of precision engineers on the other. After obtaining his Ph.D. on the design of a precision machine tool, he started working for Philips CFT (*Centrum voor Fabricage Technieken* [Centre for Manufacturing Technologies]). There he worked on semiconductor equipment, including at a CFT site in the US.

Presentation of the Rien Koster Award 2022 under the auspices of DSPE. From left to right namesake Rien Koster, winner Hans Vermeulen, jury chairman Ton Peijnenburg, and DSPE president Hans Krikhaar. (Photo: Mikrocentrum)

In 2007 he joined ASML, the current global market leader for lithography machines. There he has held various, ultimately leading positions within Development & Engineering and Research. In 2015, he was appointed part-time professor of Mechatronic System Design within the Control Systems Technology group of the TU/e department of Mechanical Engineering.

New book

In his roles at ASML and TU/e, Vermeulen is a driving force behind expanding the field. He pays attention to the basics and the history, as well as to new developments. For a long time, he was chairman and initiator of the National Mechatronics Working Group, which was set up to continue to stimulate sufficient attention for research in the field at high-tech companies and university departments outside Philips. Two years ago, he and his fellow professors from Delft and Twente, together with DSPE, took the initiative to compile a new standard work on design principles. With this updated edition of the existing books in this field, they follow in the footsteps of their predecessors, including Rien Koster. The precision industry contributes technological feats that are presented as examples on a special website and included in the book. The website went live at the Precision Fair and the book will be published in 2025 under the title "Design Principles for Precision Mechatronics".

Inexhaustible energy

According to the jury and the referents it consulted, Vermeulen is characterised by his enormous energy and drive, his ability to explain things well and make them accessible to a wide audience, his historical awareness and his willingness to collaborate. "What struck me most about Hans was his inexhaustible energy. I still see that today, for example with driving the creation of a new version of "The Devil's Picture Book" (by Wim van der Hoek, the founder of the field of precision engineering in the Netherlands and the predecessor of Rien Koster, ed.). For me, Hans is an inspirer in the field, not only technically, for precision mechanics, but above all personally: how do you make progress as a team?" Vermeulen is a team player who allows others to score and gives them a lot of space within a collaboration, according to the jury. Frequently heard keywords were: "Solid, hardworking, thorough, enthusiastic, can-do mentality."

The importance of designing

With its Rien Koster Award, DSPE wants to highlight to the precision industry the importance of designing. In this industry, which can broadly be dubbed the 'high-tech systems' sector, the Netherlands plays a leading role globally, of which the book by Vermeulen *et al.* will once again give testimony. As a group leader at Philips CFT and a professor at TU/e and the University of Twente, the award's namesake Rien Koster has made a major contribution to the Netherlands' position in this sector. Koster is also the author of the renowned textbook *Constructieprincipes voor het nauwkeurig bewegen en positioneren* ("Design principles for precision movement and positioning"), one of the predecessors of the new book. The Rien Koster Award comprises a sum of money, donated by VDL ETG, and a trophy made by students of the Leidse instrumentmakers School.

Continue on page 32

WIM VANDER HOEK AWARD FOR BETTER MEASUREMENT OF GRAVITATIONAL WAVES

During the second day of the Precision Fair, the Wim van der Hoek Award was presented under the auspices of DSPE. The prize went to Dennis Struver, who designed an active vibration isolation system for cryogenic application at JPE in Maastricht-Airport (NL) and subsequently graduated on this design from Eindhoven University of Technology (TU/e). The system works at extremely low temperatures to make a better, more sensitive gravitational-wave detector. According to the jury, his design is a "best practice" of the design principles for precise movement and positioning in the spirit of Wim van der Hoek. "Especially the clever folding of the construction, because of the limited space, and the use of a one-piece straight guide are fine examples of innovativity."

The Wim van der Hoek Award (also known as the Constructors Award) was introduced in 2006 to mark the 80th birthday of the Dutch doyen of design engineering principles, Wim van der Hoek (1924-2019). The Constructors Award is presented every year to the person with the best graduation project in the field of design in mechanical engineering at a Dutch or Belgian university of technology or university of applied sciences. This award includes a certificate, a trophy made by the Leidse instrumentmakers School and a sum of money, sponsored by TU/e institute EIASI.

Criteria for the assessment of the graduation theses include the quality of the design, substantiation and innovativeness, as well as suitability for use as teaching materials. The jury, under the presidency of DSPE board member Jos Gunsing (MaromeTech), received a total of five nominations, coming from Avans University of Applied Sciences in Breda (NL), Fontys Engineering University of Applied Sciences in Eindhoven (NL), KU Leuven University (Belgium), TU/e and the University of Twente (UT) in Enschede (NL).

The complete Wim van der Hoek Award 2022 tableau, from left to right: the nominees Jeroen Raijmann (Fontys), Roy Kelder (UT), Dennis Struver (TU/e), Alexis Van Merris (KU Leuven) and Julia Poelman (Avans); and the jury members Johan Vervoort (Vervos Technologies), Maurice Teuwen (JPE), Hans Steijaert (Vanderlande), Marc Vermeulen (ASML), Wouter Vogelesang (VH Consult) and Jos Gunsing (MaromeTech). (Photos: Mikrocentrum)

Even more sensitively

The Wim van der Hoek Award 2022 eventually went to Dennis Struver, who studied Mechanical Engineering at TU/e. He graduated this spring on the design of a vibration isolation system for application under cryogenic conditions. This system can make a gravitational-wave detector even better and more sensitive. Gravitational waves were predicted by Albert Einstein's general theory of relativity, and astronomers study these very weak signals that arise in the deep universe, for example when two black holes collide. Only since 2015 have direct measurements been possible, with kilometers-long detectors built in the US and Italy. Work is currently underway in Europe on a successor that – thanks partly to Struver's design – should be able to measure even more sensitively and thus detect even more gravitational waves. This is the Einstein Telescope, the location for which has not yet been determined. One of the candidates is the Maastricht-Aachen-Liège triangle, where the detector could be installed deep underground in the marl, protected from all above-ground disturbances.

Well-thought-out design

The Einstein Telescope should get its improved sensitivity, among other things, from working at ultra-low temperatures. This requires cooling, but commercially

The winner of the Wim van der Hoek Award 2022, Dennis Struver, with the trophy associated with the prize in the bottom right corner.

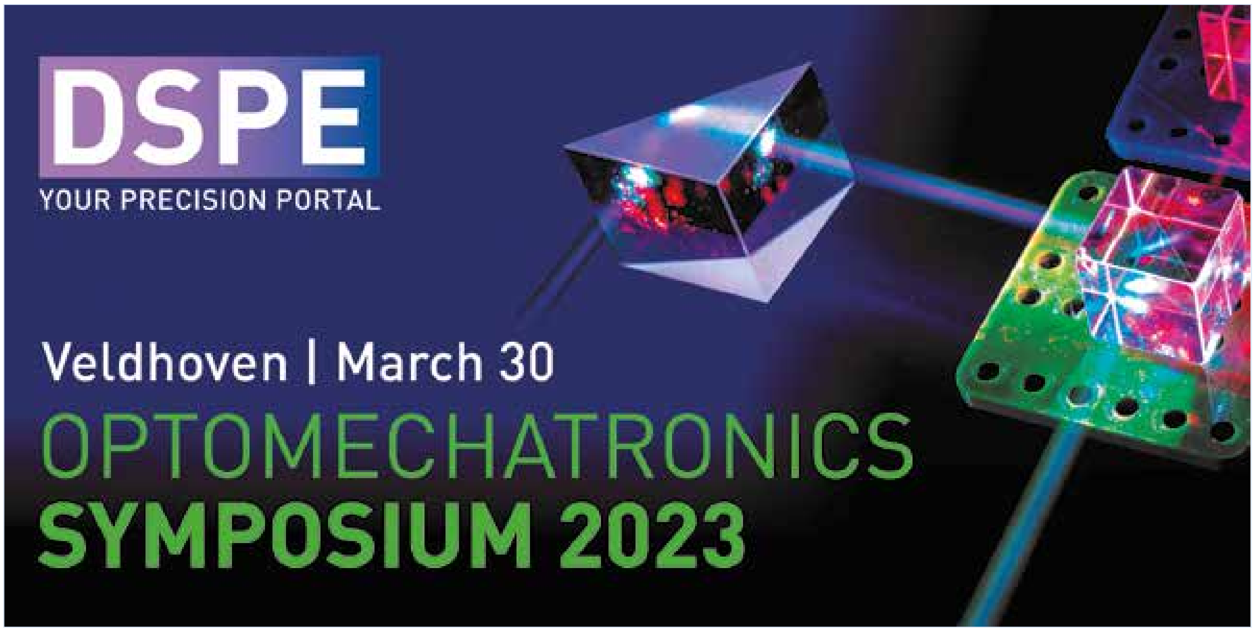
available cryocoolers produce noise that interferes with the measurement. Struver designed a cryogenic active vibration isolator to counteract the effect of the noise. "A very elegant design," the jury judged. "Dennis has shown that he is perfectly capable of coming up with an innovative mechanical and mechatronic design, including control, and analysing it for critical aspects. For a well-thought-out design, he looked at various design principles and combined the final application with thermal decoupling of the system, to prevent heating by the environment. He has great inventiveness and analytical skills and works very independently, although he also knows how to approach people for relevant input." According to the jury, Struver's design is a "best practice" of the design principles for precise movement and positioning in the spirit of Wim van der Hoek. "Especially the clever folding of the construction, because of limited space, and the use of a one-piece straight guide are fine examples of innovativity." Unfortunately, due to the late delivery of components, he was unable to build the complete system in time for testing. After completing his graduation work, he took tests later on his own initiative. The jury appreciates this effort.

Completing the circle

Struver carried out his assignment at JPE in Maastricht-Airport. This precision technology company specializes in, among other things, the development of scientific instruments that work at cryogenic temperatures, for example in a satellite in space, in a telescope on top of a high mountain, or in a gravity detector underground. In the early 1980s, JPE founder Huub Janssen was one of the last graduates of Wim van der Hoek, who in addition to his work at Philips also had an appointment as a part-time professor at the TU/e. With the prize named after Van der Hoek being awarded to Dennis Struver, the circle is now complete.

FROM PHYSICS TO PRACTICE

Next year, the DSPE Optomechatronics Week on 27-30 March 2023, featuring a Symposium & Fair in Veldhoven (NL) preceded by the three-day Optomechanical System Design course, will be a completely live event. The entire optomechatronic design process, from A to Z, leading from physical phenomena to practical solutions, defines the red line of the symposium. The programme features speakers from renowned organisations, ranging from ASML to Zeiss, and from TNO to Trioptics.



This will be the fifth edition of the DSPE initiative that started in 2013 as the DSPE Optics and Optomechatronics Symposium in Eindhoven (NL). Later editions were held in Delft (NL) in 2015, Aachen (Germany) in 2017, and again in Eindhoven in 2019, as part of a DSPE Optics Week, which also featured advanced courses.

The DSPE Optomechatronics Symposium 2023 will be held in the atmospheric ambiance of the Mikrocentrum headquarters in Veldhoven.

The DSPE Optomechatronics Week 2023 features a one-day Symposium & Fair preceded by the three-day Opto-mechanical System Design course. This course, 27-29 March in Eindhoven, is already fully booked; the next edition is scheduled for the end of 2023. The Symposium on 30 March is organised by DSPE in collaboration with the German photonics cluster Optence and the independent high-tech knowledge institute Mikrocentrum, which will act as the host at its premises in Veldhoven. The programme is listed below.

The optomechatronic design process, leading from physical phenomena to practical solutions, will be the red line of the symposium, says chairman of the organising committee Cor Ottens, system architect at ASML and chairman of the DSPE Special Interest Group Optics. "We want the participants to be inspired by the presentations, providing them with takeaways that are relevant to their own design practice. We have therefore selected speakers who do not deliver marketing pitches but can contribute in-depth presentations, naturally respecting the boundaries of confidentiality."

Cor Ottens, chairman of the organising committee for the symposium: "We want the participants to be inspired by the presentations, providing them with practical takeaways."

There are not many conferences or symposia dedicated to the combination of optics and mechatronics, according to Ottens. "For example, DSPE has its conference on precision mechatronics and our partner Optence organises optics-centred events. But it's optomechatronics that you see everywhere, from the once-famous CD players and laser printers to giant telescopes and extremely precise lithography machines. So, you not only have to design the optics but also the hardware, mechanics and electronics, to fix and manipulate these optics, thus developing a total solution."

The symposium is targeted at engineers and architects who are closely involved in designing and building optomechatronic systems. Registration is open via the symposium website.

Invitation to exhibit

Companies and knowledge institutes are invited to exhibit at the fair associated with the DSPE Optomechatronics Symposium 2023. They will have an 8 m^2, stand and their company logo with URL will be featured on the symposium website. Interested organisations can contact the event manager: Julie van Stiphout.

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INFORMATION AND REGISTRATION
www.dspe.nl/optomechatronics

Programme

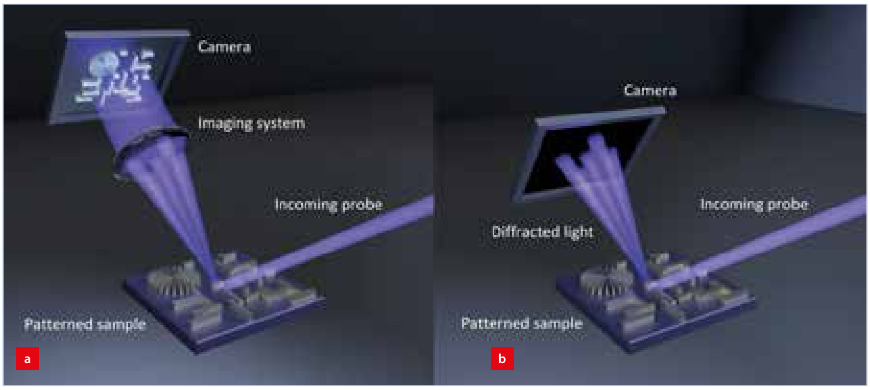
- Welcome by the chairman of the day
  Frank Schuurmans
  Vice President Research at ASML

- Keynote
  EUV High-NA Lithography – Optomechatronical aspects for high-precision metrology
  ZEISS (speaker details will follow)

- Deformable Mirror Development at TNO
  Stefan Kuiper
  Mechatronic System Architect at TNO
  TNO is developing Deformable Mirror (DM) technology, targeted for aberration correction in high-end Adaptive Optics systems in the field of astronomy, space telescopes, and laser communication. The heart of this deformable mirror technology is a unique actuator technology based on the hybrid-variable-reluctance-principle. The main advantages of this actuator technology are the inherent high reliability, linearity (> 99%), and high efficiency in terms of force per volume and unit power.
  Based on this actuator technology, TNO has built and tested a number of DMs that have found use in several applications, including ground-to-ground laser communication. Furthermore, a highly compact Fine Steering Mirror has been developed on the basis of this actuator technology, targeted for use in laser-communication systems onboard satellites. The next step on the development roadmap is the realisation of large Adaptive Secondary Mirrors (ASM) containing up to several thousands of actuators and optically-powered (concave/convex) mirror-shells of up to Ø1.4 m. These ASMs are targeted to improve the imaging performance of the world's largest astronomical telescopes. Different aspects of the DM technology will be explained in this presentation, including the actuator technology; recent experimental results will be presented; and an outlook will be given on the future development plans regarding this DM technology.

- Imaging of nanostructures without lenses
  Wim Coene
  Part-time Professor at Delft University of Technology, Director of Research at ASML
  At the end of 2018, an NWO-TTW Perspective Program was started with five academic groups in the Netherlands, on the subject of "Lensless Imaging of 3D Nanostructures with Soft X-Rays" (LINX). Within this programme, an EUV beamline has been designed and constructed at Delft University of Technology. For this, the algorithmic concept of lensless imaging (see the figure on the next page), also known as ptychography, has been developed in order to image nanostructures in future generations of chips from a number of far-field diffraction patterns.

  The table-top EUV beamline is 5 m long, and is built around a high-harmonic generation (HHG) source, which generates the harmonics in the EUV-range (10-20 nm) through interaction of a 100-W high-power IR laser with a noble gas. The EUV beam further propagates to the imaging chamber, where the coherent quasi-monochromatic EUV light is focused on the sample by an ellipsoidal mirror. The EUV light is scattered by the nanostructures at the surface of the sample, and is 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 sample stage. Such a data set provides the necessary redundancy to transform the acquired diffraction patterns into a computer-generated image of the sample by means of highly specific algorithms. The presentation will further highlight the multiple challenges that have been and are being addressed to improve the imaging resolution of the EUV beamline.



Two ways of capturing diffracted light.
(a) Conventional imaging: using an optical (imaging) system to create an image on a camera.
(b) Lensless imaging: the optical system is removed and the diffracted light is captured directly.

- Challenges and Opportunities in Gradient-Index Optics
  Andrew Boyd
  Optical Design Capability Lead at Excelitas Technologies
  A range of new manufacturing methods promise gradient-index lenses of arbitrary distribution and an expanded range of refractive index variation. These novel materials offer a new class of optical systems with improved size and mass, as well as reduced optical component count. These new GRIN (gradient-index) processes offer opportunities in both visible and infrared wavebands. This presentation will explore the new optical architectures enabled by these new degrees of freedom, such as multispectral imaging optics and low-mass avionic displays, as well the challenges ahead in design, manufacture, metrology and environmental qualification to bring this technology to mass production.

- Alignment turning for high precision optomechanical systems
  Christian Buß
  Head of R&D Alignment Turning Systems at Trioptics
  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, the use cases are very widespread. Today, the main technical challenges for alignment turning of highest-precision objective lenses are imposed by aspheric lenses, large diameter lenses, and single-micron tolerances. They often require additional pre- and post-processing to make efficient use of the alignment turning technology in the mid- to large-scale production. The smart measurement techniques and turning technology integrated in the Alignment Turning Machine from Trioptics provide a solution to achieve this increase in efficiency.
  This presentation will establish an understanding of the benefits and limitations of the alignment turning process and will compare the traditional chuck-based method of alignment turning to more modern CNC-based methods of alignment turning. Specific results will be discussed and suggestions for individual applications will be given.

- Metrology tools and solutions for actinic EUV pellicle qualification
  Andreas Biermanns-Föth
  Head of Business Section Photon Instrumentation, EUV/XUV Systems at RI Research Instruments
  EUV lithography is used for chip volume production. EUV pellicles and dynamic gas-lock windows in the scanner are corner stones for the technology. The pellicle is a thin film (≈ 50 nm thick) placed above the patterned surface of the EUV reticle, to retain particles that would have otherwise landed on the patterned side of a reticle. As these particles are then out of focus, their impact on the imaged pattern is strongly reduced from the nanometer to the micron range.

  These thin-film components must be qualified in various aspects before being used in production. In particular, the EUV transmission and reflectance at 13.5 nm in the bandwidth used in the scanner have to be quantified over the entire pellicle area, such that best quality/homogeneity for achieving the desired critical dimension in patterning is verified. RI supports the EUV lithography infrastructure with actinic metrology and test solutions and components. Based on RI's actinic EUV in-band metrology concept (AIMER^{TM}), the EUV Pellicle Reflection and Transmission Tool (EUV-PRTT) has been co-developed with ASML and has been used for pellicle production since 2020.
  This presentation will illustrate the main building blocks of the system and explain the working principle that enables the simultaneous measurement of EUV transmittance values above 90% and reflectance values as low as 0.002% with high spatial resolution and accuracy.

- Adaptive wafer table for enhanced image plane conformity to both aerial image and wafer load geometry
  Sander Hermanussen
  Doctoral Candidate in Control Systems Technology at Eindhoven University of Technology
  In line with Moore's law, the transistor count on integrated circuits doubles every two years, both by decreasing the feature size as well as stacking more functional layers. This results in more exacting requirements, not only of the projecting optics of photolithography systems, but also of the wafer table that positions the silicon wafer for lithographic exposure.

  This presentation presents an overview of the design of a deformable wafer table. 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, a prototype actuator has been manufactured in collaboration with Penn State University. During exposure, a deformable wafer table can compensate for mismatch between the aerial image and the wafer surface, similar to how an adaptive mirror system works. Moreover, dynamic excitations from the wafer positioning system can be damped. Additionally, the adaptive wafer table has the potential to mitigate friction during wafer load. In current systems, microscopic sliding between the wafer and the wafer table causes irreproducible overlay errors and degrades the tribological properties of the wafer table. By deforming the wafer table conformally to each wafer before wafer load, overlay position can be predicted in advance, and wear is reduced.

- Opto-mechanical applications in the machines of ASML
  Cor Ottens
  System Architect at ASML
  Why is optomechanics important for ASML? More and smaller structures are needed in the chips to increase the calculation power and memory capacity. The currently possible linewidth is in the nanometer range.
  In ASML's lithography machines, a pattern on a reticle or mask is exposed onto a wafer, with the number of layers on a wafer going up to 300. Therefore, the optical alignment of the layers or patterns 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. The accuracy of the measurement and positioning system must be within this 2 nm. Stability of the mechanics determines the major part of the accuracy; in particular, especially thermal drift is the biggest contributor. To reach the tight stability specifications, the correct mechanical designs must be applied that keep the optical elements in position even under extreme influences of temperature, vibrations, forces and stress. This presentation provides insight into the optomechanical design principles that are used in the machines of ASML to make the high accuracies possible.

- System design of optomechatronic medical devices
  Michiel van Beek
  Sr. Group Lead Physics & Optics at Sioux Technologies
  The field of pathology, including both structural as well as molecular analysis, is transforming from analogue into digital, requiring mechanisation and automation of visual and manual functions previously performed by human operators. System design of medical devices needed for this transition not only requires optical and mechatronic design, but also advanced image processing as well as significant effort for quality assurance, including tolerancing and calibration as well as regulatory aspects. This presentation will focus on system design aspects that are relevant for the design and realisation of a system for automated tissue dissection.

- Automated Assembly and Testing of Electro-Optical Systems
  Tobias Müller
  Technical Director and Co-founder at Aixemtec
  With the aid of a modular and open assembly and test platform, processes for the automated production of electro-optical systems can be easily implemented. The assembly and testing of electrooptical systems often requires the optical coupling of single- or multimode fibres, collimation of lasers, assembly of resonators, visual inspection of optical elements, and many more.

  In many cases, including fibre-to-waveguide alignment or the alignment of a short-focal-length lens, such as an FAC, precision down to the deep sub-μm range must be achieved. Combined with a wide range of components and products, this results in high complexity for test and assembly machines to serve a broad application spectrum, especially in research and development environments. Based on Aixemtec's modular and open assembly and test platform, a highly flexible system has now been created that allows for testing and assembly tasks for lasers, camera/vision systems or silicon photonics/PIC (photonic integrated chips) systems to be performed efficiently in an automated manner. This platform provides the ability to address specific requirements depending on the end application.

  The essential tools and process chains include:
  - Modular machine architecture with open-source programming interface for (optional) independent process development of IP-relevant processes.
  - Generic feeding and handling solutions for the various optical elements needed.
  - Simultaneous precision alignment of up to three components with collaborating 6-axis micromanipulators.
  - Processing of single fibres and fibre arrays, mirrors, lenses, chips, and many more.
  - Temperature-controlled assembly and test station, compatible with single chips, butterfly packages and customised packages.
  - Motorised and automated landing electric needle probing unit.
  - Highly integrated sensor system for pre-positioning and active alignment in up to six degrees of freedom.
  - Precision tools for automated UV-curing adhesive bonds.

ECONOMIC AND SOCIAL IMPACT

In Wim van der Hoek's younger years, working at Philips and Eindhoven University of Technology in the 1950s and 1960s, sustainability and the energy transition were not yet the social themes they are today. Nevertheless, he already pursued energy-efficient design ('green precision'), defining energy management as one of his design principles, and had an eye for the economic impact and social responsibility of the mechanical designer. He gave testimony of this in his inaugural address, as described in DSPE's Dutch-language book "Wim van der Hoek (1924-2019) – A constructive life". After philosophising about the desired qualities of a designer and the nature of his work, designing constructions, he broadened the perspective beyond engineering.

"Wim van der Hoek (1924-2019) – A constructive life"

After Wim van der Hoek passed away in early 2019, DSPE took the initiative to publish a book (in Dutch) about the Dutch doyen of design principles (Figure 1). It covers his formative years, including his World War II 'adventures', his career at Philips and Eindhoven University of Technology, his breakthrough ideas on achieving positioning accuracy and control of dynamic behaviour in mechanisms and machines, and their reception and diffusion. It concludes with his busy retirement years in which he continued to tackle design challenges, technical as well as social, believing that technology should support people.

His specialism, dynamic behaviour and positioning accuracy, was the main subject of his part-time professorship at Eindhoven University of Technology, from 1961 to 1984. There, he endeavoured to enthuse first-year students in the mechanical engineering profession and to teach fourth-year students (some 600, over the years) mechanical design. In his lecture notes, he built on his research at Philips. He collected examples of designs that were lightweight, sufficiently stiff and play-free with regard to dynamics in his famous "The Devil's Picture Book" (*Des Duivels Prentenboek*), which he presented as a source of inspiration for upcoming and experienced designers. Now, this book about Wim van der Hoek conveys the same enthusiasm.

Figure 1. Lambert van Beukering & Hans van Eerden (eds.), "Wim van der Hoek (1924-2019), Een constructief leven – Ontwerpprincipes en praktijklessen tussen critiek en creatie", ISBN 978-90-829-6583-4, 272 pages, €49.50 (€39.50 for DSPE members) plus €6.50 postage, published by DSPE in 2020.

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Social task

The results of all the design work, i.e. the constructions, meet a need and so economic factors play a role, stated Van der Hoek. "Each construction must therefore be economically justified and functionally and ergonomically sound, taking into account all aspects of manufacturability and possibly saleability." This economic aspect is not a 'bummer, but rather can give the designer's work an extra depth, for example by generalising and standardising the solutions found. Van der Hoek wanted to broaden the 'rules of the game' for the designer even further. He referred to this – it was 1962 – to "the responsibility that we bear with our unique circumstances and resources – including this beautiful university of technology under construction – for the habitability of this planet." Here he harked back to his war experiences.

"You will recall how prominent Allied leaders pointed out at the close of World War II that peace is won only when all mankind will be assured of freedom from fear, hunger and want. (...) With our technical knowledge, if adapted to the needs and mentality in the region concerned, we can contribute a lot to this. It is up to the politicians to transfer some of the budgets spent around the world on armaments to multilateral aid and accelerated development."

Learning to design

Given this enormous task, it was important not to let any (design) talent go to waste, concluded Van der Hoek. All the more so the question posed earlier arose: "Can one learn to design, can one design more efficiently, more consciously and better?" Yes, of course. "Through these two learning opportunities (presented earlier in his lecture, ed.) – gaining material for analogies through beholding, and gaining overview and insight through study and contemplation – not every designer has to wrestle through all the design problems from prehistoric times."

The limited time available for this at a technical college required a balance between the two options: "searching for inspiration together with the student, 'scanning the field for ideas', on the other hand challenging him to apply, to disclose, his knowledge smoothly and logically". In this way, Van der Hoek found his desired balance in the method of dialogue, the confrontation between critique and creation, the interaction between analysis and synthesis. In the educational situation it was not primarily about the problem and the solution found, but about the method of approach and analysis of the problem, the 'game between idea and critique'.

Motivation

Ultimately, it came down to the motivation of the (future) designer. "Teaching is not filling barrels, but lighting a sacred fire", Van der Hoek would formulate later. To conclude his inaugural address, he therefore addressed the 'Ladies and Gentlemen students'.

> "Why did you choose to study engineering? Was it only the attractive prospect of a socially highly classified and reasonably paid position that attracted you, or did the technology itself fascinate you? Did you choose mechanical engineering, because you find machines interesting and sometimes even beautiful and because as a child you were already enthusiastic about building something yourself from Meccano and the like? Perhaps you are like me then and now you have difficulty seeing the forest of your creative dreams among the undoubtedly beautiful trees of mathematics, physics and mechanics (defined by Van der Hoek as the supporting basic disciplines for a mechanical designer, ed.). But then take comfort: look and climb these trees, while you still have the chance, and later, when you have taken more distance, you will see how unusually beautiful the forest is, and more than that: you will see the road there. You will feel at home in it and you will have all the possibilities for creative work that you dreamed of when you arrived here. It is up to you to also use these possibilities to your satisfaction and where possible to the benefit of your fellow human beings, and not to falter untimely and give up your ideal. I would like to help you with this to the best of my ability."

Fun with economy car

2

The cart for investigating the influence of the spring suspension. A few wooden blocks could be slid between its parts, to convert the vehicle from suspended to unsuspended.

The research in Van der Hoek's department at Eindhoven University of Technology (THE) was driven by questions from outside, among other things, and could lead to special projects that were realised in the lab. An appealing example was the economy car. The department of Vehicle Technology of Prof. Wim Koumans, previously head of R&D at shock absorber manufacturer KONI, had been asked to participate in the Economy Marathons organised by Shell. The task was to drive as economically as possible at an average speed of 15 km/h with specially developed cars.

However, the lab was not equipped to build such a vehicle with the necessary knowledge and precision. The request to participate in the project was received with enthusiasm by Van der Hoek's group. Assistant professor Nic van Dijk applied the theories of his teacher to the design and construction of the vehicle. THE won the first race with it in 1978 and set a world record of 1:443 litres/km. When designing the vehicle for the second race, THE 2, the question arose whether it should be fitted with a spring suspension or should remain unsuspended like the first vehicle. Prof. Koumans had to be convinced that suspension provided a lower rolling resistance than non-suspension. Van Dijk came up with a kind of cart that could be changed from suspended to rigid with a few wooden blocks, whether or not stuck between the springs.

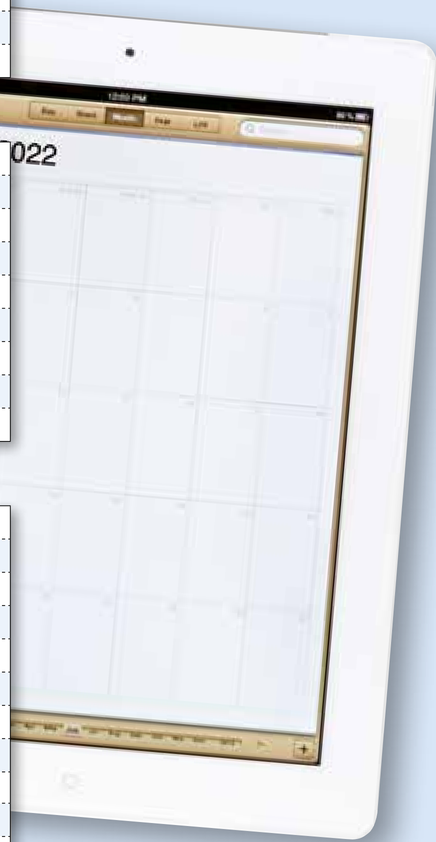
A test was done with that. A plank has been laid from a chair that sloped down to the floor, Van Dijk's colleague Peer Brinkgreve later recalled. "The cart could drive from there, in suspended and unsuspended condition. About two meters metres away was a slat that the car had to cross. That was the disruption (to test the effect of the suspension, ed.). And what did you see? Of course, what had to come out: the suspended model reached twice as far as the unsuspended model. Like little children, the crowd cheered for fun." THE 2 set a new world record of 1:732 litres/km.

3

Nic van Dijk in the THE 2 economy car.

ECP^2 COURSE CALENDAR

COURSE (content partner)	ECP^2 points	Provider	Starting date
FOUNDATION			
Mechatronics System Design - part 1 (MA)	5	HTI	5 June 2023
Mechatronics System Design - part 2 (MA)	5	HTI	30 October 2023
Fundamentals of Metrology	4	NPL	to be planned
Design Principles	3	MC	8 March 2023
System Architecting (S&SA)	5	HTI	13 March 2023
Design Principles for Precision Engineering (MA)	5	HTI	3 July 2023
Motion Control Tuning (MA)	5	HTI	19 June 2023
ADVANCED			
Metrology and Calibration of Mechatronic Systems (MA)	3	HTI	21 March 2023
Surface Metrology; Instrumentation and Characterisation	3	HUD	to be planned
Actuation and Power Electronics (MA)	3	HTI	20 June 2023
Thermal Effects in Mechatronic Systems (MA)	3	HTI	27 June 2023
Dynamics and Modelling (MA)	3	HTI	to be planned (Q4 2023)
Manufacturability	5	LiS	to be planned
Green Belt Design for Six Sigma	4	HI	29 March 2023
RF1 Life Data Analysis and Reliability Testing	3	HI	13 March 2023
Ultra-Precision Manufacturing and Metrology	5	CRANF	to be planned
SPECIFIC			
Applied Optics (T2Prof)	6.5	HTI	to be planned (Q1 2023)
Advanced Optics	6.5	MC	23 February 2023
Machine Vision for Mechatronic Systems (MA)	2	HTI	upon request
Electronics for Non-Electronic Engineers – Analog (T2Prof)	6	HTI	to be planned
Electronics for Non-Electronic Engineers – Digital (T2Prof)	4	HTI	to be planned
Modern Optics for Optical Designers (T2Prof) - part 1	7.5	HTI	to be planned (Q3 2023)
Modern Optics for Optical Designers (T2Prof) - part 2	7.5	HTI	20 January 2023
Tribology	4	MC	7 March 2023
Basics & Design Principles for Ultra-Clean Vacuum (MA)	4	HTI	19 June 2023
Experimental Techniques in Mechatronics (MA)	3	HTI	30 May 2023
Advanced Motion Control (MA)	5	HTI	23 October 2023
Advanced Feedforward & Learning Control (MA)	3	HTI	10 May 2023
Advanced Mechatronic System Design (MA)	6	HTI	to be planned
Passive Damping for High Tech Systems (MA)	3	HTI	to be planned (Q4 2023)
Finite Element Method	2	MC	9 March 2023
Design for Manufacturing (Schout DfM)	3	HTI	to be planned (Q2 2023)



ECP^2 program powered by euspen

The European Certified Precision Engineering Course Program (ECP^2) has been developed to meet the demands in the market for continuous professional development and training of post-academic engineers (B.Sc. or M.Sc. with 2-10 years of work experience) within the fields of precision engineering and nanotechnology. They can earn certification points by following selected courses. Once participants have earned a total of 45 points, they will be certified. The ECP^2 certificate is an industrial standard for professional recognition and acknowledgement of precision engineering-related knowledge and skills, and allows the use of the ECP^2 title.

WWW.ECP2.EU

Course providers

- High Tech Institute (HTI)
  WWW.HIGHTECHINSTITUTE.NL
- Mikrocentrum (MC)
  WWW.MIKROCENTRUM.NL
- LiS Academy (LiS)
  WWW.LIS.NL/LISACADEMY
- Holland Innovative (HI)
  WWW.HOLLANDINNOVATIVE.NL
- Cranfield University (CRANF)
  WWW.CRANFIELD.AC.UK
- Univ. of Huddersfield (HUD)
  WWW.HUD.AC.UK
- National Physical Lab. (NPL)
  WWW.NPL.CO.UK

Content partners

- DSPE
  WWW.DSPE.NL
- Mechatronics Academy (MA)
  WWW.MECHATRONICS-ACADEMY.NL
- Technical Training for Prof. (T2Prof)
  WWW.T2PROF.NL
- Schout DfM
  WWW.SCHOUT.EU
- Systems & Software Academy (S&SA)

25 January 2023
Cleanliness & Contamination Control Circle
First edition of knowledge sharing event organised by VCCN (Dutch Association for Contamination Control). Tentative location is Hoevelaken (NL).

WWW.VCCN.NL

14 February 2023, Veldhoven (NL)
Manufacturing Technology Conference 2023
This conference is organised by the Knowledge Sharing Centre, an independent platform that facilitates knowledge assurance and sharing in the Dutch manufacturing industry, and Mikrocentrum. The aim is to boost the knowledge about manufacturability for engineers and help them look for possibilities that did not exist before. Presenters include representatives from ASML and Thermo Fisher Scientific.

WWW.KSCEVENTS.NL

6-7 March 2023, Tucson, AZ (USA)
ASPE Winter Topical Meeting 2023
A Precision Optical Metrology Workshop.

WWW.ASPE.NET

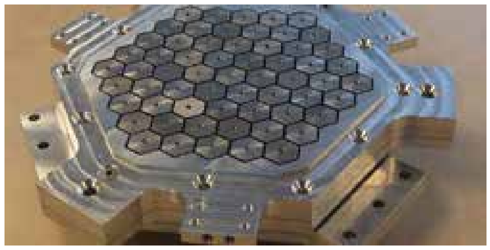
14-15 March 2023, Edinburgh (UK)
Lamdamap 2023
The 15th International Conference and Exhibition on Laser Metrology, Coordinate Measuring Machine and Machine Tool Performance.

WWW.EUSPEN.EU

21 March 2023, Rotterdam (NL)
ZIE Hi Delta 2023
Knowledge and network event for the South Holland technological industry.

WWW.HIDELTA.NL

27 March 2023, Düsseldorf (DE)
Gas Bearing Workshop 2023
Fifth edition of the initiative of VDE/VDI GMM and DSPE, focused on gas-bearing components and technology for advanced precision instruments and machines.



WWW.GAS-BEARING-WORKSHOP.COM

27-30 March 2023, Eindhoven (NL)
DSPE Optomechatronics Week 2023
This event kicks off with the (fully booked) three-day Optomechanical System Design course, followed by the Optomechatronics Symposium & Fair on Thursday.
See the preview on page 34 ff.

WWW.DSPE.NL/EDUCATION
WWW.DSPE.NL/OPTOMECHATRONICS

29-30 March 2023, Den Bosch (NL)
AM for Production
New knowledge and networking event about the industrial breakthrough of additive manufacturing (AM).

WWW.AMFORPRODUCTION.NL

12-13 April 2023, Den Bosch (NL)
Food Technology 2023
Knowledge and network event about high-tech innovations in the food industry, working towards an efficient and sustainable future of food.

WWW.FOOD-TECHNOLOGY.NL

18 April 2023, Veldhoven (NL)
Clean Event 2023
Event organised by Mikrocentrum to connect professionals from the entire chain around industrial cleanliness.

MIKROCENTRUM.NL/NL/CLEANLINESS/CLEAN-EVENT

1 June 2023, Enschede (NL)
TValley Tech Conference
Event devoted to the cutting edge of robotics, mechatronics and artificial intelligence: recent developments, future possibilities and TValley partner projects.

WWW.TVALLEY.NL

7-8 June 2023, Den Bosch (NL)
Vision, Robotics & Motion
This trade fair & congress focuses on smart production automation, featuring the components for a completely integrated system: from vision and optics, robotics and motion control, to data-science solutions.

WWW.VISION-ROBOTICS.NL

12-16 June 2023, Copenhagen (DK)
Euspen's 23th International Conference & Exhibition
The event features latest advances in traditional precision engineering fields such as metrology, ultra-precision machining, additive and replication processes, precision mechatronic systems & control and precision cutting processes. Furthermore, topics will be addressed covering robotics and automation, precision design in large-scale applications, applications of precision engineering in biomedical sciences, and sustainable energy systems and precision engineering.

WWW.EUSPEN.EU

DSPE CONFERENCE ON PRECISION MECHATRONICS 2023: CALL FOR ABSTRACTS

In 2023, there will be a completely live edition of the DSPE Conference on Precision Mechatronics on 26-27 September. Once again, the stage will be set in hotel De Ruwenberg in Sint-Michielsgestel (NL), which at previous DSPE conferences provided an inspiring and relaxed atmosphere for meeting peers in precision mechatronics. The theme of this fifth edition is 'Rethinking the system' and the call for abstracts is open until 15 February 2023.

The theme, 'Rethinking the system', is inspired by current global issues, such as the drive for sustainability, the footprint of our modern society, and the scarcity of resources. There is a growing awareness that, in order to make a bright and healthy future possible, we need to rethink the current systems of production, consumption and disposal. It is encouraging to see a growing number of initiatives to search for novel manufacturing methods, alternative resources, energy-saving options and refurbishment approaches. As a result, system boundaries within which companies are operating shift and their business models are changing. In this transition, precision mechatronics can play an important role, not only by enabling research and development of novel technologies, but also by reflecting on system thinking.

The conference by and for technologists, designers and architects in precision mechatronics is targeted at companies and professionals who are members of DSPE, Brainport Industries, Mechatronics Contact Group (MCG), Mechatronic Systems Knowledge Exchange (MSKE), and selected companies/institutes. Besides oral presentations, posters and demonstrations, the conference programme features ample opportunities for discussions, networking, and sharing ideas and experiences.
The early bird registration bonus is valid until 15 May 2023.

The organising committee – Adrian Rankers, Marc Vermeulen and Annemarie Schrauwen – invites the submission of short abstracts (in English, max. one A4 page and preferably including illustrative images) for 20-minute oral presentations, demonstrations and posters. Since the demonstration of practical solutions and possibilities is important in the process of knowledge transfer and is always highly appreciated by the participants, abstracts for demonstrations are particularly welcome.

The conference location: hotel De Ruwenberg in Sint-Michielsgestel.

A template for preparing an abstract is available on the conference website. The deadline for submission is 15 February 2023 and notification of acceptance will be sent before 3 April 2023. All accepted contributions will be published as extended abstracts in the digital conference proceedings.

Abstract submission
ANNEMARIE.SCHRAUWEN@DSPE.NL

Information and registration
WWW.DSPE.NL/CONFERENCE

VOLUNTER IN THE SPOTLIGHT:
DSPE WEBMASTER PETER GIESEN

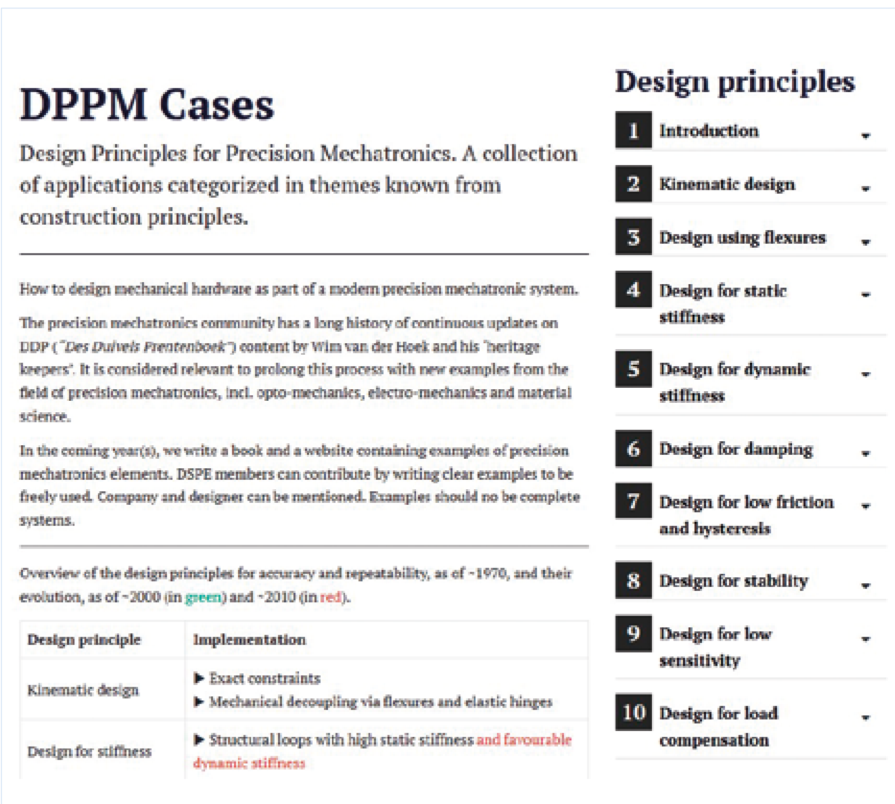
As an organisation, DSPE is mainly run by volunteers. They are selflessly committed to the society and put in many hours, often behind the scenes. With this column, DSPE wants to put its volunteers in the spotlight. The second profile introduces Peter Giesen, mechanical lead engineer in TNO's Optomechatronics department. As a long-time DSPE board member, he is the unofficial webmaster for the new DSPE website and ambitious projects such as the Thermomechanics and the Design Principles for Precision Mechatronics sub-websites.

Peter Giesen studied Mechanical Engineering at the University of Twente (NL) and graduated with Prof. Rien Koster on the design of a precision guiding mechanism for space applications. He carried out this project at TNO in Delft (NL), where he entered into service after graduating, never to leave again. Recently, he celebrated his 25th work anniversary with TNO. "From the bonus I received, I'll have to buy the watch with an inscription myself," he says with a wink. At TNO, he has been an (opto)mechatronic jack-of-all-trades, contributing to the development of scientific instrumentation, semiconductor equipment, flexible electronics and additive manufacturing. "As one of my managers used to say: 'At TNO you do work that you enjoy and if you let it fall on your toes, it hurts.' That's my motto as well. It's fun working here and I like to be a technical lead in projects. However, I'm not interested in taking up project management." At the moment, Giesen is working on optical systems for monitoring the reactor wall and plasma of ITER, the international nuclear-fusion research and engineering megaproject.

His ITER involvement illustrates Giesen's keen interest in thermomechanics, which got him working on the Thermomechanics section of the DSPE website (*www.dspe.nl/knowledge/thermomechanics*), which was launched in 2014. It was not his first involvement with DSPE. Fifteen years ago, he was a member of the committee that helped to professionalise Mikroniek's editorial standards. And in 2010, he became a DSPE board member at the instigation of current DSPE vice president Pieter Kappelhof, his then colleague at TNO.

Having demonstrated his webmaster skills with the Thermomechanics website, he was asked to support the construction of the new overall DSPE website. "I'm not a professional in this area, but it helps that I'm not put off by (information) technology and have mastered html. Following some discussions with our website provider, I had to dive deep into html and Wordpress (the site's content management system, ed.). It's not easy, because it has a large number of functions, but I always succeed in finding my way."

It does take up many hours of his free time, while he also has a busy social life. "I play tennis and sing in a pop choir, with which we even recorded a commercial for Bavaria, about Santa and Sinterklaas (his Dutch counterpart, ed.) meeting in the current strange times; it is a hit on YouTube." Nevertheless, he has been intensively involved in the latest project, the presentation of showcases on the Design Principles for Precision Mechatronics website. This is related to the initiative to update the design principles, led by the professors of precision engineering and mechatronics at the three Dutch universities of technology – Delft, Eindhoven and Twente – in association with DSPE (see the previous issue of Mikroniek). "This will run for a few years, but now that I've finished the tedious job of defining the layout, it will run smoothly. I just like to contribute."



Peter's Giesen latest website project for DSPE: the Design Principles for Precision Mechatronics website, which was launched at the Precision Fair last month.

WWW.DSPE.NL
WWW.TNO.NL

TAKING ECP2-CERTIFIED COURSES ON THE PATH TO A SENIOR ARCHITECT ROLE

Last October, Moiz Hyderabadwala, senior mechanical engineer at ASML, received a Bronze certificate from ECP2, the European certified precision engineering course programme that is a collaboration between euspen and DSPE. The ECP2-certified courses he has taken thus far, provided him with the fundamentals required to work in one of the world's leading high-tech regions specialising in mechatronics, the Netherlands. Combined with the courses he is now planning to take, they help him to grow towards a senior architect role.

Euspen's ECP2 programme grew out of DSPE's Certified Precision Engineer programme, which was developed in the Netherlands in 2008 as a commercially available series of training courses. In 2015, euspen, DSPE's European counterpart, decided to take certification to the European level. The resulting ECP2 programme reflects industry demand for multidisciplinary system thinking and in-depth knowledge of the relevant disciplines. A certificate scheme was instigated to promote participation. The Bronze certificate requires 25 points (one point equals roughly one course day), Silver requires 35 points and Gold 45 points, which qualifies a participant for the title 'Certified Precision Engineer'.

Mechatronics region

Moiz Hyderabadwala did his bachelor's in Mechanical Engineering at the Visvesvaraya National Technological University, India, and obtained his master's degree in Mechatronics and Controls at the Georgia Institute of Technology, USA. After a brief stint as a system engineer in Bangalore, India, he decided to head for the Netherlands. "I wanted to work as an engineer in the multidisciplinary field of mechatronics and in my opinion the high-tech region of the Netherlands is one of the few locations in the world that specialises in mechatronics." He was hired by ASML and worked as a mechatronics integration engineer for five years. He then switched to finite-element analysis (FEA) and is currently a senior mechanical (FEA) engineer.

His managers at ASML stimulated him to take courses to broaden his scope. "For example, my managers in the Mechanical Analysis department, Fred Huizinga and Paul Verhoeven, encourage engineers to not just think as an FEA engineer, but to try to understand their customer and his problem at a higher level, taking into account the complete mechatronics architecture of the (sub) module involved. With the mechatronics knowledge I have gained, I can collaborate more closely with the customer, thinking along with the architect and proposing simulations that can really help him."

High-tech foundation

Hyderabadwala took the courses of Mechatronic System Design, Parts 1 and 2, Dynamics and Modelling, and Motion Control Tuning. He describes them as the fundamentals required to work in the high-tech region of the Netherlands. "For example, we had a three-day troubleshooting session with one of ASML's suppliers. The knowledge from these courses really helped us to solve the problem. Any mechatronic architect should have this foundational knowledge."

Moiz Hyderabadwala (centre) receiving the ECP2 Bronze certificate, flanked by DSPE board member Bart Dirkx (COO of Fastmicro) on the left and High Tech Institute teacher Hans Vermeulen (architect at ASML and TU/e professor).

He now plans to take courses such as Advanced Motion Control, "which fits the multi-axis, multi-variable problems we are dealing with", and Experimental Techniques in Mechatronics. "In the System Dynamics department, a lot testing is done, as it goes hand in hand with the modelling. In this course, I can learn how to use our models to predict and validate test outcomes, and to understand how to process large amounts of data."

Ultimately, Hyderabadwala's ambition is to move towards a senior architect role. "Using my experience as a mechatronics integration engineer and an FEA engineer, I want to understand the complete system control, give advice on the simulation strategy, and identify the risks in a design." The ECP2-certified course System Architecting may be the next stop on the path to that goal.

WWW.ECP2.EU

Katja Pahnke switches from Eindhoven Engine to Prodrive Technologies

Katja Pahnke has stepped down from her role as managing director of Eindhoven Engine on 1 November, 2022, to join the board of Prodrive Technologies, a global leader in electronics, software and mechatronic solutions. As chief development officer and board member, she will lead Prodrive Technologies Innovation Services. In addition to R&D, this includes talent, leadership and organisational development.

With Eindhoven University of Technology (TU/e) professor Maarten Steinbuch she was the managing co-founder of Eindhoven Engine. Its aim is to accelerate innovation in the Brainport (greater Eindhoven) region through challenge-based research in its public-private research facility at the TU/e Campus. Teams of the region's most talented researchers from industry, knowledge institutes and students cooperate in Eindhoven Engine research programmes to deliver breakthrough technological solutions.

WWW.EINDHOVENENGINE.NL
WWW.PRODRIVE-TECHNOLOGIES.COM

Katja Pahnke. (Photo: Angeline Swinkels)

New compact and dynamic motion platform

Symétrie, located in Nimes (Fr) and specialising in high-precision positioning and motion hexapods, has introduced HEGOA. This compact hexapod of 420 mm height has been designed for high-dynamic applications in industry and research. It can position payloads of up to 50 kg with speeds of 200 mm/s and 50°/s, while offering travel ranges of ±100 mm in X and Y, ±50 mm in Z, ±23° in Rx and Ry, and ±30° in Rz. An acceleration of 800 mm/s^2 in translation and 200°/s^2 in rotation is guaranteed.

Its small diameter of 500 mm makes it ideal for applications in a laboratory or in a space-constrained environment. Thanks to its six degrees of freedom (DoFs), HEGOA hexapod can help testing instruments that will be on board of vehicles later. The 6-DoF hexapod control is facilitated by an ergonomic graphical user interface that allows generating sinusoidal trajectories or importing external trajectories, registered via sensors for example. Optionally, an external real-time trajectory (ERTT) control feature is available. It lets the user control the hexapod in real-time using its own trajectory generator that can be coupled to sensors, cameras, remote control systems, etc.

WWW.SYMETRIE.FR

New High Purity Test Centre

In an increasing number of industry sectors such as the semiconductor supply industry, precision optics, vacuum, laser and analysis technology, electronics as well as the new drive technologies in the automotive industry, cleanliness demands have to be fulfilled, which require clean environments and appropriately designed cleaning machines and processes.

Last month, Ecoclean officially inaugurated its new High Purity Test Centre in Dettingen unter Teck, Germany. With its new technology centre, Ecoclean has created the opportunity to carry out cleaning tests for the design of cleaning processes for high-tech components with extremely high cleanliness requirements and to check the results directly on site.

Ecoclean is part of the SBS Ecoclean group, which has 12 sites around the globe. The group develops and produces machinery, systems and services for a wide range of applications. These involve industrial parts cleaning and degreasing, ultrasonic precision parts cleaning, high-pressure water-jet deburring, surface preparation and surface treatment.

WWW.ECOCLEAN-GROUP.NET

Drastically reducing the cost of photonic chips

Integrated photonics will have a sustainable impact on society, but its adoption is hampered by long product development cycles and limited production throughput. Improving and scaling measurement and test technology are crucial for accelerating the uptake of integrated photonics. To address these challenges, the Photonic Integration Technology Center (PITC) has launched the Metrology programme, aimed at developing design-for-test methodologies and new product characterisation and test automation tools.

Photonic integrated chips can increase the bandwidth of tele- and data-communication enormously, and enable innovative, light-based sensing applications. Founded in the world-leading Dutch photonics ecosystem, the PITC aims to accelerate the uptake of integrated photonics by bridging the divide between research and application. The main barriers for the market adoption of integrated photonics are a long time-to-market and a limited throughput in photonic chip production.

Improving test processes

The development cycle is too long because new designs require verification and optimisation through characterisation. The number of tests required to stabilise a process and increase throughput is relatively high. Therefore, testing processes must improve in accuracy, reliability, throughput/speed, and cost-efficiency, explains Sylwester Latkowski, scientific director of PITC. "There is an urgent need to improve the scalability of the currently available test solutions, to facilitate an efficient process from the prototyping to the pilot phase, and to production in small batches and ultimately large volumes. Testing will be crucial in gaining the market's confidence in the expected yield and performance of photonic devices."

The new Metrology programme is aimed at developing design-for-test methodologies and new product characterisation and test automation tools. It is PITC's first large shared research programme, bringing together integrated photonics designers (BRIGHT Photonics), photonic chip manufacturers (SMART Photonics), photonic product suppliers (VTEC and PhotonFirst), and automated test equipment suppliers (Salland Engineering, FiconTEC and APEX Technologies). The programme has a multiyear outlook and a launching budget of around five million euros, provided on an equal basis by the participating companies and PhotonDelta, a leading integrated photonics ecosystem based in the Netherlands. It is still open to interested companies.

"Our ambition is to reduce product development cycles by three months through enabling 'right first time' design, thus preventing unnecessary and costly design iterations," states Latkowski, who is also acting Metrology programme lead. "New test tools will help to drastically increase testing throughput. Depending on the complexity of the photonic product to be tested, the throughput on average has to increase from minutes to seconds per device. If this proves to be out of reach, then massively parallel testing procedures can serve as an alternative. Overall, we are striving for a throughput increase by a factor of ten. Production flow data analysis can also contribute to this."

Predictive test methods

VTEC Lasers & Sensors, located in Eindhoven (NL), is one of the programme's consortium partners. VTEC is an innovation solutions company that specialises in the integration of optics and data to create customised systems for a wide variety of industries, including telecommunication, manufacturing, environmental, and free-space communication. CEO Jan Mink explains, "Test and measurement are among our biggest challenges. We employ dedicated test engineers, and our designers also engage in testing, to tailor their designs to the customer's requirements and prevent production losses."

Many product characteristics can be measured in the lab, Mink continues, "But in production we need a simple indicator that tells us whether we will have a sellable or an unsellable product. When we can take accurate measurements that give a good prediction for the final product quality early on, we can prevent the costly manufacturing and packaging steps for products that fail once packaged." Metrology helps to increase the yield of chips, Latkowski confirms.

"With adequate testing sequences and procedures in place, you can perform efficient design and prototyping iterations to bring the production process to the expected target quickly." Mink adds, "We need predictive test methods, with the proper test equipment at the right cost, to take the step from small to large volumes with high reliability. This is exactly the subject of the work package we are leading. This programme offers us a platform for exploring various test technologies, for example to reduce test time and extend our measurements to the 100 Gbit/s range, and getting to know the photonics supply chain."

Learning from electronics testing

The Metrology programme's consortium includes experts in electronics testing and suppliers of automated test equipment. Latkowski explains that these companies can expand their portfolio of test systems into integrated photonics, by learning about new types of signals and materials. "In this way, they can benefit from the programme, while their expertise in electronics testing will benefit the photonics companies because the semiconductor technologies are thirty years ahead in terms of high-throughput, large-volume production. Together, the partners can work on developing new test procedures, for example in the packaging and assembly processes, for the integration of electronics and photonics."

WWW.PITC.NL
WWW.PHOTONDELTA.COM

Next-generation asphere measurement solution

Aspheric lenses, or aspheres, are becoming more and more popular. The more complex surface profile of an asphere not only reduces or eliminates spherical aberration but can also reduce other optical aberrations, such as astigmatism. The result is a lens that creates sharper and clearer images. Aspheric surfaces are used in a variety of optical systems, as a powerful way of reducing the number of elements required. This simultaneously enhances a system's performance, and ultimately reduces its size and weight.

Manufacturers working in the optics sector are highly concerned with producing aspheres that are both cost-effective and conform precisely to the design intent. However, testing the accuracy of an asphere's shape and deviation from its design can be a considerable challenge, as it requires the measurement of the tiniest nanometer deviations in shape. The production process for aspheres can be iterative, with multiple part generations and measurement steps to achieve the required level of precision. The goal is to minimise the number of iterations and reduce the time it takes to produce a surface. Here, ultra-precise metrology tools play a crucial role.

Smaller aspheric lenses, for cameras, hand-held mobile devices, and contact lenses, are typically manufactured using moulding technologies, which produce low-cost and relatively high-performance lenses. Larger, more precise, and expensive aspheres are made through grinding and polishing a glass substrate. These aspheres are often used in safety-critical and demanding applications such as telescopes, lithography equipment, and defence applications.

There are several parameters to consider when selecting a metrology tool for aspheric optics. Test surface size, aspheric departure, number of surfaces, and measurement time are a handful of considerations that help guide tool selection or measurement technique. As manufacturers continue to produce a growing number of different optics of varying size and shape, they need a flexible metrology system that can measure multiple parts without major re-tooling.

Optical metrology manufacturer Zygo Corporation, a business unit of Ametek, has been at the forefront of the development of interferometry-based metrology solutions for the measurement of aspheres for many years. The company has just innovated the Verifire Asphere+ (VFA+), which is the latest member of the Verifire™ series of laser Fizeau interferometers. It represents a complete line of high-performance metrology instruments for the measurement of plano, spherical, and aspherical surfaces and material characteristics.

The VFA+ provides precise, high-resolution, fast, and full-aperture metrology for axisymmetric aspheres. This allows faster convergence on deterministic polishing feedback for more efficient surface generation, measurement of the vertex radius to describe the shape of an aspheric surface, and coverage of aspheric form error and mid-spatial frequency surface characteristics.

The system is also flexible, with the ability to measure a range of aspheres with only the change of the reference optic. The VFA+ is equipped with an optional secondary stage that supports a computer-generated hologram (CGH) extending the asphere shape capability to nonsymmetric freeforms and off-axis aspheric optics. With the ability to measure a part two different ways, quality assurance becomes more cost-effective, is easier to execute, and delivers a high level of confidence in measurement results.

In addition, the VFA+ has an option for multi-part automated measurement of trays of optics. This is a unique capability, so ZYGO claims, and facilitates high throughput for significantly improved efficiency in the volume production of aspheres.

WWW.ZYGO.COM

Nexperia invests in sustainable alternatives to batteries

Semiconductor company Nexperia, headquartered in Nijmegen (NL), has announced a broadening to its portfolio of power management products to include energy-harvesting solutions. Energy can be harvested from light, vibrations, radio waves or temperature gradients and can therefore be used to replace batteries in low-power applications like smart wearables and autonomous wireless sensor nodes.
The expansion of Nexperia's expertise comes through the acquisition of Dutch company Nowi, located in Delft. Nowi has developed a novel energy-harvesting power management IC that combines top harvesting performance with the world's smallest assembly footprint and lowest bill-of-material cost. The manufacturing capacity and capability of Nexperia as well as its global infrastructure will ensure that together, Nowi will be able to speed the production of these solutions enabling higher volume production and shipping by the end of 2022 and early 2023.
"Nowi represents a strategically important investment because energy harvesting is the perfect complement to Nexperia's existing power management capabilities," a Nexperia spokesman commented. "This decision means Nexperia can now offer customers a sustainable alternative to battery power for their products, that will be available in the market quickly."

WWW.NEXPERIA.COM
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New Swiss advanced manufacturing centre

The manufacturing industry is going through a period of profound change, driven in part by the advent of 3D printing and other advanced technologies. In order to support Swiss industry at this critical juncture, EPFL and CSEM have joined forces to create the Micro-manufacturing Science & Engineering Center (M2C), a new focal point for pure research, technology transfer and everything in between.

EPFL (École Polytechnique Fédérale de Lausanne) is a leading technical university, based in Lausanne. CSEM (Centre Suisse d'Electronique et de Microtechnique), headquartered in Neuchâtel, is the innovation centre that builds on the Swiss legacy of watchmaking and microtechnology.

The M2C, which focuses on high-precision 3D microfabrication, will cover every step of the development process – from pure research at EPFL laboratories to the transfer of sustainable, high-value-added technologies to industry under the guidance of CSEM. The new centre will catalyse collaboration between academic, institutional and industrial partners, as well as serve as an education and training platform for members and users.

With 3D printing, every step in the process can be digitised – from design to production. Moreover, a single machine can build fundamentally different objects. The scientists and engineers at the M2C will explore ways to capitalise on new materials and production systems through design, development and testing. Thanks to their distinctive characteristics, 3D-printed parts appeal to sectors and industries as diverse as space exploration, custom prosthetics, microfluidic devices and watchmaking.

Moreover, because sensors and other technologies can be built directly into these components, they open the door to the collection of varied and precise data sets for applications such as predictive maintenance and complex system monitoring. The M2C team will develop solutions for systems and components on scales ranging from a few microns to several dozen centimeters.

WWW.M2C.SWISS
WWW.CSEM.CH
WWW.EPFL.CH

M2C will investigate the potential of advanced additive micro-fabrication, which allows the creation of very complex items. (Photo credit: CSEM)

"An exciting EB-PBF printer"

Last year, Japanese scientific instrumentation specialist JEOL launched the electron-beam metal additive manufacturing machine JAM-5200EBM. Using its high-level-performance electron microscope and electron beam lithography technology for semiconductor manufacturing, concerning automatic e-beam focus and spot shape correction, JEOL developed this EB-PBF (electron-beam powder bed fusion) machine, featuring high power, high density and high speed. Thanks to the long-life cathode and helium-free operation ('e-Shield' technology prevents the scattering of powder during printing), cost reduction and mass production of parts of high quality and reproducibility can be achieved, so JEOL claims.

At the invitation of JEOL, The Barnes Global Advisors, a US-based additive manufacturing (AM) consultancy, subjected the JAM-5200EBM to a stress test, of which the first part was published last month on *www.3dprint.com*. The machine achieved a printed dimensional accuracy of +/–0.5 mm, as well as a porosity of less than 0.3%.

"The JEOL JAM-5200EBM is an exciting EB-PBF printer that brings potential value to the metal AM industry," the final conclusion read. "Propelled by a best-in-class high-power melt source, fast build rate, layer-by-layer thermal management, and long-life consumables, the printer has the best process economics amongst current EB-PBF offerings."

WWW.JEOL.COM
WWW.BARNESGLOBALADVISORS.COM

JEOL's electron-beam metal additive manufacturing machine JAM-5200EBM.

Example of a printed product: an electron source chamber, for which approx. 25% weight reduction was achieved compared to the conventional design.

Clean 4-in-1 sensor

Sensofar Metrology, headquartered in Barcelona (Spain), has launched the S neox Cleanroom. This latest version of Sensofar's most powerful and advanced sensor head fits within the strictest classification of particle contamination, ISO Class 1; it is also ESD (electrostatic discharge) compatible. The S neox Cleanroom is one of the latest additions to Sensofar's integrable heads line, for both in-line production and robot-mounted sensing applications.

The S neox 3D optical profilometer features Sensofar's 4-in-1 sensor technology, combining four optical technologies in the same sensor head: confocal, CSI (coherence scanning interferometry), PSI (phase shifting interferometry) and focus variation; these techniques are covered in ISO 25178. The S neox sensor covers thickness measurements from 50 nm to 5 mm, at a measurement noise level down to 0.01 nm.

All the changes to the S neox sensor design have been focused on minimising the main sources of particles: the cover is made of stainless-steel instead of plastic; the gap between the sensor head and the motorised nosepiece has been covered; and finally, a vacuum connection has been added to remove the particles from the sensor head.

WWW.SENSOFAR.COM

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