The magazine of the Paul Scherrer Institute PSI

# Advanced Manufacturing

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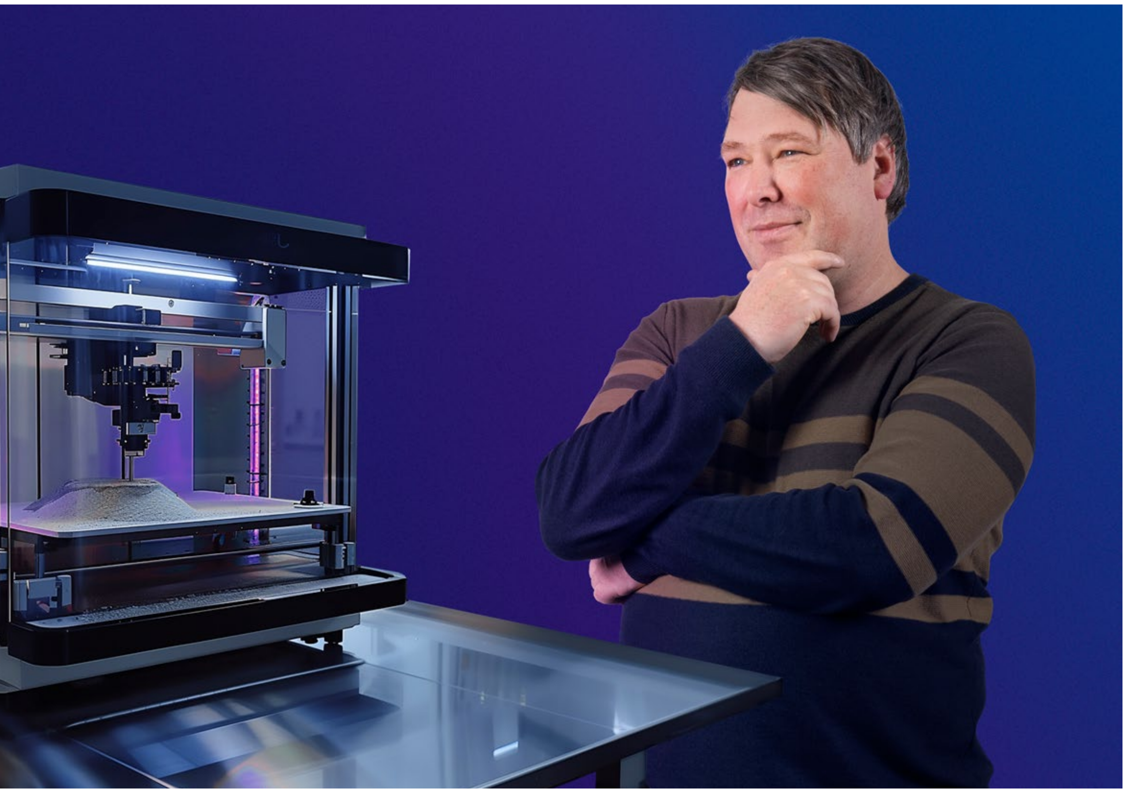
PSI

# Key topic:
# Advanced Manufacturing



Background

## Faster, more precise, more reliable – the future of manufacturing

Advanced manufacturing means using state-of-the-art production methods. Researchers at PSI are helping to make techniques such as 3D printing more reliable and to advance the miniaturisation of high-performance chips.

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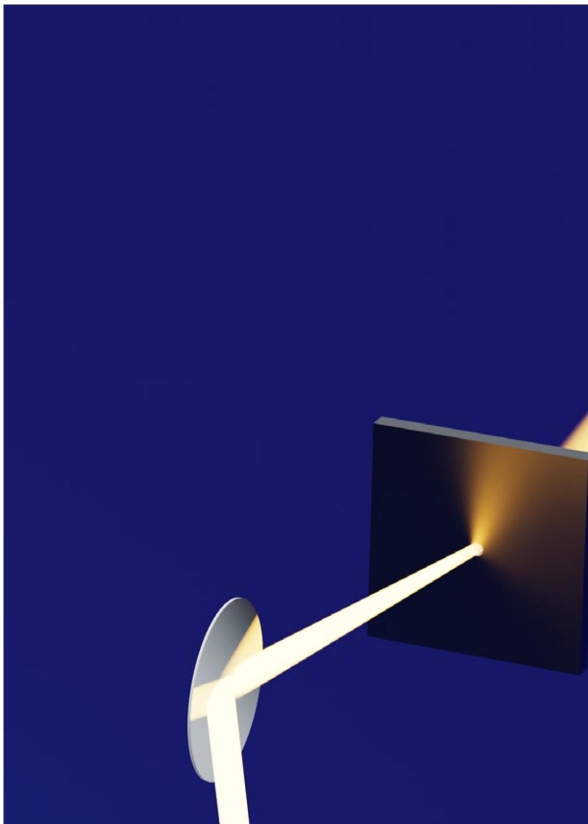

Infographic

## Light as a tool for tiny structures

An infographic shows how researchers at PSI have written extremely fine structures in a photoresist, setting a new world record.

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## Science meets industry – innovation with an impact

Hans Priem and Cees Maris of VDL ETG explain what advanced manufacturing means in industry and talk about their collaboration with PSI.

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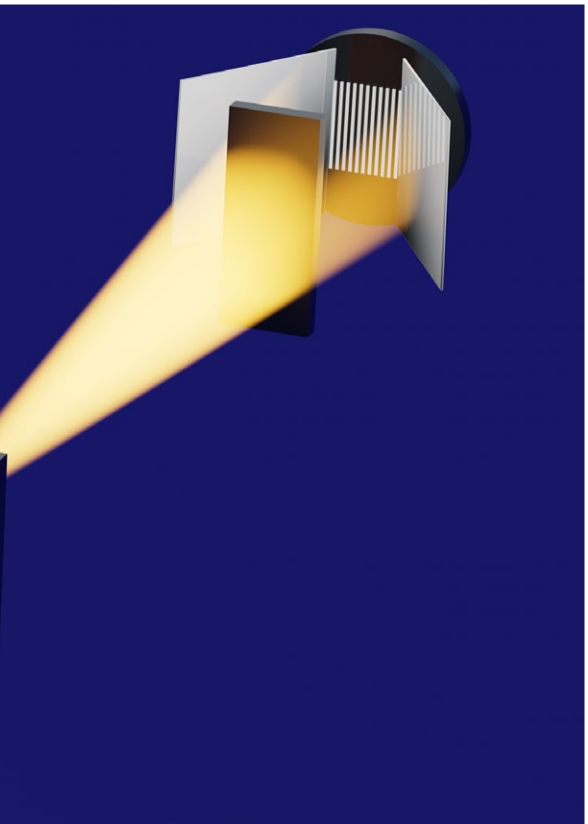

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# “Advance and build things”

Science is known for its thorough and rigorous approach. Industry seeks concrete solutions for people’s needs. The collaboration between the two is currently leading to new production technologies: advanced manufacturing. More precise and more efficient production methods are in demand in areas such as medical technology, the semiconductor and optics industries and the aerospace sector.

At the Paul Scherrer Institute PSI, we are developing innovative analytical methods for this very purpose at our unique large research facilities. Our particle accelerator-based large research facilities themselves are also keeping pace with the times: for this photo, I am standing on the concrete cover of the completely new electron storage ring of the Swiss Light Source SLS. As part of our current upgrade project, SLS 2.0, this core component of the facility has been completely rebuilt so that the SLS will soon be providing light for research that is about 40 times as brilliant as before.

A well-known example of advanced manufacturing is 3D printing. At the SLS, PSI researchers are using specially designed printers to study how the microstructure of materials changes during the printing process – with the aim of using their findings to improve the process and, as a result, the material properties.

The technology transfer centre ANAXAM provides a concrete interface between PSI and industry. It makes its analytical expertise available to industrial companies wishing to carry out experiments and measurements at PSI’s large research facilities. This often involves optimising processes and products in the field of advanced manufacturing. In this issue, you can read how ANAXAM has helped companies in Würenlos and Winterthur, among others.

Park Innovaare, which opened right next to PSI in 2024, also plays a central role in this issue. In addition to its own state-of-the-art laboratories, it offers companies access to PSI’s research infrastructure. The company VDL ETG, a long-standing partner of PSI, has moved into Park Innovaare. Also based at Park Innovaare, a start-up founded by a former PSI researcher is developing a novel manufacturing process to produce a type of sensitive electronic skin – such as for the fingertips of a robot.

“Advance and build things” is one way to describe these collaborative ventures between PSI and industry. Together we are making progress and, in the process, creating new things for the society of tomorrow.

Yours sincerely, Christian Rüegg, PSI Director


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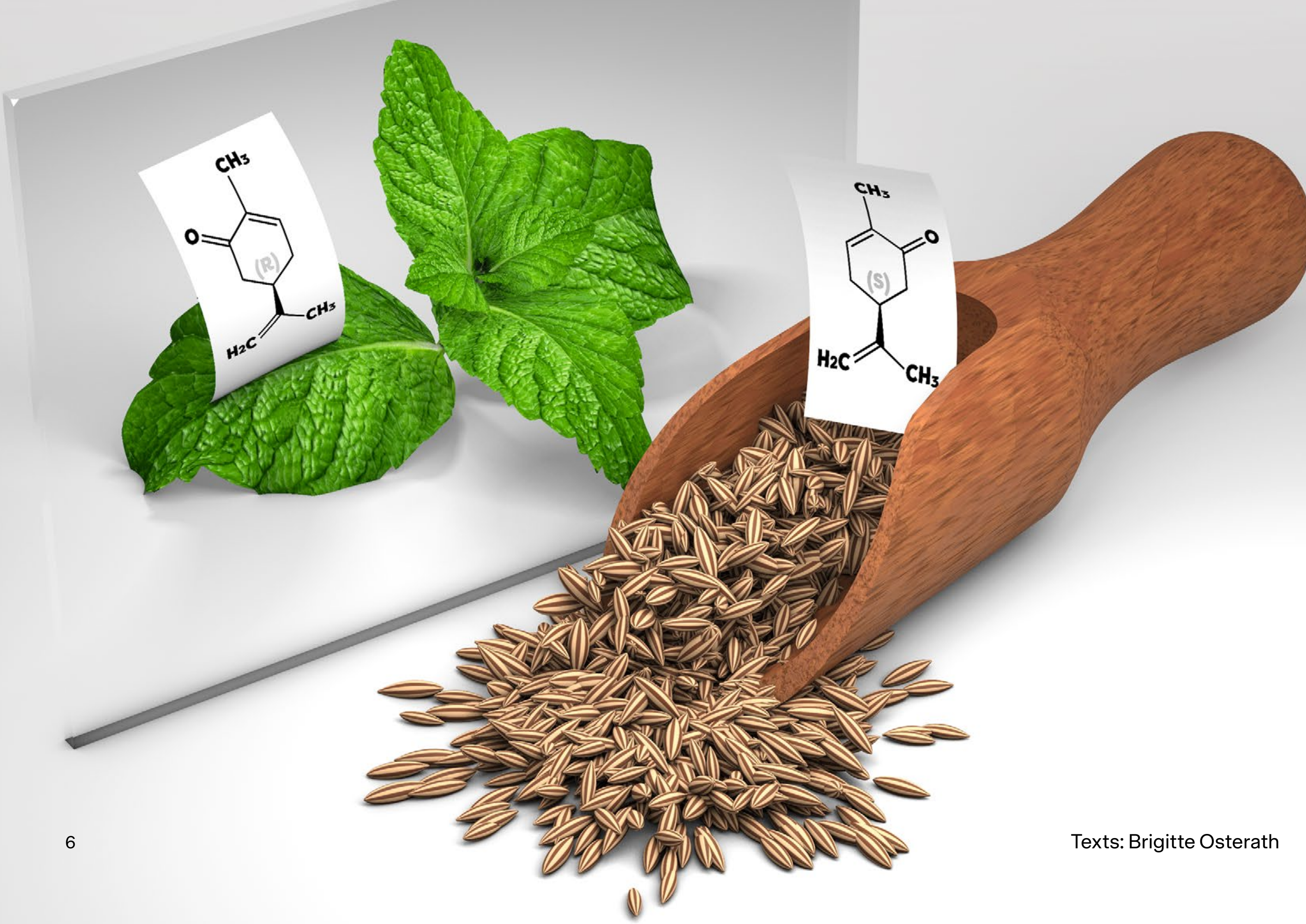
# The same, yet not the same

Four fingers and a thumb, five fingernails, and all the joints in fixed positions relative to each other: in principle, our left and right hands look the same. But no matter how we twist them and turn them, they can't be superposed on each other. In fact, they are not identical, but mirror images of each other.

The same phenomenon also exists with molecules: Two versions of the same chemical compound contain the same sequence of atoms, but they are mirror images of each other. The difference is often hard to see on paper; in three dimensions, it becomes clearer.

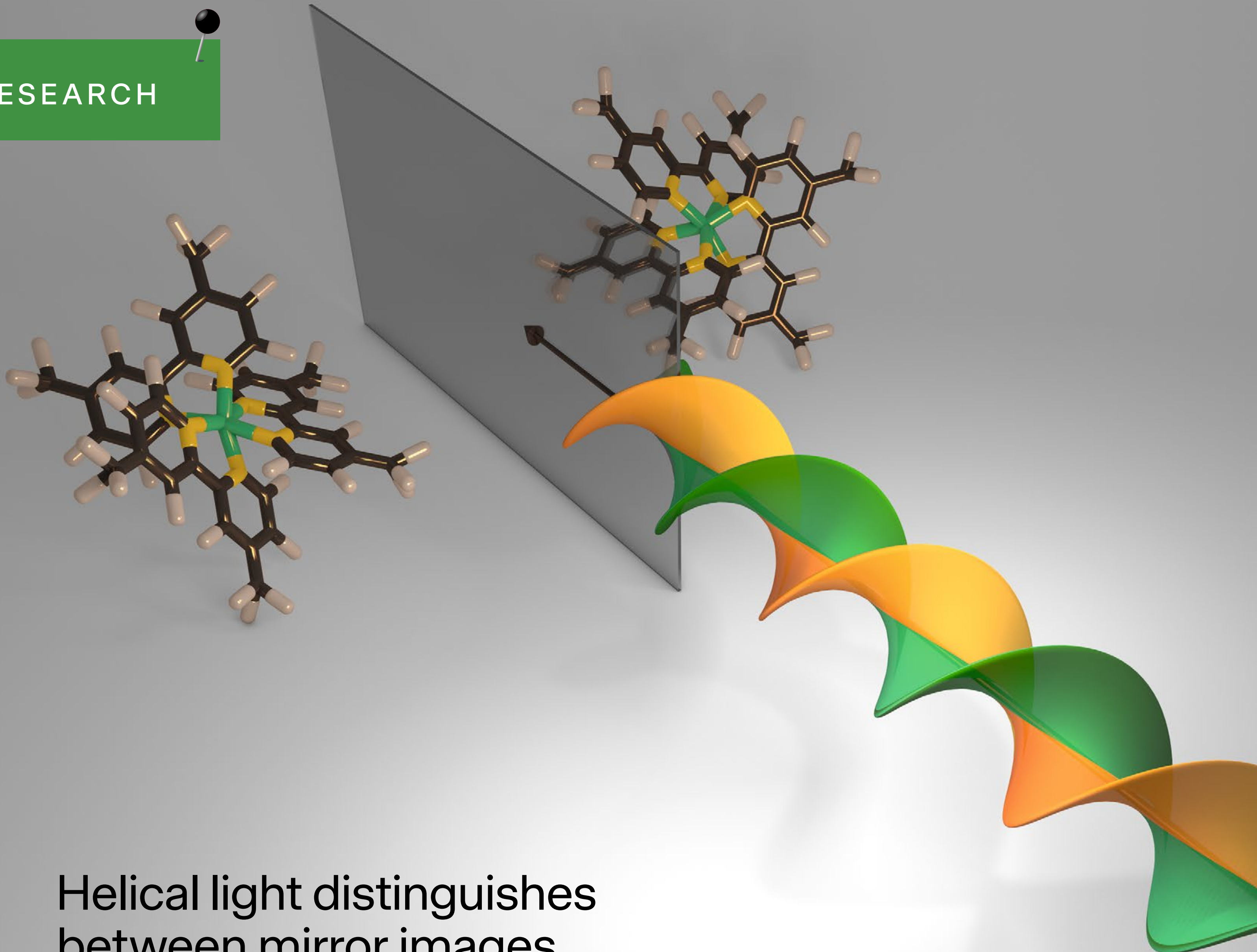
In chemistry, too, we speak of the left-handed and right-handed forms of a molecule, or the S and R forms for short. (S and R stand for sinister and rectus, Latin for left and right). The two versions of a molecule are called enantiomers. Carvone is one such molecule, existing in one configuration and its mirror image. It is one of the aromatic substances: S-carvone is found in caraway, and R-carvone in spearmint.

It seems obvious to us that we have a left and a right hand. But olfactory receptors in our noses also have a handedness, so we can easily distinguish between the smells of certain enantiomers. This is why S-carvone smells like caraway to us, while R-carvone smells like mint.






Texts: Brigitte Osterath

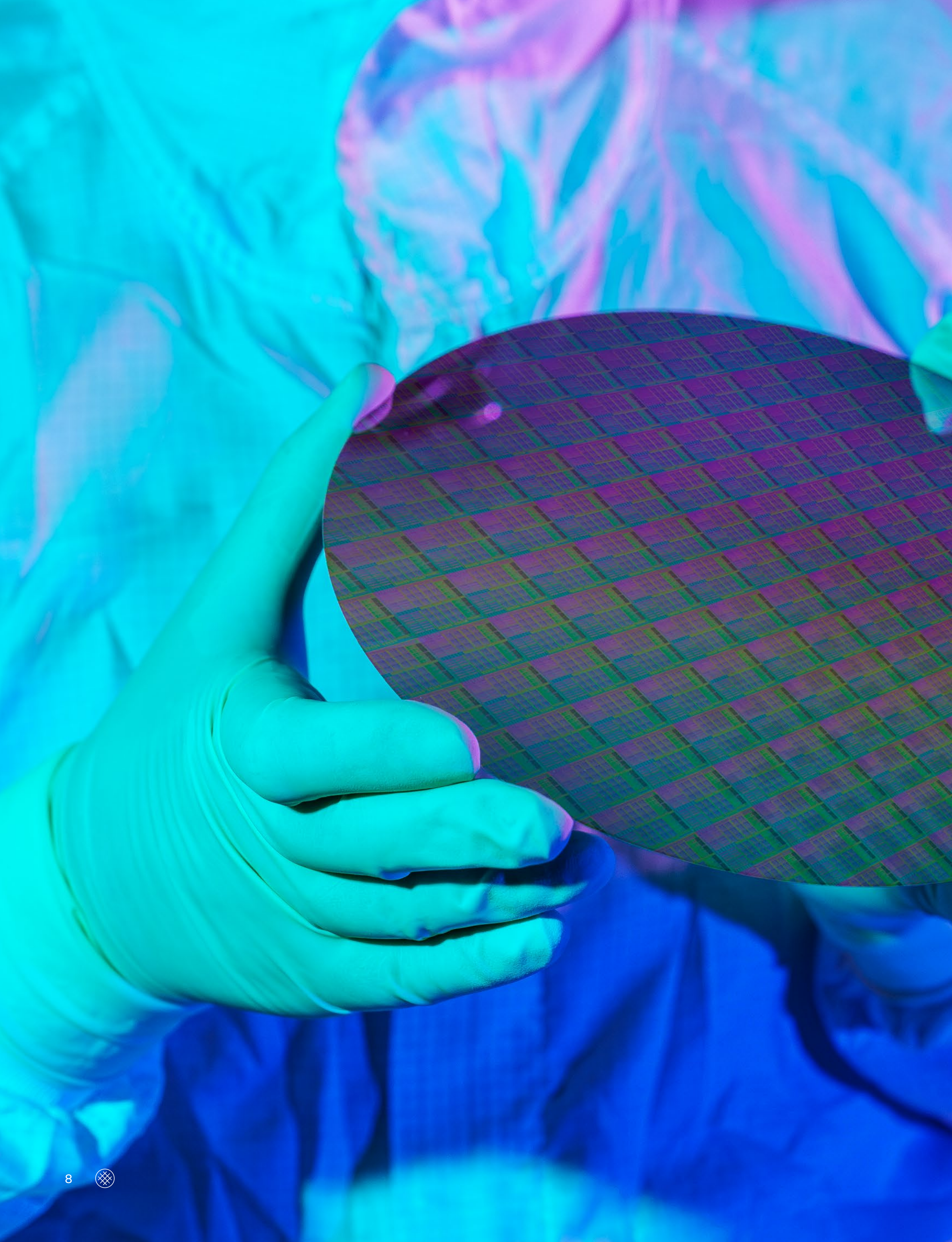


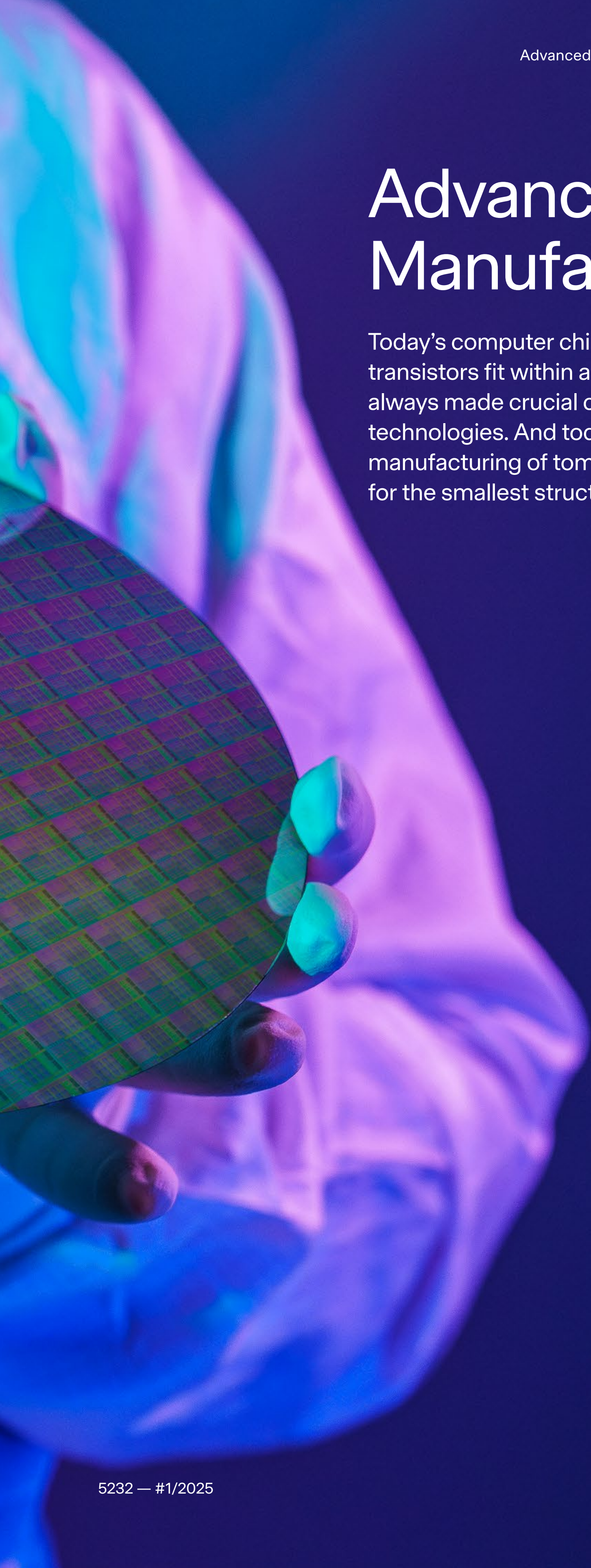
# Helical light distinguishes between mirror images

Researchers at PSI have developed a new method of distinguishing between enantiomers, that is left-handed and right-handed molecules. This is made possible by helical X-ray light.

Enantiomers often have very different effects in the body: One version of a molecule may act as a drug, while the other may be toxic or harmful. A well-known example of this is thalidomide, which gained woeful notoriety in a major pharmaceutical scandal in the 1960s. It is therefore important to be able to distinguish a specific molecule from its mirror image and to separate them. This is difficult, however: the two versions of the molecule have the same chemical properties; only their three-dimensional shape is different.

Researchers from PSI, EPFL, and the University of Geneva have sent X-ray light from the Swiss Light Source SLS through special diffraction lenses known as spiral zone plates. These bend the wavefront into a helical shape, so that the light itself also becomes handed. It turns out that enantiomers absorb this radiation to different degrees. The signals can be used to distinguish between the image and the mirror image, and the distinctions are even sharper than with the established method of differentiation used to date. A real alternative!





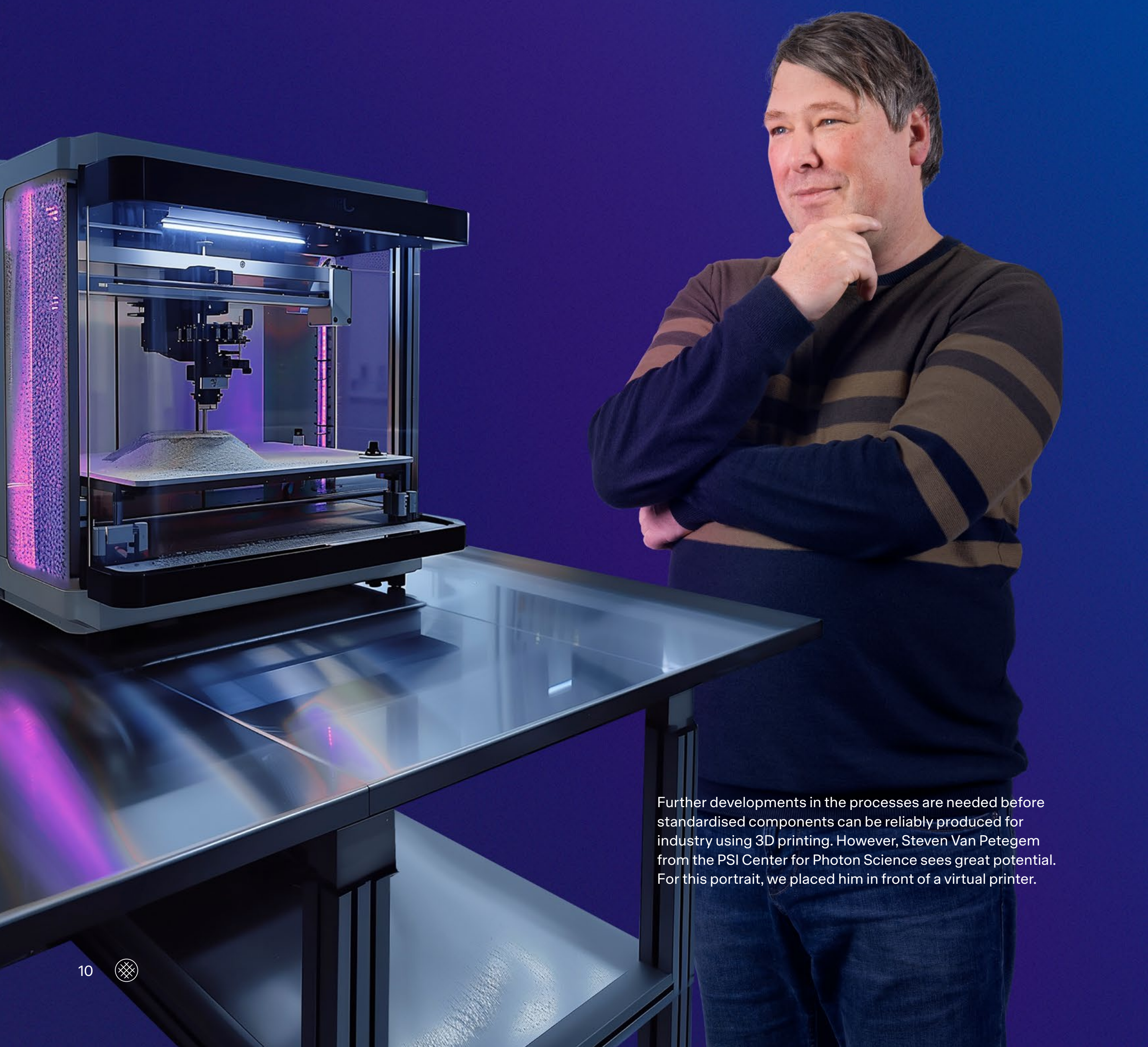
# Advanced Manufacturing

Today's computer chips are incredibly densely packed: up to 100 billion transistors fit within an area the size of a thumbnail. Research has always made crucial contributions to cutting-edge manufacturing technologies. And today it is helping to develop the advanced manufacturing of tomorrow – also setting a new world record at PSI, for the smallest structures ever created using photolithography.

# Faster, more precise, more reliable – the future of manufacturing

New, state-of-the-art manufacturing techniques, known collectively as advanced manufacturing, are of key importance to Switzerland's future as an industrial location. At the Paul Scherrer Institute PSI, researchers are working to further perfect 3D printing, studying new materials for the semiconductor industry and developing a "robot skin" full of tiny sensors to give machines sensitive fingertips.

Text: Barbara Vonarburg



Further developments in the processes are needed before standardised components can be reliably produced for industry using 3D printing. However, Steven Van Petegem from the PSI Center for Photon Science sees great potential. For this portrait, we placed him in front of a virtual printer.

Printing workpieces or entire products in three dimensions, known as 3D printing, is perhaps the best-known example of advanced manufacturing. This additive manufacturing technology holds great promise not only for the aerospace and automotive industries, but also for medicine. “The potential is enormous,” says Steven Van Petegem, a researcher in the Structure and Mechanics of Advanced Materials Group at the PSI Center for Photon Science. However, a major challenge still needs to be overcome before it can be used in an industrial scale: the process is not yet reliable enough. “There are only a few materials with which a 3D printer is capable of producing a standardised component a thousand times with consistently high quality. Further developments are still needed to manufacture parts for an aeroplane, for example,” Van Petegem explains.

The component might, for instance, contain cracks or pores. To explain why this happens, it is necessary to find out what goes on during the printing process. This is why researchers at PSI have developed special miniature printers that can be installed at the large research facilities. “With our unique facilities and machines, we can look deep inside the material during the printing process and see how the microstructure develops during production,” explains Markus Strobl, head of the Applied Materials Group at the PSI Center for Neutron and Muon Sciences.

The PSI researchers started out five years ago with a device measuring just under 50 centimetres that was designed for use at the Swiss Light Source SLS. The mini-printer from Villigen is now so popular internationally that it is in constant operation and is also used at synchrotron facilities in Hamburg and Grenoble. This success spurred the researchers to build a second, slightly larger device, which they installed for the first time at the Swiss Spallation Neutron Source SINQ in 2024. “The experiments with it worked straight off, an outstanding accomplishment on the part of our PhD student Shieren Sumarli in particular,” says Strobl.

Both miniature printers use the same process: laser-based powder bed fusion, one of the most common 3D manufacturing techniques, even on a large scale. Metal is applied as a fine powder to a build plate, and a laser beam moves across the powder, selectively melting it and creating the desired shape. This is followed by the next thin layer of powder, which is again melted by the laser. The part grows layer by layer. Using synchrotron light or neutrons, this process can be closely observed on site (in situ) and in real time (operando).

Currently, the researchers are particularly interested in producing parts from several different materials. Controlled 3D printing of multiple materials could allow functional parts to be manufactured without having to join and assemble different components. In the experiments at SINQ, they printed a combination of steel and copper, which is suitable for the construction of heat exchangers, for example. The steel provides mechanical stability, while the copper is a good conductor of heat. Using neutrons, the researchers observed for the first time that magnetic phases formed during the printing process. They suspect that this phenomenon may be related to the formation of cracks.

In other experiments at the SLS, they studied combinations of copper and nickel or aluminium. “We achieved impressive results that show what happens when the molten metal cools extremely quickly, at rates of one million degrees per second,” explains Van Petegem. “The synchrotron light of SLS allows us to take extremely fast images, up to 40,000 per second.” This method is particularly suitable for examining very thin samples. The neutrons of SINQ, on the other hand, penetrate deeper into the material, revealing stresses in the crystal lattice at the atomic level, among other things. “The two methods complement each other perfectly,” says Strobl.

Cracks that develop during printing can also be heard – and thus measured acoustically. A highly sensitive microphone is positioned in a so-called printing process chamber, where it records acoustic signals during the production process. This project is supported by the Swiss National Science Foundation as part of the Sinergia programme; in addition to PSI, EPFL and Empa are also involved. The researchers are using X-rays and neutrons to assign specific acoustic signals correctly. This is where artificial intelligence comes in useful. Thanks to machine learning, the recorded sound, which seems chaotic to humans, can be interpreted at lightning speed. This would

> “Very high accuracy is important. Only then will industry adopt this method for quality control.”
>
> Steven Van Petegem, researcher at the PSI Center for Photon Science

> "Over the years, almost all microchip manufacturers have come to PSI to carry out tests."

Yasin Ekinci, laboratory head at the PSI Center for Photon Science

Silicon is the basis of today's computer chips. Yasin Ekinci, head of a laboratory at the PSI Center for Photon Science, holds one of the circular wafers made of the ultrapure material. The semiconductor industry uses photolithography to create extremely fine structures on it. We have used image processing to suggest these on the wafer.

allow manufacturers to tell when something was going wrong and correct it during the process. "Very high accuracy is important," explains Van Petegem. "Only then will industry adopt this method for quality control."

### Promoting Switzerland as an industrial location

"The demands on materials are much higher today than they used to be," explains Frithjof Nolting, head of the Laboratory for Condensed Matter at the PSI Center for Photon Science. "Advanced manufacturing is an important, topical issue with which we are promoting Switzerland as an industrial location," he says. Many materials are made up of different elements having different functions. This requires precise, detailed knowledge. Whereas in the past, to put it simply, people were only interested in the hardness, composition or elasticity of a material, today you need to know its micro- and nanostructure to understand how it will behave during a particular manufacturing process. "The techniques available at PSI mean that we can provide such information; that is our strength," says Nolting.

In 2019, he was one of the founders of the technology transfer centre ANAXAM, which helps industrial companies to use PSI's large research facilities to study their materials and manufacturing processes. ANAXAM stands for Analytics with Neutrons and X-Rays for Advanced Manufacturing. It is two-thirds publicly funded, with the remaining third coming from industrial partners. "ANAXAM gives interested industrial companies and research institutions access to its own analytical expertise and to PSI's large research facilities SLS and SINQ for carrying out experiments and measurements. This enables our customers to optimise their processes and products, particularly in the field of advanced manufacturing," says Christian Grünzweig, managing director and CEO of the centre.

The Geneva-based company Givaudan, for example, used a beamline at the SLS to examine the 3D structure of puffed snacks for which new ingredients were being introduced. Huba Control in Würenlos, a company specialising in pressure and flow measurement technology, was able to increase the robustness of newly developed sensors. Using high-resolution synchrotron computed tomography, the company was able to optimise the path of glass fibres through the plastic injection-moulded section of the measuring tube. And the company Winterthur Gas und Diesel, which designs ship engines, used the SLS to study additively manufactured injection nozzles for diesel engines in order to improve the manufacturing process and produce nozzles with optimal flow properties.

"ANAXAM's goal is to support industrial customers with its analytical expertise throughout the entire life cycle of their products and processes, so that they can offer innovative and high-quality products to the market," says Grünzweig. "With around 50 projects per year, I feel this is a great success story," adds Nolting. In 2023, a second technology transfer centre was founded at PSI. The Swiss Photonics Integration Center (Swiss PIC) serves the photonics industry, which focuses on the use of light to transmit information. Both centres are part of the Advanced Manufacturing Technology Transfer Centers network, or AM-TTC for short, which is committed to ensuring that new manufacturing technologies find their way from research laboratories to industrial applications.

### Microchip manufacturers test new materials

The research institute in Villigen has long been a well-known name in the semiconductor industry. "Over the years, almost all microchip manufacturers have come to PSI to carry out tests," says Yasin Ekinci, head of the Laboratory for X-ray Nanoscience and Technologies, which is also part of the PSI Center for Photon Science. "In the semiconductor industry, advanced manufacturing means photolithography." Ultraviolet light strikes a photomask, which serves as a template for the circuit paths and transistors on the chip. A complex optical system shrinks the image of this mask and projects it repeatedly onto a silicon layer coated with a photoresist.

"Initially, there were around 1,000 transistors on a chip; today, up to 100 billion transistors can fit on a chip the size of a thumbnail," says Ekinci. This incredible miniaturisation has only been possible by switching to light with ever shorter wavelengths in photolithography. Today, the most powerful chips, such as those found in top-of-the-range smartphones, are made using extreme ultraviolet (EUV) light with a wavelength of 13.5 nanometres (1 nanometre is one millionth of a millimetre). This required a completely new technology, in the development of which PSI has played a major role.

The high-performance chips are manufactured using scanners that are probably the most complex machines ever built. Testing on the original devices would be risky as well as involving a huge amount of effort. So the industry takes advantage of the fact that the Swiss Light Source SLS too generates extreme ultraviolet light. "Here at the SLS we have a much simpler, faster and less expensive method for EUV lithography," explains Ekinci. "Although we cannot use it to manufacture transistors, we can create extremely fine structures and offer a variety of testing options." His team even holds a world record. While industrial

EUV photolithography today produces structures with line widths of about ten nanometres, the finest patterns produced at SLS have a line width of just five nanometres. “These are the smallest structures ever made by humans,” says Ekinci.

In particular, a great many new potential photoresists have been tested at PSI. This is because the established materials are no longer suitable for EUV lithography. The tests carried out at PSI looked into whether a new photoresist was able to meet the requirements of the lithography process in terms of resolution and sensitivity. This collaboration with industry demands circumspection and confidentiality. Ekinci would have liked to develop a new photoresist himself, but for a long time he hesitated: “If we had done something similar to what our customers were doing, it might have been seen as a breach of trust,” he explains. “But now we have dared to try something completely new.”

Existing photoresists are based on polymers, which are large chains of molecules. “At the atomic level, they look like a bunch of cables,” says Ekinci. “If you want to write ever more finely, you need much smaller molecules as building blocks.” His group has therefore spent the last two years developing a new type of material based on a metal oxide. However, to convert this academic research into an industrial product will require large investments. That is why the PSI group is now working with the Finnish company PiBond, which has founded a subsidiary in Park Innovaare. PiBond will continue the development begun by PSI and commercialise it.

### A skin for robots

Barbara Horvath’s newly founded spin-off company Inveel is also based at Park Innovaare. “Imagine a robot wanting to lift this coffee cup,” says the materials scientist, reaching for the cup on the table in front of her. “If its fingers were covered with the skin we are developing, it would be able to do this very easily.” Horvath has been awarded a Founder Fellowship by PSI, to help her turn her research results into an actual product.

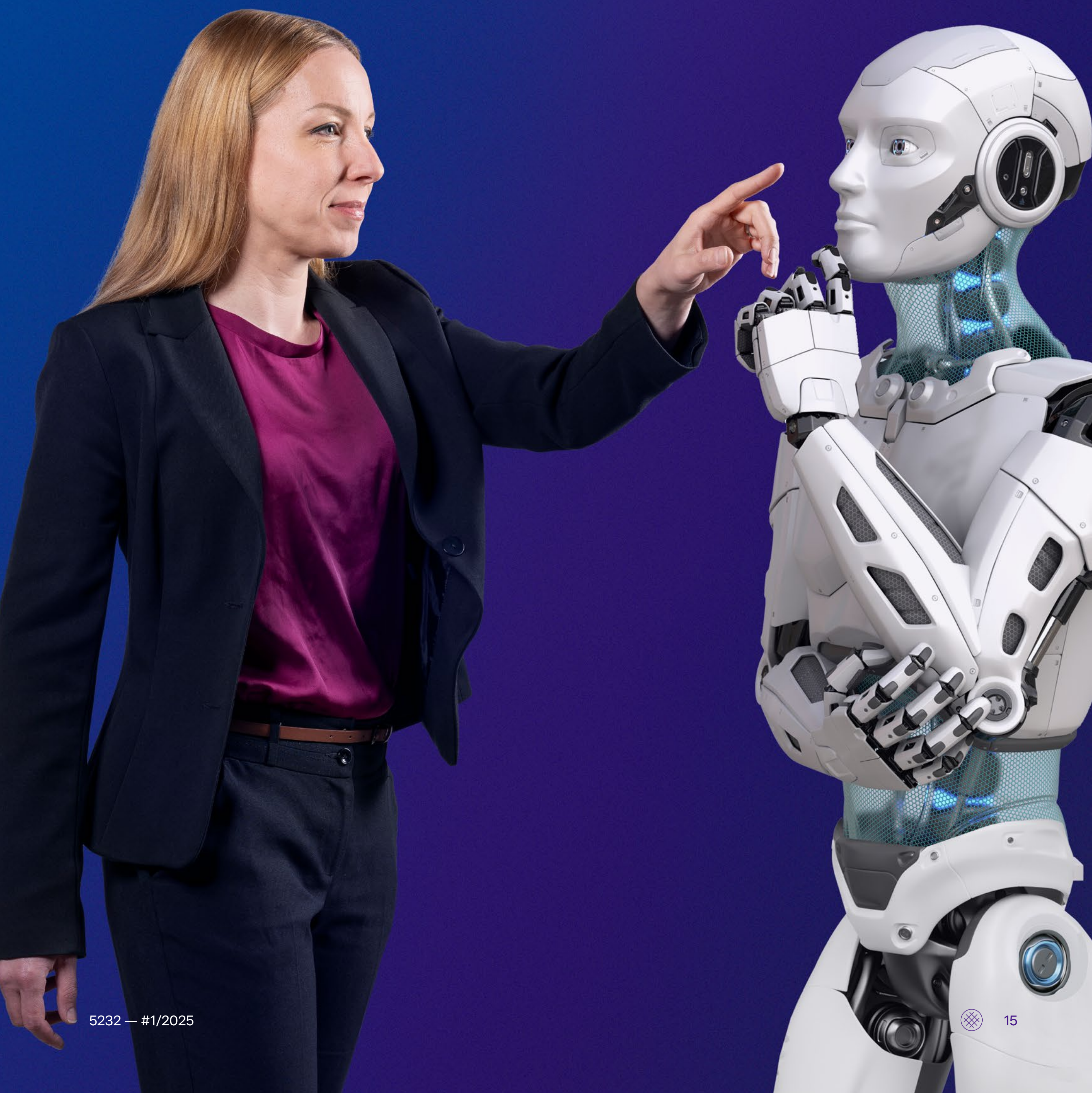
As a postdoctoral researcher at PSI, Horvath developed a new manufacturing method for printing electronic circuits directly onto a polymer surface “at very high resolution, very quickly and covering large areas,” she explains. She and her team are now working on a prototype of robot skin. Tiny sensors are printed in close proximity to each other on a large-area film, on a scale down to just a few hundred nanometres. “If you apply this skin to a robot’s fingertips, it can not only feel individual points, but also assemble them to form a kind of tactile map that tells it whether it is touching the top, bottom or the middle of an object,” explains Horvath. “This allows it to grip and handle the object much better.”

Horvath’s process begins with the design and manufacture of a precise stamp. This takes place in PSI’s newly built, 450-square-metre cleanroom at Park Innovaare. “Here we have the necessary high-tech machines and excellent conditions,” she says. The stamp is brought into contact with the material to prepare the surface. This enables the precise placement of metallic nanoparticles in the next step. These in turn are finally fused into tiny nanowires. Horvath does not want to reveal any further details: “We are still applying for patents, and I do not want to jeopardise this process.”

The manufacturing process could be used for many other applications, such as smart windows that only allow certain wavelengths of incident light to pass through, thereby regulating the temperature. But for now, Horvath wants to concentrate on getting the robot skin ready for the market. Temperature and humidity sensors could also be printed onto the polymer surface. This would allow a robot to sense when someone is breathing nearby. “At the moment, that sounds very futuristic,” she admits. But she is convinced that this development will assert itself: “A robot like this could soon pick up my cup and return it.” ●

> “If you apply this skin to a robot’s fingertips, it can not only feel individual points, but also assemble them to form a kind of tactile map.”
>
> Barbara Horvath, CEO and co-founder of Inveel GmbH

With her spin-off company Inveel, former PSI researcher Barbara Horvath is developing a manufacturing technique that allows electronic circuits to be printed onto a polymer surface. The aim is to create a kind of sensitive electronic skin, perhaps for a robot like the one we have fictitiously depicted here.



# Light as a tool for tiny structures

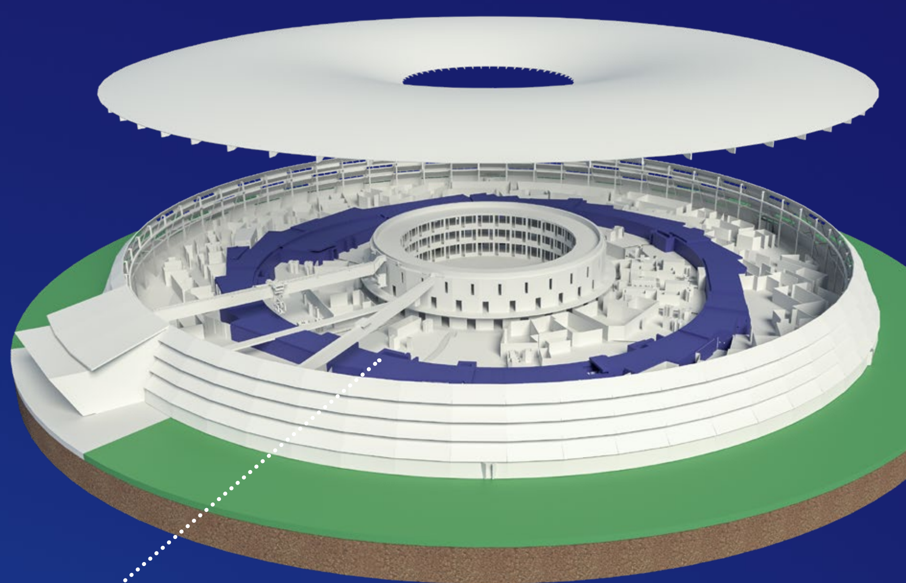
The performance of our smartphones and graphics cards is determined by features that can't be seen with the naked eye. The key is a process known as photolithography: a special kind of light draws a blueprint of the chip onto a wafer coated with photoresist. For the latest chips, extreme ultraviolet (EUV) light is used to create structures as small as possible. The systems that produce these high-performance chips are extremely complex and expensive. The light comes from a plasma source that is 200,000 degrees hot and is sent through an optical system made up of 35,000 individual parts.

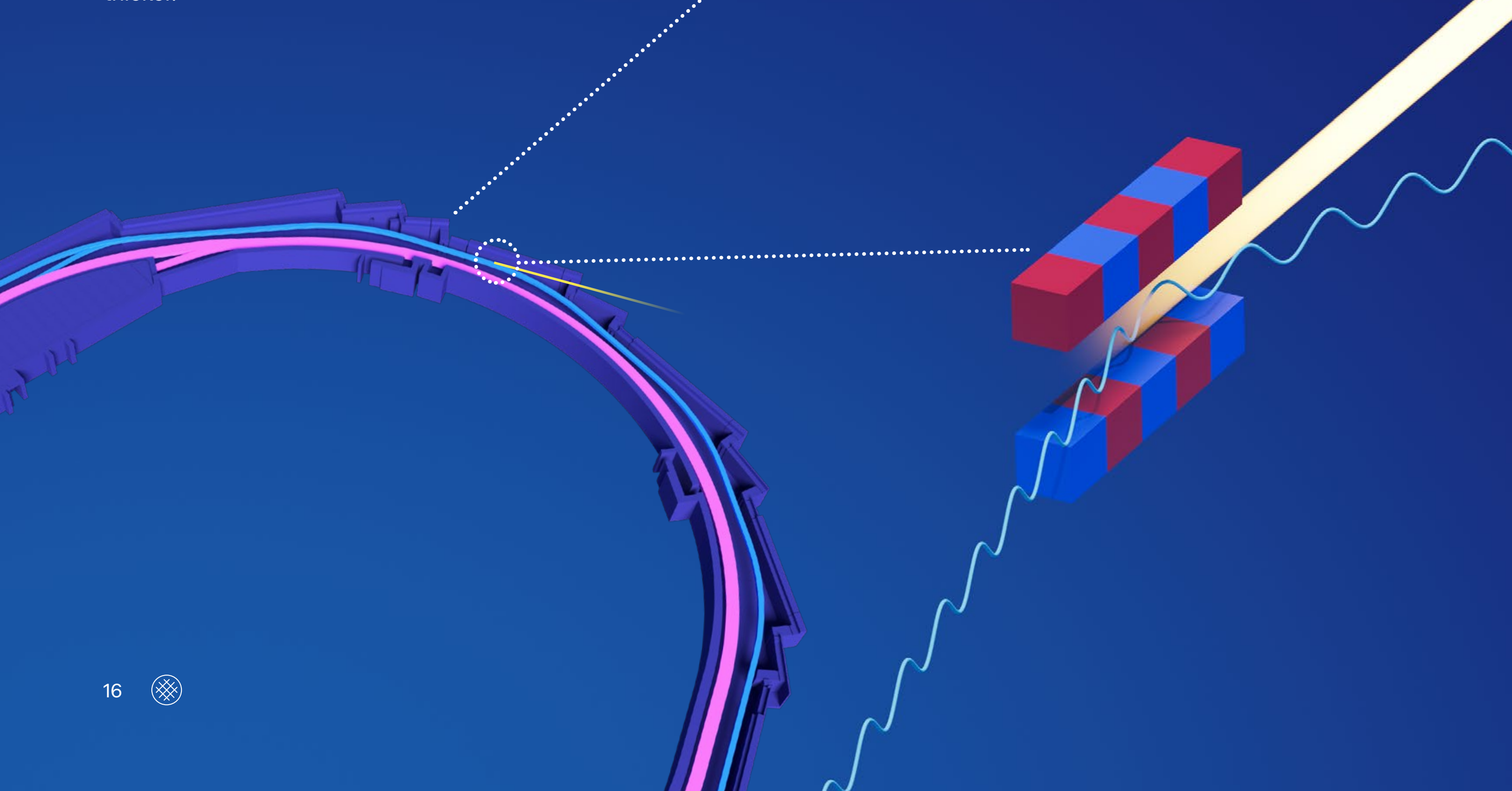
Researchers at PSI have developed a new method for EUV lithography that is simpler and less expensive. It is based on the superposition of two light beams, whose interference can either increase or decrease the intensity of the light; this is known as interference lithography (EUV-IL). The new method does not require a plasma source and uses a simpler optical system. Although the process is not suitable for manufacturing microchips, it is widely used in industry for materials testing and can produce extremely fine patterns with a very high resolution.

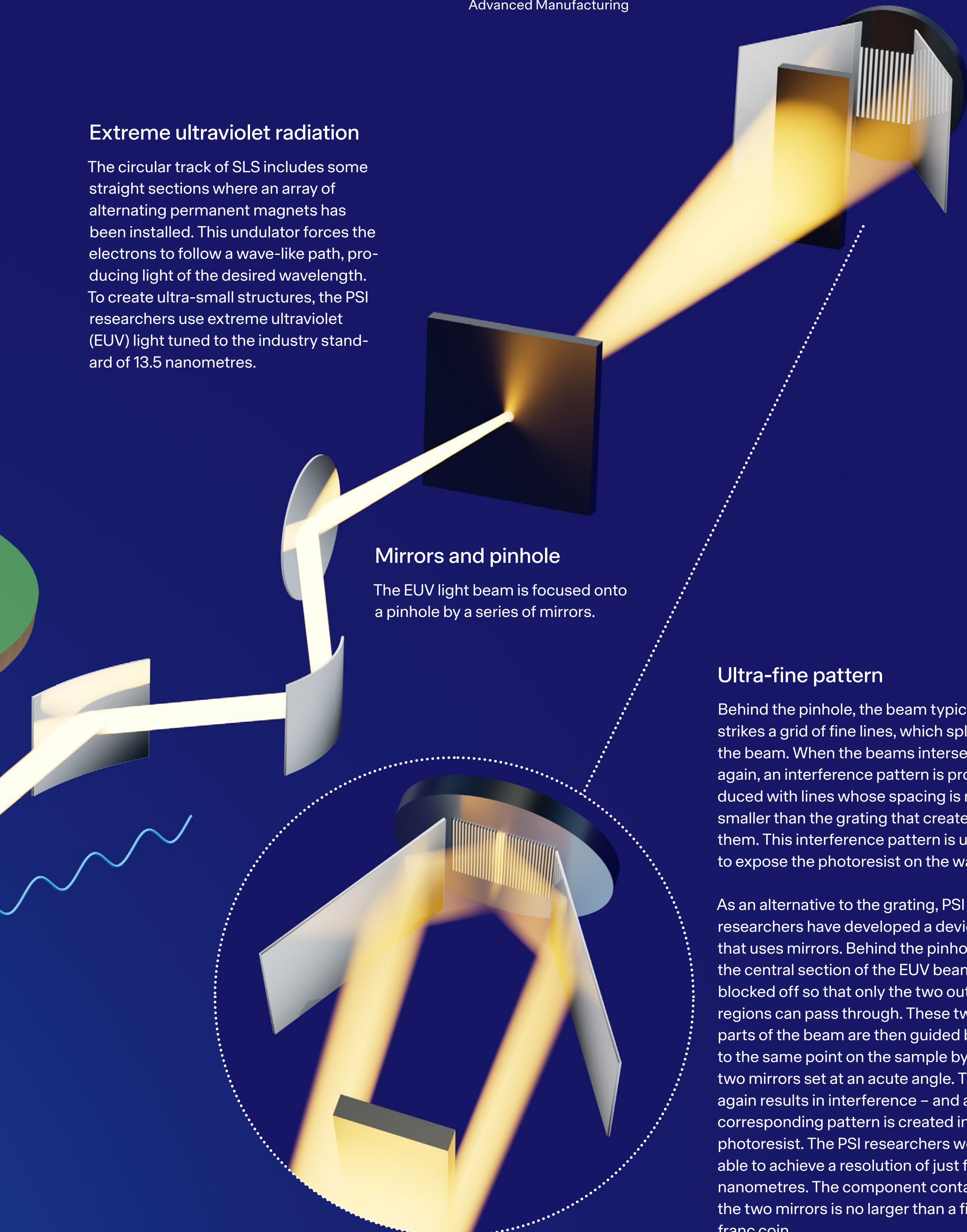
The most advanced chips have conductor paths with a separation of about ten nanometres. The PSI method has been used to draw lines in the photoresist that are only five nanometres apart – a world record. A human hair is approximately 12,000 times thicker.

## Light from the large research facility

At the Swiss Light Source SLS at PSI, accelerated electrons are used to produce particularly intense light. The electrons race around a circular track, with a total circumference of 288 metres, at almost the speed of light and emit synchrotron radiation. Among many other applications, this radiation can also be used for photolithography.







## Extreme ultraviolet radiation

The circular track of SLS includes some straight sections where an array of alternating permanent magnets has been installed. This undulator forces the electrons to follow a wave-like path, producing light of the desired wavelength. To create ultra-small structures, the PSI researchers use extreme ultraviolet (EUV) light tuned to the industry standard of 13.5 nanometres.

## Mirrors and pinhole

The EUV light beam is focused onto a pinhole by a series of mirrors.

## Ultra-fine pattern

Behind the pinhole, the beam typically strikes a grid of fine lines, which splits the beam. When the beams intersect again, an interference pattern is produced with lines whose spacing is much smaller than the grating that created them. This interference pattern is used to expose the photoresist on the wafer.

As an alternative to the grating, PSI researchers have developed a device that uses mirrors. Behind the pinhole, the central section of the EUV beam is blocked off so that only the two outer regions can pass through. These two parts of the beam are then guided back to the same point on the sample by two mirrors set at an acute angle. This again results in interference – and a corresponding pattern is created in the photoresist. The PSI researchers were able to achieve a resolution of just five nanometres. The component containing the two mirrors is no larger than a five-franc coin.

# Science meets industry – innovation with an impact

Since 2023, the Dutch VDL Enabling Technologies Group (VDL ETG) has had a branch in Park Innovaare in Villigen – right next to PSI. As part of the family-owned VDL Groep, VDL ETG is a global supplier to companies that build high-tech manufacturing equipment and use state-of-the-art production lines. Hans Priem is Business Development Manager at VDL ETG. Cees Maris has primary responsibility for VDL ETG at Park Innovaare.

Interview: Barbara Vonarburg

**What does your company manufacture?**

**Hans Priem:** We are a so-called contract manufacturing partner. For example, our customers may sell machines for manufacturing semiconductors or products used in analytics, aerospace, medicine and many other fields. These machines are immensely complex; they may use a high vacuum, for example, and have very high accuracies and a huge throughput. Our customers outsource part of the development, production, assembly and testing of modules or entire systems to us. So we are active in the field of high-end and high-tech contract manufacturing.

**What does advanced manufacturing mean to you?**

**Cees Maris:** In our industry, we are always striving to push the boundaries of what is possible. To do this, we need to understand in detail the physics behind the products we develop. This allows us to offer our customers optimised solutions that result in first-class performance of innovative products. I would call this approach advanced manufacturing, and we believe that it can be achieved through intensive collaboration with PSI and other partners in Park Innovaare, as well as by connecting research and industry.

**Hans Priem:** At the moment we have the right infrastructure and thus the capabilities to serve our customers' needs. But the challenge is not just to have these technologies available now. Today, we are already thinking about what will be needed in five or ten years' time. Based on input from our customers as well as our own assessments and initiative, we decided to strengthen our existing relationship and our already intensive cooperation with PSI and to establish a branch at Park Innovaare. We know the institute very well, having already worked with PSI on the construction of the SwissFEL and various other projects.

**The X-ray free-electron laser SwissFEL is the latest large research facility at PSI. What was VDL ETG's contribution to the construction of this more than 700-metre-long facility, which includes a linear accelerator?**

**Hans Priem:** We manufactured more than 12,000 high-precision components that together form the central elements of the SwissFEL accelerator tube. These specially shaped copper discs have to meet very precise dimensional and positional tolerances of a few micrometres, and the geometry varies from disc to disc. The discs were manufactured by VDL ETG Switzerland in Trübbach in eastern Switzerland. It was something quite special for us to be able to produce such a large number with such high precision. If you are good at precision manufacturing – and I think we are – it's very important to get involved in projects like this because of the advances in technology. This is an opportunity for us to develop our skills and then apply this precision manufacturing to our main business areas, for example as a supplier for the construction of special large high-resolution electron microscopes and for our customers in the semiconductor industry.

**To what extent can accelerator technology be used in semiconductor production?**

**Cees Maris:** One of the areas we work in is semiconductor metrology, the technology used to make measurements. We find that there is an

The internationally operating company VDL ETG also has offices at Park Innovaare – and has a direct view of PSI's Swiss Light Source SLS from the window. Together with PSI researchers, VDL ETG is working on prototypes for microchip inspection, as well as in the field of magnetic and cryogenic technology, as Hans Priem (left) and Cees Maris explain.

ever-increasing need for the inspection of microchips and wafers, because the semiconductor industry requires so many steps to produce a chip and to finish a wafer – often there are 600 process steps for a wafer. Testing and measurement methods are needed for quality control. Accelerator-based X-ray light sources are becoming increasingly important for these inspections. With the Swiss Light Source SLS and the X-ray free-electron laser SwissFEL, PSI has a lot of expertise in the field of accelerator-based X-ray light sources. Realising such large research facilities also requires strong magnets and a good vacuum. These aspects also apply to many of our products. So the technology behind them is also of great interest to us.

**Hans Priem:** In addition, accelerator technology is used in medicine, for example in proton therapy, which PSI has pioneered. And it is important for the development of Flash therapy, a very targeted cancer treatment in which very high doses of radiation are administered in short pulses.

**So the areas in which VDL ETG is active partly overlap with the research areas of PSI?**

**Hans Priem:** Yes, researchers at PSI are actually studying the same challenges as we are, but from a different angle. The combination of these two perspectives leads to a number of important new insights on both sides. This is also why it is strategically important for us to be part of Park Innovaare and PSI. It is a long-term investment to ensure that we will still be successful in five years' time.

In the projects we carry out at sites in the Netherlands, we sometimes work on questions for which PSI may already have answers. We want to contribute to such projects through our team at Park Innovaare.

**Could you give us an example?**

**Hans Priem:** Yes, for example, we are part of the team that is building the prototypes for microchip inspection. Another area is magnet and low-temperature or cryogenic technology. If you build a prototype but don't understand the details of the physical principles involved, you could run into problems later during production. That's why it makes much more sense to locate such a prototype project at Park Innovaare. If we run into something that we don't understand, we can simply walk across the street to PSI and talk to the right experts with the right skills, who can help us.

**What specific prototype project are you currently working on with researchers at PSI?**

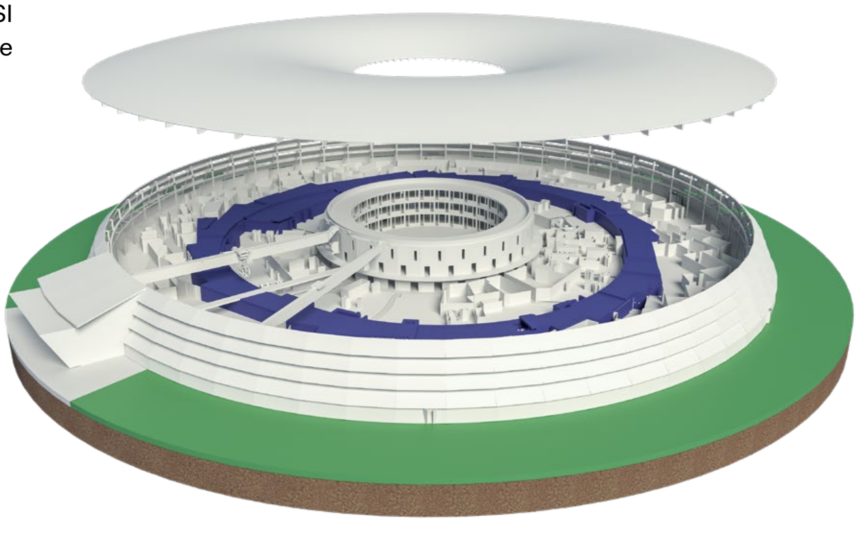
**Cees Maris:** Together with the team from the Magnet Section at PSI, we are conducting experiments on so-called pulsating heat pipes (PHP) at very low temperatures. A PHP is a tube filled with a medium that exists in both the gaseous and liquid phase in the temperature range applied. Gas bubbles created in the PHP cause the liquid to move back and forth. The idea is that we can use the PHP to transport heat from a superconducting magnet to the cooling system very efficiently.

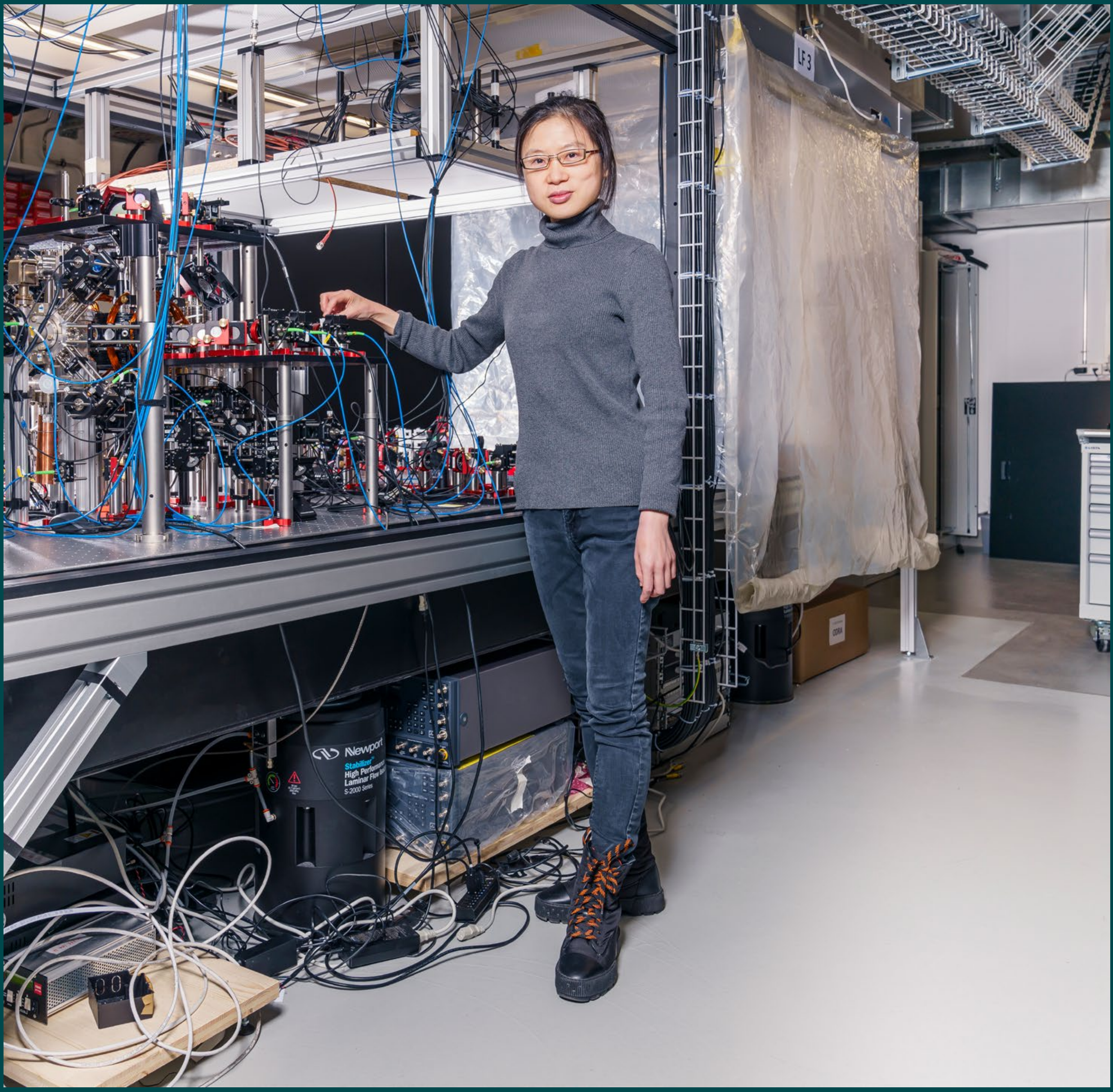
Superconducting magnets are increasingly used in accelerators and magnetic resonance imaging. Superconductivity offers a number of advantages. You can make very strong magnets that use little energy. However, they have to be cooled to very low temperatures. Our joint team built a test bed in the PSI Magnets laboratory. We filled the PHP with neon and tested the thermal conductivity at temperatures of minus 245 degrees Celsius. The facilities at PSI for this type of experiment are very good, but above all it was the people from the Magnet Section, the Department of Accelerator Technology and the Vacuum Section who made this project possible in a very pleasant collaboration. The initial results of these experiments are promising. We see potential applications for these technologies in the semiconductor industry and in space exploration. For the latter, an interesting aspect is that the system works without gravity.

**Would you say that your collaboration with PSI and here at Park Innovaare is something special?**

**Hans Priem:** I cannot stress enough how important our friendship with PSI and the Park Innovaare team is to us. Rationally speaking, it's strategic in nature, but it's also a lot of fun. And we are very proud to be part of this enormously productive and innovative network. ●

VDL Groep is an industrial group and family business based in Eindhoven, the Netherlands. VDL Enabling Technologies Group (VDL ETG) is part of VDL Groep and employs around 6,000 people worldwide. One of VDL ETG's locations is in Trübbach in eastern Switzerland. VDL ETG Switzerland has around 200 employees and specialises in the system integration of high-precision components, mechatronic systems and complete modules in various sectors of the high-tech industry. Dutch-born Hans Priem has been a manager at VDL ETG since 2010. Cees Maris, also from the Netherlands, is an engineer who has been working at VDL ETG since 2018 and has been building up the VDL ETG office in Park Innovaare since 2023.






# Applied quantum knowledge

Wenchao Xu works at the PSI Center for Photon Science in the field of quantum optics and quantum engineering. In her laboratory, she uses quantum mechanical effects to explore the physical principles in this field of research and develop practical applications. To this end, she controls and manipulates electrically neutral atoms at the single-atom level and uses their controllable interactions for quantum simulations and quantum calculations. Her goal is to build an error-correctable large-scale quantum computer with fast computing operations.

# PSI research at Switzerland's most-visited museum

Energy Science for Tomorrow (ES4T) is a joint initiative of ETH Zurich, EPFL, EMPA, PSI and the Swiss Museum of Transport. Its aim is to make energy issues understandable and tangible for every generation and thereby promote the dialogue between science, business and society.


Making energy research something visitors can experience: Alicia Siliézar in the House of Energy. The Swiss Museum of Transport is creating a platform for political and social dialogue on energy issues.

Text: Benjamin A. Senn

The Emission Explorer exhibit confronts visitors to the Museum of Transport with some very personal questions: “What do you eat?” or “How often do you buy new things?” The questions are colourfully presented on an interactive screen with five possible answers: Do I live a ‘vegan’ lifestyle, or do I eat meat ‘like a lion’? Do I ‘almost never’ buy things, or do I ‘love to shop’? The questions call for critical self-assessment and at the same time a certain amount of courage – after all, with the personal answer on the screen, you are also exposing yourself to the next person in line.

Since October 2024, the Emission Explorer has been located in the House of Energy as part of the permanent exhibition at the Museum of Transport, Switzerland’s most-visited museum, with over one million admissions in 2023. The exhibit was financed by the ETH Board, which aims to encourage a dialogue within society as part of the ES4T joint initiative. As its name suggests, the exhibit aims to explore visitors’ emission behaviour and sensitise them to their very personal carbon footprint.

“With five simple questions, we want to show in a playful way how personal behaviour can influence carbon emissions,” explains Alicia Siliézar, part of the team behind the ES4T initiative. An archaeologist by training, she has experience of working in various museums and exhibitions, and alongside her involvement in the ES4T, she also works at the PSI Visitor Center. “In addition to personal emissions, our exhibit also looks at systemic emissions, those to which we contribute indirectly because they arise through the local infrastructure, for example.”

**Dialogue platform for energy topics**

With the opening the House of Energy in April 2023, the Swiss Museum of Transport not only inaugurated a modern and energy-efficient new building, it also entered new thematic territory with the exhibition it houses. Right alongside the Railway Hall with its collection of historic Swiss trains – a place that probably awakens school trip nostalgia for many a Swiss visitor – the permanent exhibition Experience Energy! now takes visitors on a journey into the sustainable Switzerland of the future.

The new permanent exhibition Experience Energy! uses a wide variety of interactive stations to highlight different aspects of energy and climate – including climate protection, the future security of energy supplies and the impact of energy consumption on global warming.

Various partners from business, education, and research have been involved in the design of the exhibition and thus find a platform for political and social dialogue. In addition to the institutions of the ETH Domain, the Aargau power company Swissgrid and the energy and infrastructure company BKW are also represented – the latter shows, in its exhibit, how intelligent living of the future could reduce energy consumption.

For research such as that carried out at PSI, the ES4T joint initiative offers completely new opportunities: "This platform helps us communicate energy issues to a broad audience – and thus to strengthen people's understanding of the importance and urgency of restructuring our energy supply: away from fossil fuels and towards renewable energy sources," explains Christian Bauer, an environmental scientist at PSI's Laboratory for Energy Systems Analysis. Mirjam van Daalen, Head of Communications at PSI, also points out: "Through this joint initiative, we are bringing the coordinated, concentrated knowledge of our research in the ETH Domain to a family audience."

At the opening ceremony for the House of Energy, Martin Bütikofer, Director of the Swiss Museum of Transport, explained how the topic of energy fits in with the museum. He was quoted at the time by the paper Luzerner Zeitung as saying, with a twinkle in his eye: "We could have decided to build a new house for old locomotives. There are also countless old bicycles that we don't yet have. These are great hobbies, but they don't move us forward as a society. Energy has everything to do with mobility, 100 percent."

But energy as a form of propulsion is only one aspect of the exhibition. It also highlights current issues such as global warming, climate protection and the future security of energy supplies. For example, a hologram of the Swiss environmental pioneer Bertrand Piccard takes us on an animated journey into a renewable energy system for Switzerland in 2050. A digital globe visualises the connection between people's energy use and its impact on the climate and the planet.

"Through this joint initiative, we are bringing the coordinated, concentrated knowledge of our research in the ETH Domain to a family audience."

Mirjam van Daalen, Head of Communications at PSI

### The art of communication

But how can complex scientific topics be communicated to a broad audience in an age-appropriate manner? "Experience Energy was able to reach 200,000 visitors in the first three months – that's an impressive level of visibility," says Alicia Siliézar. "Many of our visitors are grandparents and their grandchildren – and that's the big challenge: How do we create exhibits and workshops that appeal to such a wide age range?"

There is no magic formula for the perfect exhibit. "Something like that comes about through collaboration," explains Siliézar. "As institutions, we provide the ideas, talk them over and work with the Museum of Transport to find an appealing way of implementing them."

This is how the Emission Explorer took shape: based on a scientific study by EMPA, the initiative agreed on those five everyday questions. "The discussion then gave rise to the idea of capturing the carbon dioxide ($CO_2$) produced in a balloon and thereby visualising it," says Siliézar.

The first prototype consisted of a simple shoebox that used a hydraulic system to inflate a physical balloon and then blew the metaphorical 'carbon dioxide' collected into the visitors' faces. "As we went on, we agreed to show the balloon digitally on the screen," Siliézar recalls. "The hydraulic system – the pumps that make it work – have remained, however. Aside from an easy-to-understand message, visitors also want something they can touch," says Siliézar with a smile.

### Contributing your own expertise

It's not just about communicating the science; such a colourful joint initiative also calls for internal communication skills. "It's the first time a cooperation of this kind has been pursued, with all the different perspectives and the needs of the institutions involved. We have learned a lot from each other in this collaboration in order to realise exciting exhibits and workshops," says Siliézar.

Organising live events on site is also an important part of ES4T: "In collaboration with iLab, PSI's school laboratory, we were able to organise a workshop during the Energy Days – a weekend devoted to the topic of renewable energy sources at the Swiss Museum of Transport. During this three-day event, kids were able to get hands-on experience and carry out simple experiments under the guidance of PSI experts and researchers."

A lot of creativity is also called for when designing the exhibits: "At the moment we are working on a diorama – a display case consisting of both mechanical and digital elements. In four stories, corresponding to the four seasons, visitors will learn about different forms of energy storage in a flexible energy system. We at PSI are taking the lead here," says Siliézar. At the same time, ETH Zurich is working on an interactive exhibit for the very young that allows them to experience different forms of energy. "This should appeal particularly to a very young audience – and at the same time, the accompanying adult should also learn something from it."

The Experience Energy! exhibition is growing: In addition to their personal carbon footprint, visitors will soon be able to learn even more about the exciting energy research being carried out within the ETH Domain. ●

# Latest PSI research news

## 1 Beijing's smog, decoded

Air pollution causes several million deaths worldwide every year. In the Chinese capital Beijing, local and regional measures have already succeeded in improving air quality – but not quite to the extent hoped for.

Researchers from PSI, Beijing University of Chemical Technology and the University of Helsinki have now jointly applied a new method to better study the smog in the city. Using a new type of mass spectrometer, they were able to analyse the particulate matter in the air at the molecular level in real time, providing an unprecedented level of detail about where it comes from and how it forms.

They found that secondary organic particulate matter – particles suspended in the air that form as they travel through the atmosphere – comes from different sources depending on the time of year. In winter, it comes from burning wood and coal, mainly in the greater Beijing-Tianjin-Hebei region. In summer, when air flows in from the south, urban emissions such as those from traffic and industry are dominant, probably coming from the much larger Xi'an-Shanghai-Beijing area. From this it is clear that air pollution does not only originate in the metropolis itself, but also comes from hundreds of kilometres beyond.

Further information:
https://bit.ly/3XsyCOS

## 2 ESA in Switzerland

The European Space Agency ESA has a new point of contact in Switzerland: ESA and PSI have jointly launched the European Space Deep-Tech Innovation Centre ESDI. It is located in the Switzerland Innovation Park Innovaare, right next door to PSI.

A contract between ESA and PSI also defines ESDI's first platform: Phi-Lab, which is linked to PSI and develops instruments to encourage innovation. It draws up research programmes to promote new and innovative projects in Switzerland and provide financial support for them. The first programme, starting in 2025, focuses on the development of technologies in quantum research, data science and materials science.

ESDI was initiated by the Swiss State Secretariat for Education, Research and Innovation SERI and will receive support from the ETH Domain beginning in 2025.

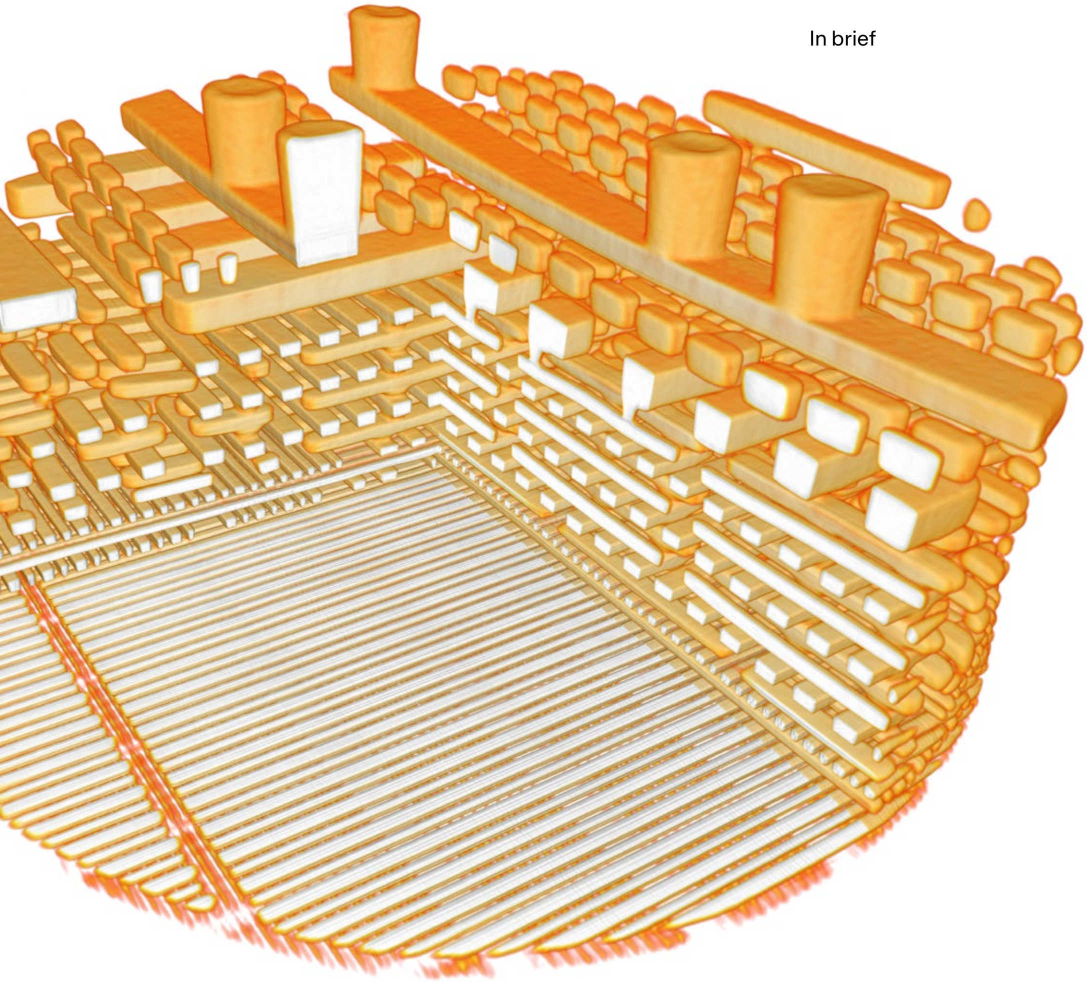
Further information:
https://bit.ly/41hdV9E

## 3 92 million years

To explain the formation of asteroids and planets or to determine the age of rocks, it is important– among other things – to know the half-life of the element samarium-146 as precisely as possible. New research has now led to the most precise value to date: 92.0 ±2.6 million years. That is how long it takes for half of this radioactive substance to decay. Previous measurements carried out since the 1950s have repeatedly produced contradictory results.

Since samarium-146 does not occur naturally on Earth, experiments and measurements are challenging. The new value is the result of a collaboration between PSI and the Australian National University. From a sample irradiated at the Swiss Spallation Neutron Source SINQ at PSI, the researchers were able to extract a tiny amount of samarium-146 – so little that a single grain of icing sugar weighs 10 times as much. Accordingly, the necessary measurements took several months. The researchers used state-of-the-art methods to precisely determine the number of samarium-146 atoms and their rate of decay. This made it possible to calculate the half-life.

Further information:
https://bit.ly/41zoDcS



**4** nanometres – that's 4 millionths of a millimetre – is the image resolution achieved with the new ptychographic technique.

**15** million detector images were generated to reconstruct the chip in three dimensions.

**100** million transistors fit inside one square millimetre of a modern computer chip.

## 4 New X-ray world record

Imaging a state-of-the-art computer chip in three dimensions with a resolution of 4 nanometres – this world record in X-ray microscopy was achieved by researchers at PSI in collaboration with ETH Lausanne EPFL, ETH Zurich and the University of Southern California.

Computer chips are technological marvels. Nowadays, it is possible to pack more than 100 million transistors per square millimetre into state-of-the-art integrated circuits – and the trend is upward. In cleanrooms, highly automated optical systems etch the nanometre-sized conductor tracks into silicon blanks. The structures created by this complex and elaborate manufacturing process turn out to be just as difficult to characterise and image.

Instead of using conventional lenses to make these tiny structures visible, the researchers turned to ptychography – a computational imaging technique that combines many individual images into a single high-resolution image. By using shorter exposure times and an optimised algorithm, they were able to beat their own 2017 world record by a considerable margin. They used X-ray light from the Swiss Light Source SLS for their experiments.

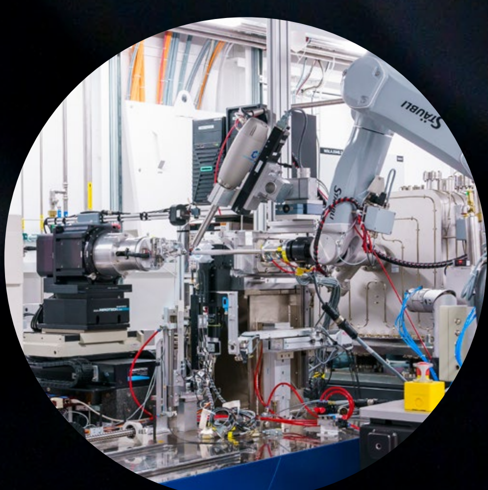
Further information:
https://bit.ly/41p15X4

# Kelvin: The low-temperature scale

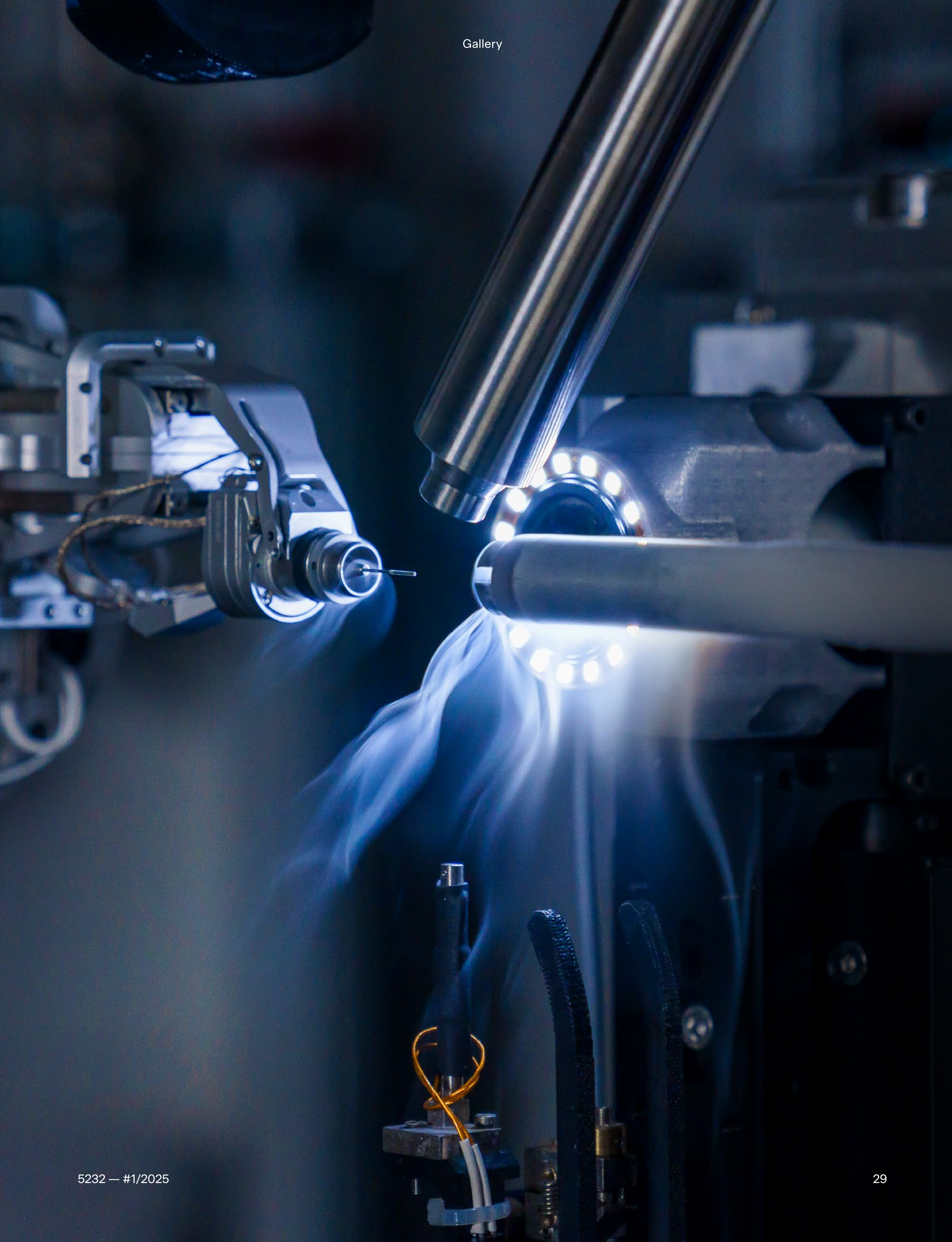
Zero Kelvin – the temperature known as absolute zero. Since heat is energy, lower temperatures mean less energy, but there is no such thing as negative energy. Expressed in the more familiar temperature scale, zero Kelvin is −273.15 degrees Celsius: nothing can get colder than that. Some researchers at PSI are conducting experiments at temperatures close to absolute zero; others are tinkering with technical means of reducing the temperature as efficiently as possible.

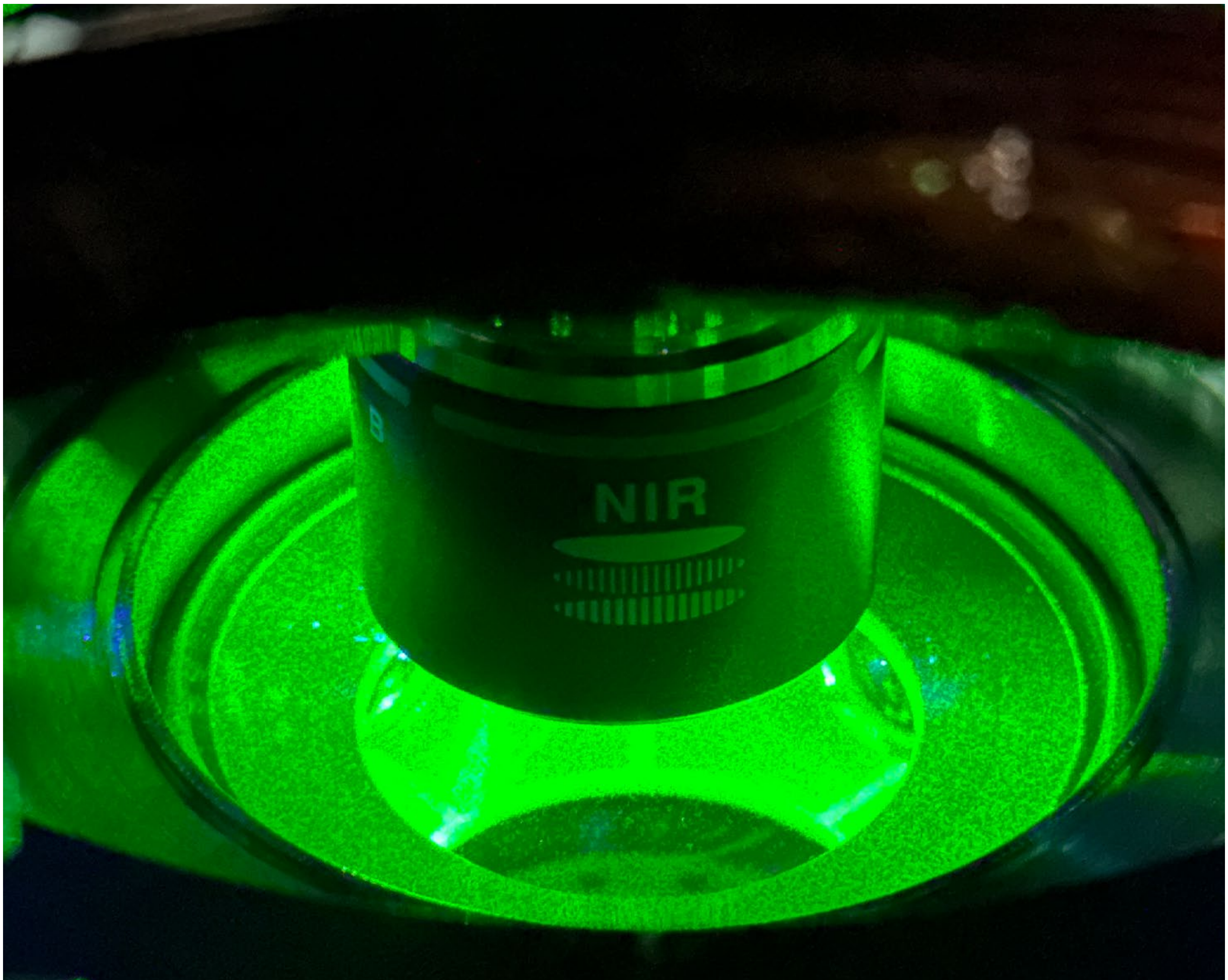
Text: Christian Heid

## Protein sample

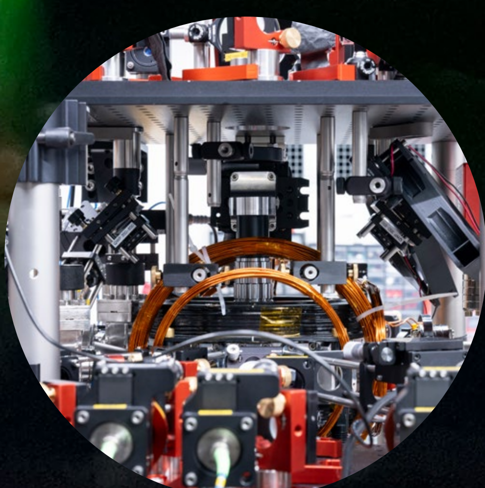


Ice crystals can be seen on the tube-shaped sample holder at the end of the robot arm, which has travelled horizontally from the right-hand edge of the image to just in front of the circle of light. The robot automatically retrieves protein samples from a cooling bath of liquid nitrogen and transports them to the experimental position that can be seen, like a needle, opposite the end of the sample holder. The protein crystals are then irradiated with X-ray light from the Swiss Light Source SLS. The three-dimensional structure of the protein can be calculated from the diffraction pattern. This allows researchers to gain insights into the molecular architecture and thus into how the proteins function.





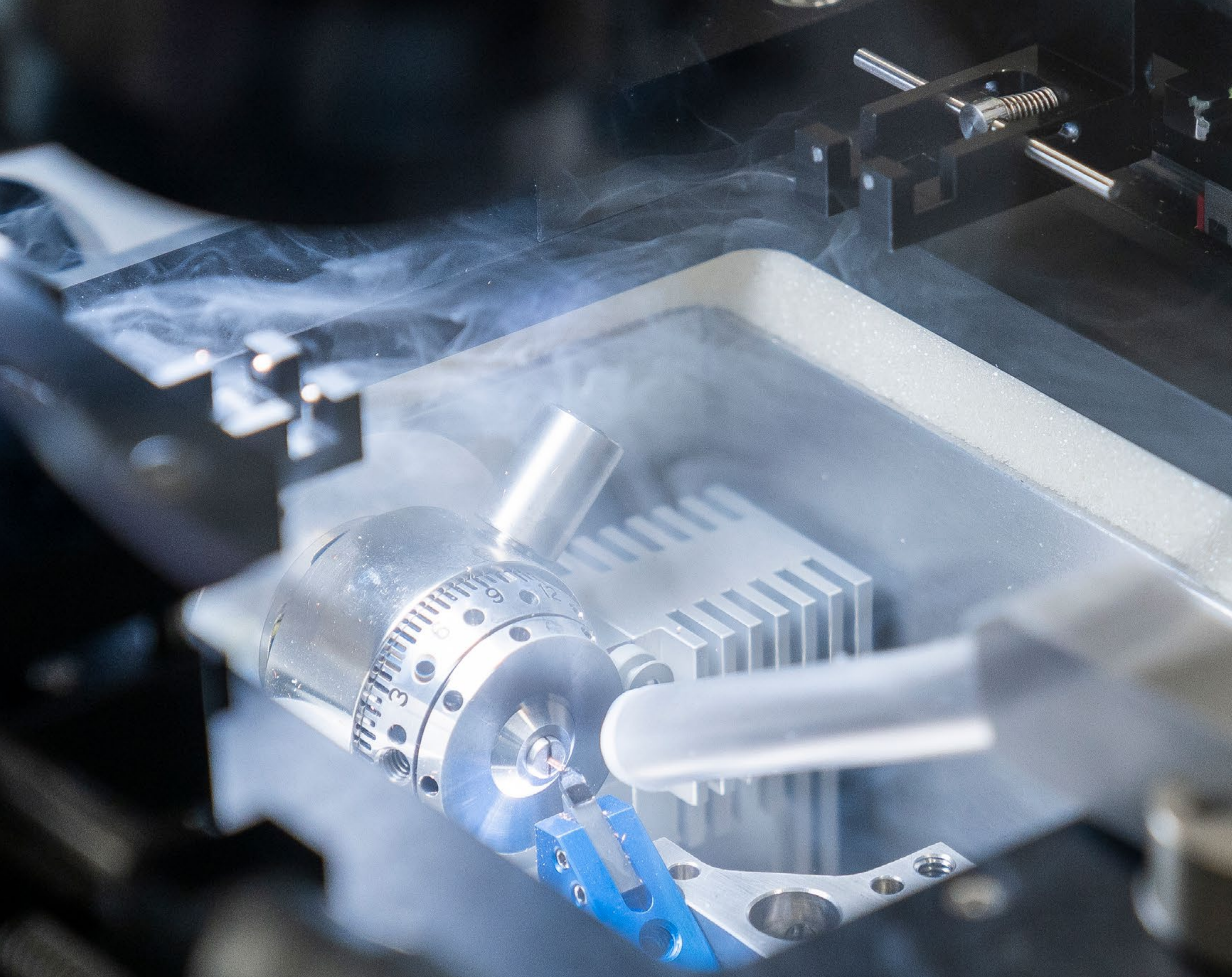

## Cold atoms



Green light spreads out from the evacuated experimental chamber. Inside it are the atoms that are to be cooled. The green light comes from a laser and hits the atoms in a precisely synchronised manner. When they absorb the energy of individual light packets, they release a larger amount of energy immediately afterwards – each time becoming even colder than before. The principle is called laser cooling. It brings the atoms close to absolute zero, at −273.15 degrees Celsius. This makes it possible to determine and analyse their quantum nature. At the PSI Center for Photon Science, researchers use this approach to gain new insights in the field of quantum mechanics.

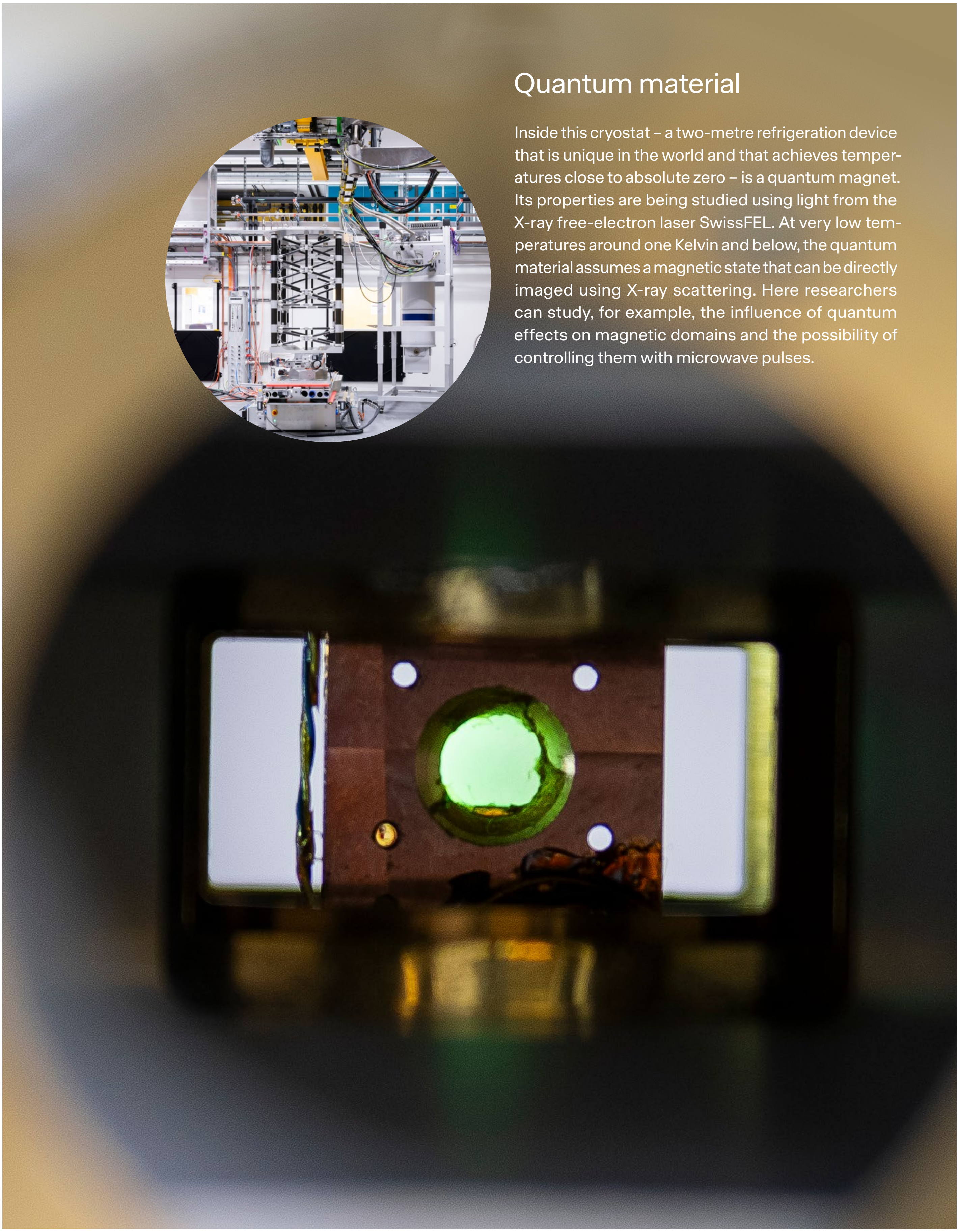
## Pulsating heat pipes

These delicate, silvery heat pipes contain a dual-phase flow of helium or neon; that means the substances are partly gaseous and partly liquid. The vertical pipes are connected, at their lower end, to a heat source. At their upper end, a condenser is connected to a cryocooler: a refrigeration device that is able to maintain a constant low temperature below –240 degrees Celsius. In this design, known as pulsating heat pipes, the flow of helium or neon leads to an efficient passive heat transfer. Such a thermal connection is a key element for the optimisation of superconducting systems that need to be cooled to low temperatures. The development and implementation of this arrangement is part of the joint efforts of PSI's magnet section and the company VDL ETG (see page 20).



## Tissue sections

A cold mist of nitrogen hovers around the interior of a microtome, a cutting device used to produce tissue sections. A diamond knife is mounted in a blue holder. Directly behind the cutting surface of the knife are the very small, frozen tissue samples, which are fixed in a kind of drill chuck. The sample is moved up and down while the knife advances towards the sample, producing ultrathin sections, typically between 50 and 150 nanometres thick. To preserve the sample in its natural state in amorphous ice, it must be very cold: −150 degrees Celsius. In the Laboratory of Biomolecular Research, the ultra-thin tissue samples are used to improve our understanding of physiological processes. From there, new therapeutic possibilities can be explored.



## Quantum material

Inside this cryostat – a two-metre refrigeration device that is unique in the world and that achieves temperatures close to absolute zero – is a quantum magnet. Its properties are being studied using light from the X-ray free-electron laser SwissFEL. At very low temperatures around one Kelvin and below, the quantum material assumes a magnetic state that can be directly imaged using X-ray scattering. Here researchers can study, for example, the influence of quantum effects on magnetic domains and the possibility of controlling them with microwave pulses.

# Attorney for cutting-edge technology

Former PSI doctoral candidate Stephanie Smit now works as a patent attorney for a company that is among the most important in the world. That's because this company builds machines that are worth a fortune and are highly sought after.

Text: Jan Berndorff

Not every important company is also known to the general public. In the current ranking of the most valuable companies in the world, Apple and Microsoft are at the top with a market value of more than three trillion US dollars each. But the business of these two renowned high-tech companies depends, for better or worse, on a company that has its headquarters in the tranquil town of Veldhoven in the Netherlands, where former PSI doctoral candidate Stephanie Smit has been working for five years now. It may not be one of the most expensive companies in the world, but with a market value of around a quarter of a trillion US dollars, it is still one of the top five in Europe. Amazingly, it is still completely unknown to most people.

ASML? "When I applied for the job here, I had honestly never heard of it before," says Smit. Founded in 1984 as a joint venture between Philips and ASM International, ASML has grown enormously in recent years: since 2019, sales have doubled to almost 28 billion US dollars per year, and profits have more than tripled to nearly eight billion US dollars. ASML has more than 43,000 employees worldwide, 23,000 of whom work at the headquarters alone.

The reason why hardly anyone knows the company, despite its size and success, is that it does not manufacture products for consumers. Its customers are large microchip manufacturers including Intel, Samsung and TSMC, which in turn supply tech companies such as Microsoft and Apple. ASML makes machines that can be used to 'print' essential components for microchips – in a process known as lithography. And microchips are in greater demand than ever, because they are found in computers, mobile phones, tablets and almost every kind of smart electronic device. They are the basic building blocks of the modern digital world.

In this industry, ASML is not just anyone. It is the world market leader for lithography machines. "ASML is the company the world depends on" was a headline in the Austrian newspaper Der Standard in 2023.

As a patent attorney working for this company, Stephanie Smit makes sure that new ideas and technologies are legally protected. But how does a former PSI researcher who worked on nanofabrication end up becoming an attorney?

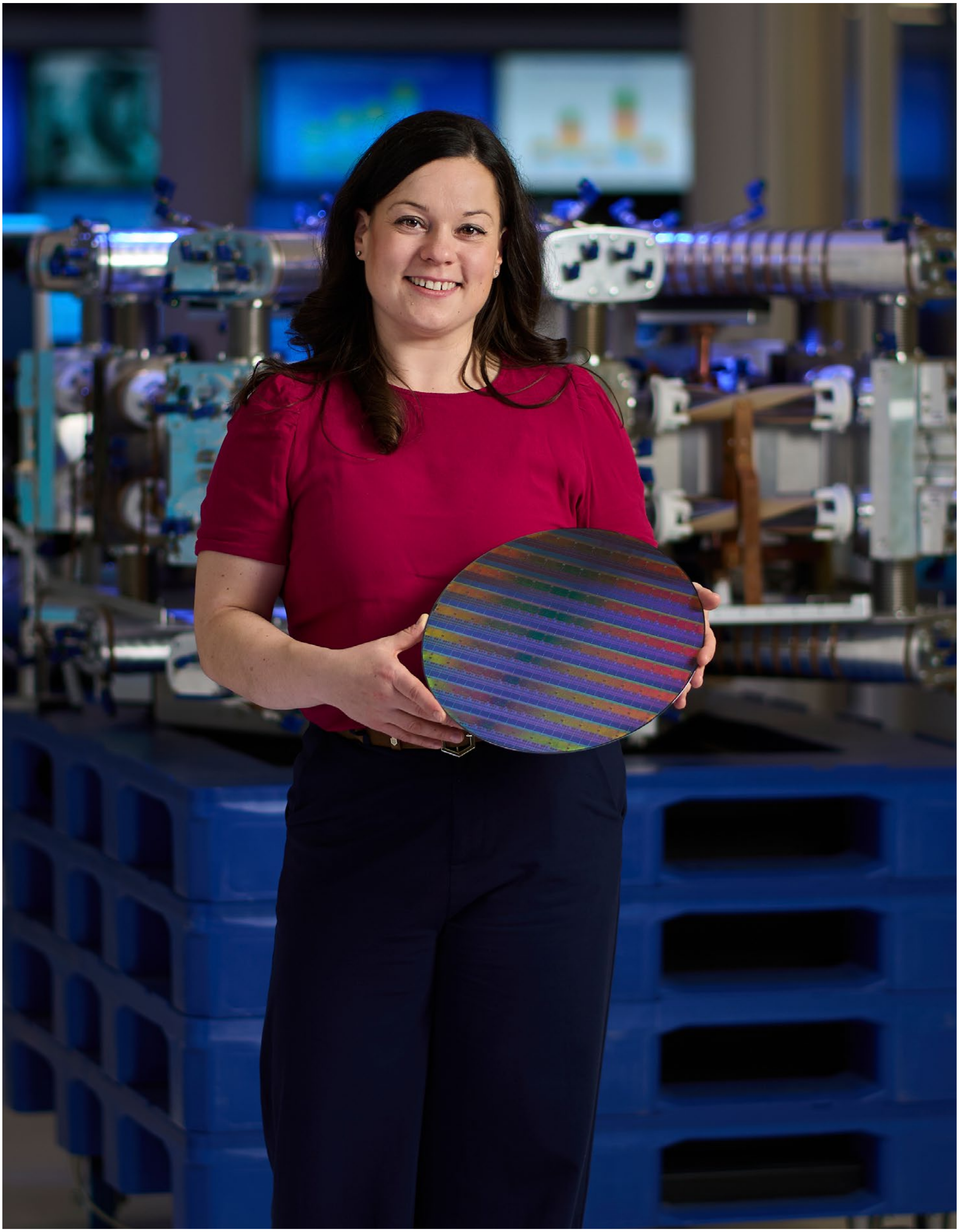
**A patent attorney is not necessarily a lawyer**

"It is a common misconception that patent attorneys are lawyers," Smit explains. Of course, you have to know your way around patent law. But a scientific background is just as important: patent attorneys must understand the research and technology behind products so that they can translate the innovation, so to speak, into the legal language of a patent. "And for this, my studies in physics, and above all my work at PSI, were the best possible preparation," says Smit.

Smit, who grew up on the Shetland Islands, studied in the Scottish city of Aberdeen. "It was probably my father who instilled in me a passion for physics and technology from an early age," she says. He was a keen amateur pilot and passed on his fascination with aeronautics to his daughter. "I also got my pilot's licence, but then I decided on something more down-to-earth and studied physics."

At the same time, Smit developed an interest in languages and cultures. After her preliminary diploma, she went to Krakow for a year to immerse herself in Polish culture. In addition to English and some Polish, she now speaks French, German, and Dutch. This international articulacy, combined with her open, communicative nature, is a great advantage in her job as a European patent attorney. After all, she has to interact with specialists from different countries in order to secure patents.

Her time in Krakow inspired her to do an internship abroad after finishing her studies. "I applied to IAESTE, an organisation that arranges technical and scientific internships abroad, also in Japan and




"It isn't that far from high-tech research to high-tech industry."

Stephanie Smit, patent attorney for ASML

Canada, but PSI in Switzerland was my first choice. Because that's where the cutting-edge research is done. "Especially in view of the opportunity she was given to work hands-on on a complex topic: in ptychographic imaging, in which a sample is scanned with a particle beam for microscopic examination, Smit had to independently set up a special laser configuration. "I knew little about this from my studies, but my colleagues gave me a lot of support."

She found it exciting to help develop a completely new research approach. Outside the workplace, too, she enjoyed her time in Switzerland and did a lot with other interns and students. Last but not least, it was here that she met her husband, a native of the Netherlands who was also an intern at PSI at the time.

**PhD at the Swiss Light Source**

Having both completed their master's degrees in Aberdeen, they returned to PSI for their doctoral research. Now working in the Laboratory for Micro- and Nanotechnology, Smit studied the magnetic structures of samples using the Swiss Light Source SLS. "I'm very happy about everything I learned at PSI, which now helps me in my job. But above all, I met many wonderful and brilliant people with whom I am still in touch today."

It was one of those colleagues who gave her the idea of becoming a patent attorney: "She said that, knowing me as she did, it would suit me. I had to look into it first. And it's true: this job is a perfect match for my interests." After completing her PhD, Smit did a postgraduate course in patent law at Queen Mary University in London and worked for a patent law firm. "However, I missed the international research atmosphere and the connection with technology. By that time, my husband and I had had two of our three children, and decided we would prefer to raise them in the Netherlands."

When she heard that ASML was looking for a patent attorney, she saw this as her opportunity. "And we actually felt right away during the interview that it was a good fit – not least because of my background at PSI. It isn't that far from high-tech research to high-tech industry."

Smit has this to say about her employer's machines: "The latest lithography systems are probably among the most complex machines that mankind has ever come up with." They are as big as a house and chock-full of laser technology and optical components.

Roughly speaking, lithography works by shining highly concentrated light through a stencil onto a millimetre-thin silicon plate called a wafer. A layer of photoresist is fixed in tiny structures while the unexposed remainder of the layer is precisely washed away – or vice versa. The process is repeated several times, leaving behind an apparently mirror-smooth wafer with densely packed, microscopically small transistors – the switching elements with which the microchips carry out their calculations.

**A question of wavelength**

Lithography machines use ultraviolet light because its short wavelength enables more precise imprinting than visible light. The density of the transistors determines the performance of the microchip. ASML started with 2,200 transistors per square millimetre. Today, 45 million fit into the same tiny area.

Modern machines work with light in the deep ultraviolet (DUV) range, usually with a wavelength of 193 nanometres. ASML has a global market share of around 85 percent for such machines. But ASML recently became the only supplier in the world to offer EUV systems as well. EUV stands for extreme ultraviolet and works at a wavelength of just 13.5 nanometres – making it possible to build even more powerful chips.

ASML delivered the first EUV machine to Intel in early 2024. According to the Reuters news agency, the cost was around 350 million US dollars. The DUV variants are not much less expensive, though. So it's no wonder that ASML only needs to sell a few hundred of these systems a year and can still make good money from them. Nor is it any wonder that the average person rarely comes into contact with such machines, and that ASML is therefore not as famous as Microsoft or Apple.

And it is hardly surprising that Stephanie Smit finds it exciting to negotiate the patents of such a manufacturer – ASML holds more than 21,000 patents in total, covering all kinds of parts and mechanisms in the machines. "I've been here for five years now, and I'm still amazed to be working for a company on which so much depends," says Smit. "But I particularly like my colleagues here. They are just as great as the ones I met at PSI." ●

# From our base in Aargau we conduct research for Switzerland as part of a global collaboration.


5232 is Switzerland's prime address for experiments on large research facilities. The Paul Scherrer Institute PSI even has its own postcode, a distinction that seems justified for an institute that extends over 342,000 square metres, has its own bridge across the River Aare, and has around 2,300 employees – more people than in most of the surrounding villages.

PSI is situated on both banks of the River Aare in the canton of Aargau, in the municipal areas of Villigen and Würenlingen. Its main areas of research are in the natural sciences and engineering. Funded by the federal government, it belongs to the domain of the Swiss Federal Institute of Technology (ETH Domain), which also includes ETH Zurich, ETH Lausanne (EPFL), and the research institutes Eawag (Swiss Federal Institute of Aquatic Science and Technology), Empa (Swiss Federal Laboratories for Materials Science and Technology) and WSL (Swiss Federal Institute for Forest, Snow, and Landscape Research). We conduct basic and applied research and thus work on sustainable solutions for central questions from society, science and business.

**Complex large research facilities**

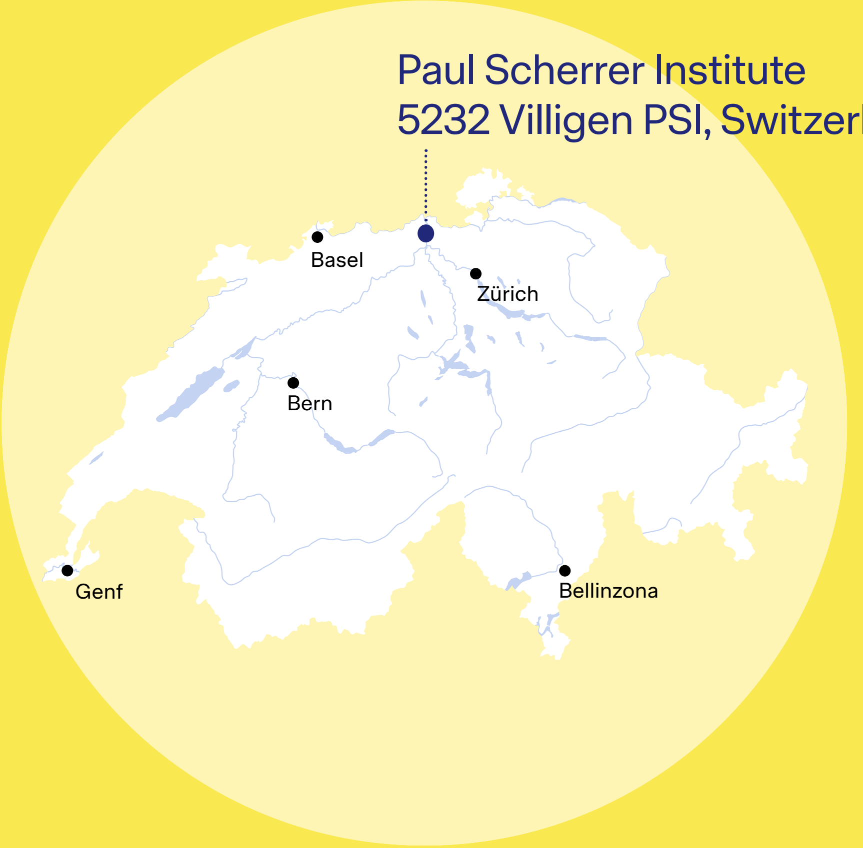
Switzerland's federal government has given PSI the mandate to develop, build, and operate large, complex research facilities. These are the only such facilities within Switzerland, and some are the only ones in the world.

Running experiments at our large research facilities enables many scientists from the most diverse disciplines to gain fundamental insights for their work. The construction and operation of these kinds of facilities involve so much time, effort, and cost that comparable measurement equipment is not available to academic and industrial research groups at their own institutions. That is why we keep our facilities open to all researchers worldwide.

To obtain a time slot to use the experimental stations, however, both Swiss and foreign scientists first have to apply to PSI. Selection committees comprising experts from all over the world assess the scientific quality of these applications and recommend to PSI which candidates should be given measurement time. Even though there are around 40 measuring stations where experiments can be carried out at the same time, there is never enough capacity for all of the proposals submitted – around one-half to two thirds have to be rejected.

Around 1,900 experiments are performed every year at PSI's large research facilities. Time slots are free of charge for all researchers working in academia. In a special process, users from private industry can buy time to carry out proprietary research and use the PSI facilities for their own applied research. For this, PSI offers special research and development services.

PSI operates five large research facilities in total where the internal processes of materials, biomolecules, and technical devices can be explored. Here scientists use different beams to "illuminate" the samples they want to investigate in their experiments. The beams available for this



800
scientific articles a year based on the experiments performed at PSI's large research facilities

5,000
scientists from across the globe perform experiments at our large research facilities every year

5
large research facilities that are unique in Switzerland

range from particles (neutrons or muons) to intense X-ray light from a synchrotron or X-ray laser source. The different types of beams allow a wide variety of material properties to be studied at PSI. The high complexity and cost of the facilities is due to the massive size of the accelerators needed to generate the different beams.

### Four main areas of research

However, PSI not only acts as a service provider for researchers, but also carries out an ambitious research programme of its own. The findings produced by PSI scientists help us to understand the world better, and also lay the foundation for developing new types of equipment and medical treatments.

At the same time, our own research is an important prerequisite for the success of our user service programme for the large research facilities. Only researchers personally involved in current scientific developments in the fields external researchers are working in can support them in their investigations and further refine the facilities to ensure they continue to meet the needs of cutting-edge research in the future.

Our own research is concentrated on four focus areas. In the area of Future Technologies, we investigate the diverse properties of materials. With the knowledge this yields, we create the foundations for new applications – whether in medicine, information technology, energy production and storage, or new industrial production methods.

The goal of our work in the focus area Energy and Climate is developing new technologies for a sustainable and safe energy supply, as well as for a clean environment. Also in this area, we are investigating interconnections within Earth's climate system.

In the focus area Health Innovation, researchers are looking for the causes of diseases as well as for potential therapeutic methods. In addition, we operate the only facility in Switzerland using protons for the treatment of specific cancer diseases. This special technique makes it possible to destroy tumours in a targeted way while leaving the surrounding health tissue largely undamaged.

In the area Fundamentals of Nature, researchers are seeking answers to fundamental questions about the basic structures of matter and the functional principles of nature. They investigate the structure and properties of elementary particles – the smallest building blocks of matter – or clarify fundamental processes in living organisms. The knowledge gained in this way opens up new approaches to solutions in science, medicine and technology.

### The brains behind the machines

The work at PSI's large research facilities is challenging. Our researchers, engineers, and professionals are highly specialised experts. It is important for us to foster this expertise. So we want our employees to pass on their knowledge to the next generation, who will then put it to use in a variety of professional positions, not just at PSI. Around a quarter of our staff are therefore apprentices, doctoral students, or postdocs. ●

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**Editorial team**
Monika Gimmel,
Martina Gröschl,
Christian Heid,
Dr. Laura Hennemann (Lead),
†Sebastian Jutzi (Lead),
Benjamin A. Senn,
Dr. Mirjam van Daalen

**Translation**
Patrick Regan

**Editor**
Daniel Bullinger

**Design concept**
Scholtysik & Partner AG and
Studio HübnerBraun

**Design, Art Direction and Layout**
Studio HübnerBraun

**Photos**
Paul Scherrer Institut PSI/
Markus Fischer,
except: pages 35–36: Henning Mack;
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**Illustrations and graphics**
Studio HübnerBraun,
except: pages 6–7: Daniela Leitner;
pages 16–17, 20: Mahir Dzambegovic.

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# Coming up in the next issue

One hundred years ago, human beings discovered how nature behaves and can be described on the tiniest scale: the year 1925 marked the birth of quantum mechanics. This physical theory makes it possible to express laws that apply at and below the level of atoms in the form of mathematical formulae, and so to make predictions.

Since then, quantum mechanics has become a central part of modern physics, triggering countless developments and technologies. Its effects are used in modern experiments, including many at PSI. Progress is being made towards quantum computers. The quantum properties of novel materials are being studied and could form the basis of future technologies. And quantum mechanics can even help in the development of pharmaceuticals.

**Paul Scherrer Institute PSI**
Forschungsstrasse 111
5232 Villigen PSI
Switzerland
www.psi.ch