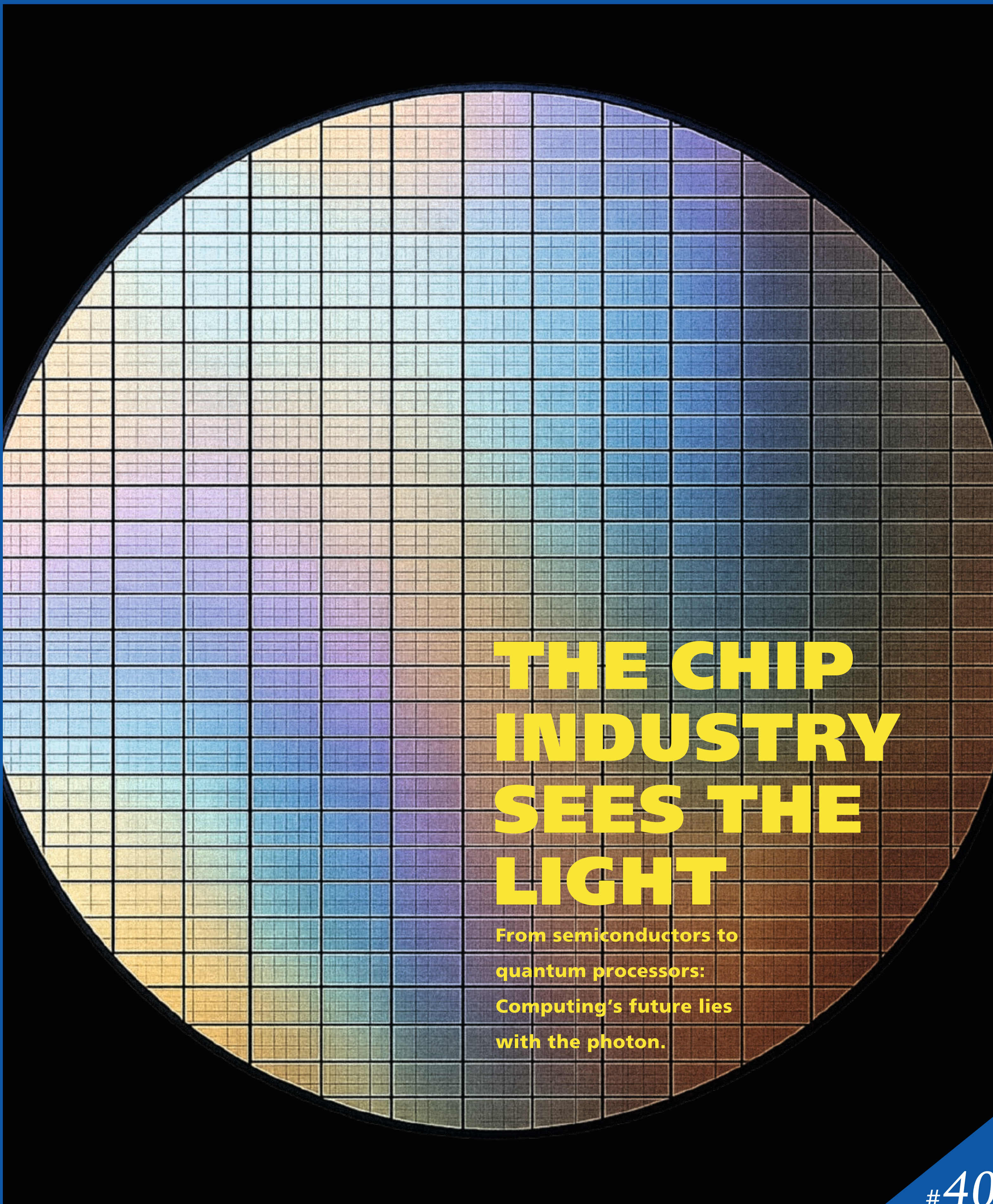
LASER COMMUNITY.

Of people and photons



THE CHIP INDUSTRY SEES THE LIGHT

From semiconductors to quantum processors: Computing's future lies with the photon.

#40

The punch card is the forerunner of the microprocessor and memory chip: In the 20th century, it heralded the transition from mechanical to digital data processing.

LASER COMMUNITY. *#40*

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Julian Rentzsch

Dear Readers,

Artificial intelligence, connected factories and autonomous driving—both the world of work and our everyday lives are changing rapidly. At the heart of this change are increasingly powerful microchips. Producing these efficiently is the major challenge facing the chip industry. TRUMPF has been working closely with the leading companies in this sector for many years. We have therefore dedicated this issue of *Laser Community* to, among other things, the microchip. Photonics and laser technology are often the key drivers behind the many leaps of innovation in this field. One very well-known example of this is EUV technology. To find out more about where lasers are used in the chip industry and what innovations we can expect in the coming years, turn to *page 12*.

On *page 18*, we look at a different but no less exciting field of application for laser tech: the prevention of collisions with space debris. Should a satellite run into a piece of scrap, this could shut down communication networks back on Earth. And were the ISS space station to be hit, that could spell disaster. In our interview with Wolfgang Riede from the German Aerospace Center (DLR), he explains how lasers can be used to divert debris from a collision course. Together with his team, he is working every day to free space of this threat.

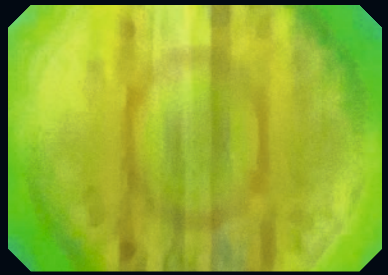
Although lasers will not be able to dispose of nuclear waste for the foreseeable future, they may soon be used to screen nuclear waste casks. Why is this so important? In the Asse interim storage facility in Lower Saxony alone, there are over 126,000 containers of nuclear waste. Sooner or later, this will have to be removed. That's a dangerous job, not least because nobody knows what's inside many of the casks—and therefore how radioactive the contents are. X-rays are of no use in scanning these casks. TRUMPF has therefore joined forces with Focused Energy, RWE and other industry and research partners to solve this problem. To find out how lasers can help with this task, turn to *page 24*.

A joint venture between ElringKlinger and OPmobility is showcasing the strength of laser tech in everyday industrial applications. EKPO develops fuel cells for the propulsion of not only cars, trucks and buses but also trains and ships. The core component of these fuel cells are bipolar plates. It takes maximum precision to weld the thin metal foils—a job that is best performed with our fiber lasers. To discover why laser tech plays such an important role in the mobility transition, turn to *page 26*.

We wish you an enjoyable and inspiring read!

DR. RER. NAT. HAGEN ZIMER

Chief Executive Officer for Laser Technology
Member of the Managing Board of TRUMPF SE + Co. KG



Oh, dear!

Admittedly, we fell for it too. When a purported image of a photon went viral, we were thrilled. Until we realized it couldn't be true. See **page 10**.

Oh, yeah!

In 2013, *Laser Community* predicted which laser processes would become standard in chip fabrication. Let's see if we can do it again! See **page 12**.

Oh, Mexico!

Chemistry, art history, astronomy—many disciplines have benefited from laser tech. Now it's the turn of archaeology and Mayan studies. See **page 26**.

LASER COMMUNITY.

Bryan Tarnowski, Gernot Walter, Benjamin Yuen

Jeannette Petri, TRUMPF

Fraunhofer ILT / Ralf Baumgarten, Die Magaziniker & AI, Bryan Tarnowski

Dennis Haasler from Fraunhofer ILT takes a look …

… at the new one-kilowatt USP laser, together with Steffen Rübling from TRUMPF.

Fraunhofer ILT / Ralf Baumgarten

RAMP UP THE POWER!

A new and extremely powerful ultrashort pulse laser is now ready for rollout. Yet how do we harness this immense performance for industrial applications? And where might this beam source best be used? A team from Fraunhofer ILT has all the answers.

Countless industries are just dying to get their hands on a really powerful ultrashort pulse (USP) laser—be it battery producers, the fuel cell industry, toolmakers, aerospace companies, semiconductor manufacturers … Wherever there's a need to texture surfaces to a high precision, drill fine holes or ablate large areas, USP lasers are the most precise and material-friendly tool in town. Yet the world is a cruel place: Whereas USP delivers great results, the process is too slow for a number of applications and therefore not economical enough. Many a brave product idea has stumbled at this hurdle.

Whenever there's a desire for more speed, laser technology has always had a proven recipe: a beam source with more power! Dennis Haasler is an expert in process technology at the Fraunhofer Institute for Laser Technology ILT. "A lot of applications in industry are simply crying out for greater median power, which would make the use of USP lasers economically viable," he explains. →

Test application: high-speed ablation of a polymer matrix in compound bipolar plates for fuel cells.

"A lot of USP applications in industry are simply crying out for greater median power."

Dennis Haasler, Fraunhofer ILT

Haasler and his team have hosted a powerful guest in their lab since the summer of 2024: the preliminary model of the TruMicro 9000, which is being prepared for market launch. The new laser from TRUMPF has a median power of one kilowatt—many times more than what is currently available for industrial USP applications. The engineers at Fraunhofer ILT have made it their task to find out how this high-power USP laser can best be harnessed in various industries. "With such a huge jump in performance, we need to rethink machining strategies and process technologies and to try out some new ones," says Haasler. This huge increase in power also brings new challenges.

UNTAMED STALLION "Using a kilowatt laser is a bit like trying to ride an untamed stallion," says Haasler of the project's early days. Such a high median power brings complications that were once unknown in the world of USP lasers. "At ten watts of USP power, it didn't really matter if there was a speck of dust on a coated deflection mirror," Haasler explains. "But, at one kilowatt, that will literally blow the optics."

Increasing power brings increasing complexity. The experts at Fraunhofer ILT encapsulate the beam path to protect it from dirt and also monitor beam guidance. At high median power, there is also the possibility of thermal effects in the optics, which then deflect the focus. However, this can be avoided through clever control. And if, in the pursuit of higher productivity, a lot of material is ablated over a very short time, this can also lead to problems: "Sometimes, there just isn't long enough for the ablated material to disappear, with the result that the next laser pulse mainly hits smoke and dust, rather than the target material."

The team at Fraunhofer ILT has systematically investigated how such complications can be avoided or controlled. The solutions include optimized scanner paths, cross jets and extraction systems, modified processing strategies, and a variety of system configurations.

So, what's the best way to use this additional USP power? "Selectively!" says Haasler. The expert from Fraunhofer ILT is not disappointed, merely realistic. It is largely what he expected from the new laser: "There are lots of processes you can't run continuously at full power. Often, the laser is really only on for a fraction of the time—because, for example, the scanner first has to accelerate, jump or decelerate. Current hardware is often not fast enough." The so-called duty cycle—i.e., the effective degree of utilization of the laser power—is sometimes only 10 to 20 percent.

However, there are four strategies that can help here. Firstly, in so-called burst mode, several pulses are emitted in ultrafast succession. This results in greater material removal during ablation. Secondly, in the case of optical stamping, the desired pattern is directly imparted by the beam shape itself. In other words, the entire structure is engraved into the material in one go instead of it being traced out with a small spot. Thirdly, if rotating polygon scanners are used, pulse frequency can be cranked up high. This is because such scanners have an extremely high deflection rate and therefore deflect the pulses much more quickly than normal scanners. Finally, parallelization with multibeam optics splits a single, superpowerful laser beam into a large number of partial beams of medium power. In this way, it is possible, for example, to drill around 100 holes simultaneously. "These are the four basic strategies, which can also be combined, depending on the application," Haasler explains.

WHO WILL BENEFIT FROM THIS? In the end, it's all about real applications. And here, too, the Fraunhofer team has already achieved some impressive results: for example, the microtexturing of battery electrodes, with the laser generating 12 million tiny holes per minute; or the high-speed cutting of films, wafers, paper, fabrics and displays. Similarly, the selective decoating of bipolar plates for fuel cells has now been demonstrated in the lab at high surface rates. Furthermore, it will now be possible to produce extremely fine filters for applications in the food and display industries. The new TruMicro is able to drill 900 of these minuscule holes in one pass.

Haasler takes stock: "Together with TRUMPF, we've been able to turn the one-kilowatt ultrashort pulse laser into an option for industry. And we have plenty more ideas for other areas in which it might be used." ■

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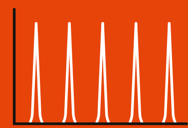
Fraunhofer ILT / Ralf Baumgarten

4 STRATEGIES FOR TAMING USP POWER

01 BURST MODE

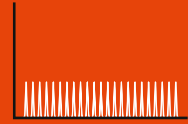
A burst of powerful pulses, followed by a short pause, results in greater material removal.

02 OPTICAL STAMPING



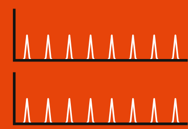
The intensity distribution is set in such a way that the laser creates the entire pattern in one pass.

03 POLYGON SCANNERS



A rotating scanner distributes high-frequency pulses across the workpiece extremely quickly, thereby increasing processing speed.

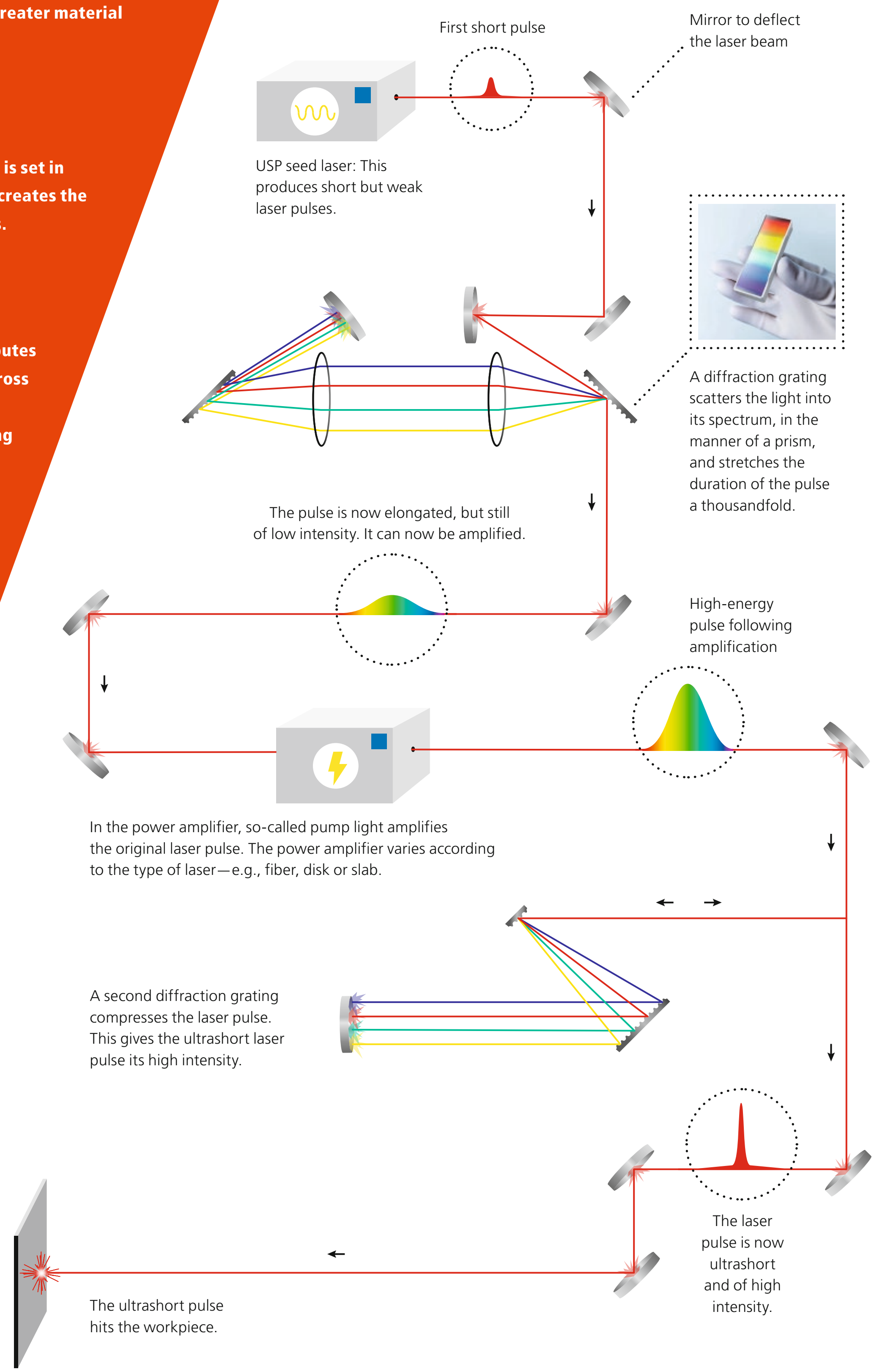
04 MULTIBEAM OPTICS



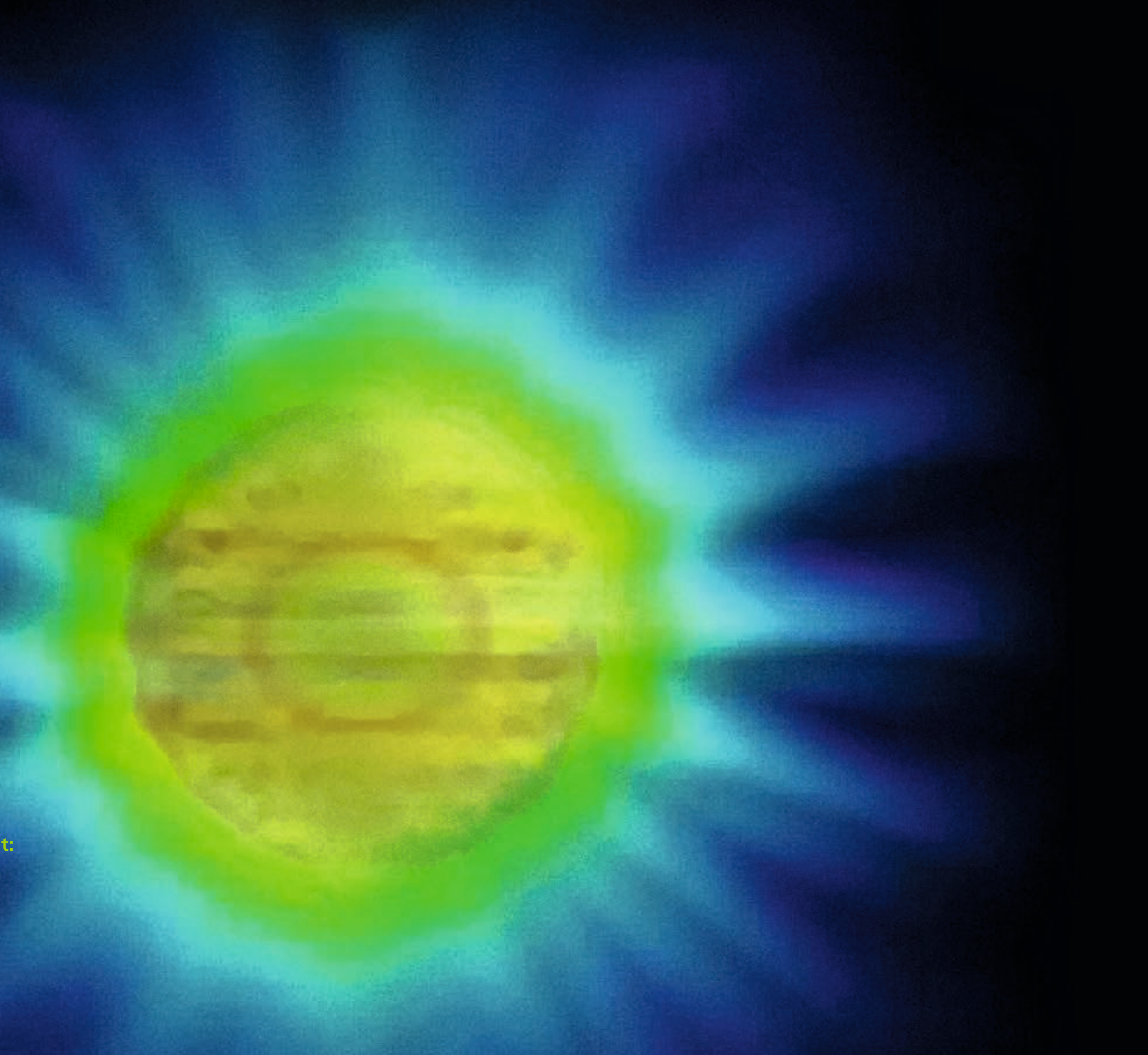
Splits the laser beam into many spots, enabling the parallel drilling of up to 900 holes.

USP lasers once revolutionized precision machining and surface texturing (see right). Now they have even more power (see left).

HOW A USP LASER WORKS



POWER



Harbinger of light: This visualization of the intensity distribution of a photon shows the likelihood of actually encountering one.

THIS IS NOT A PHOTON

For a brief moment, the world thought it had the first ever image of a photon. Not quite—but that's okay. What you see here will soon be facilitating better quantum computers and advances in laser technology.

In science, major breakthroughs often come when researchers are looking for something else. That's what happened to a team from the University of Birmingham. They were looking to understand how atoms and molecules emit photons. To this end, they developed a complex mathematical model that greatly simplifies the interactions between light and matter in order to then simulate them. An inadvertent by-product of this process was a lemon-like visualization of the shape of a photon—the first time ever such an image has been created. Delighted by this world first, the media rapidly trumpeted it as an actual photo of a photon. To the layperson, that might not sound like much of a difference. However, what the image shows in fact is not the physical appearance of a photon but rather a visualization of its intensity distribution—i.e., the probability with which researchers will encounter a photon at a certain location and in a certain state. Bright areas indicate where there is a higher probability of a photon appearing during a measurement. In other words, the lemon-like shape is most definitely not an image of a photon. But that's okay: Thanks to the Birmingham study, our understanding of how light and matter interact with one another is now greater than ever before. And this new knowledge will enable scientists to influence such interactions in specific ways and thereby develop even more advanced technologies: interception-proof communication systems, for example, or optical sensors that can detect pathogens. It will also help improve quantum computers—and, of course, generate some really exciting ideas for laser technology. ■

Benjamin Yuen

GLORY

HIROSHI'S NEXT BIG THING

Hiroshi Amano helped develop LED lighting and was awarded the Nobel Prize in 2014 for this work. Now he's busy on another pioneering project.

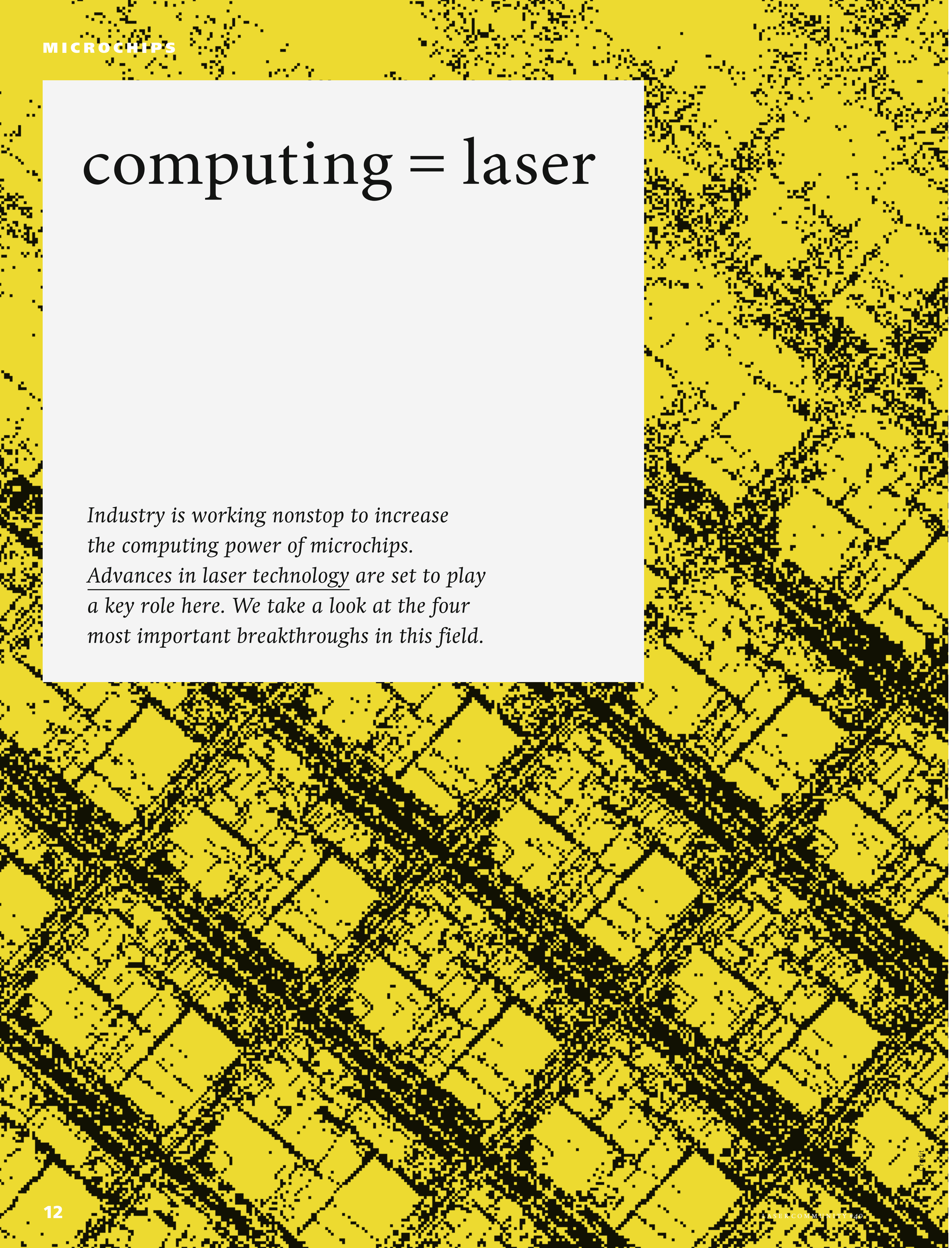
Back in the 1980s, everyone knew that lighting from light-emitting diodes (LEDs) would be many times more efficient than that from light bulbs or fluorescent tubes. The big question, however, was how to produce blue light with an LED. None of the other colors posed a problem. But to produce bright white light, an admixture of blue is essential.

In part working independently of one another, three Japanese researchers each came up with clever ideas about how to create a blue LED. Today, LED lighting is well on its way to conquering the whole world. Back in 2014, the Nobel Prize Committee honored the three scientists for their breakthrough invention. One of them was Hiroshi Amano, born in 1960.

Rather than resting on his laurels, Amano still goes to the lab each day. His latest project? Laser diodes for deep ultraviolet light. What makes DUV so special is that it destroys bacteria and viruses. This light could therefore be used to disinfect surfaces such as operating tables or ambient air and drinking water. Working DUV diodes have already been developed, yet these could be made more efficient. Hiroshi Amano is on the case. ■

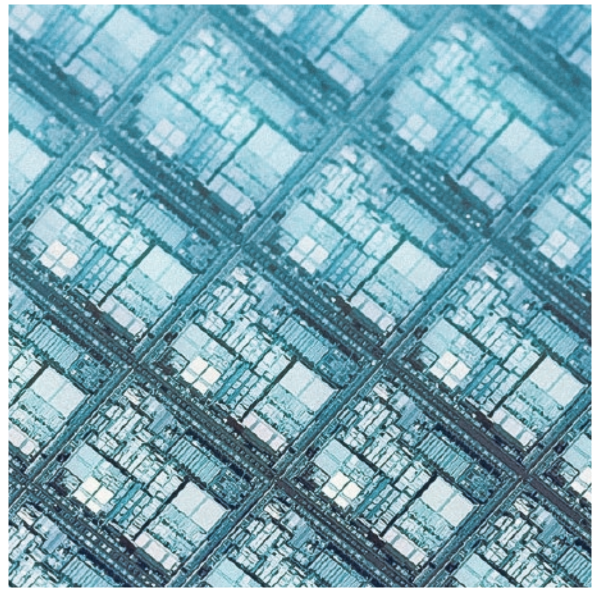
Hiroshi Amano is a physicist at Nagoya University in Japan. This photo from 2014 shows him with his first major invention, the blue LED.

Jiji Press Photo



computing = laser

Industry is working nonstop to increase the computing power of microchips. Advances in laser technology are set to play a key role here. We take a look at the four most important breakthroughs in this field.



TRUMPF

01

recent history

THE EUV SAGA — HOW THE CO_2 LASER CAME TO THE RESCUE

Everyone thought the CO_2 laser had seen its best days. The good old workhorse from 1990s' metalworking had started to look a bit clunky—not least because the light from this type of laser doesn't like traveling along a laser light cable. At the start of the 2000s, metalworkers were moving towards newer and more flexible technology such as disk and fiber lasers. It was only for really tough and dirty jobs that the CO_2 laser remained in use.

Then, around 2005, salvation arrived from the most unlikely of sources: It was the ultraclean, high-precision semiconductor industry, of all things, that began to take a closer interest in the roughneck CO_2 laser. The hope was that it would help solve a perennial problem in chip architecture: how to squeeze more computing power into less space. Or, in other words, how to shrink the microchip. The idea was to use extreme ultraviolet radiation (EUV) to create even finer transistor circuits on silicon wafers, in a process known as photolithography. The only question was how to produce the EUV light. It turned out that ultrareliable high-power CO_2 lasers from TRUMPF were the only way of delivering the initial beam needed to generate EUV light of the requisite quality for industrial use.

For the first time, laser tech provides the answer to an existential question for the semiconductor industry.

In 2017, the Dutch photolithography giant ASML shipped the world's first EUV system. Today, we all use EUV-printed microchips in cell phones and smart watches. The heroic deeds of engineers from TRUMPF, ASML and all the other industry partners have been eloquently recorded elsewhere. In his bestselling classic of 2022, *Chip War*, US tech author Chris Miller, for example, describes the new EUV system as "the most complex machinery ever made." It is by no means the first or only occasion that the semiconductor industry has turned to laser tech. The crucial point about EUV, however, is that here the laser provided a new answer to that existential question for chip manufacturers: where to find more computing power. And it won't be the last time the laser comes up trumps.

02

the present

TRUMPF

CHIP STACKS—LASER TECH HELPS REPLACE SILICON WITH GLASS

It's the same story, merely a new chapter: As the chip industry seeks to squeeze ever-greater computing power into an ever-smaller space, the name of the game is a process known as advanced packaging. Instead of building one large, highly integrated chip, the idea is to efficiently combine a large number of smaller, specialized chips in a compact whole and thereby form a more powerful overall system—each one of these chips being optimized for a specific function: processing, memory, graphics, AI acceleration. This not only meets the demand for greater performance on a smaller footprint. It also spreads the thermal load in a better way, so that the chip doesn't overheat even when delivering massive computing power. In order to shorten the signal paths and thus increase computing speed, manufacturers such as Nvidia or TSMC are now starting to stack these special chips rather than placing them side by side.

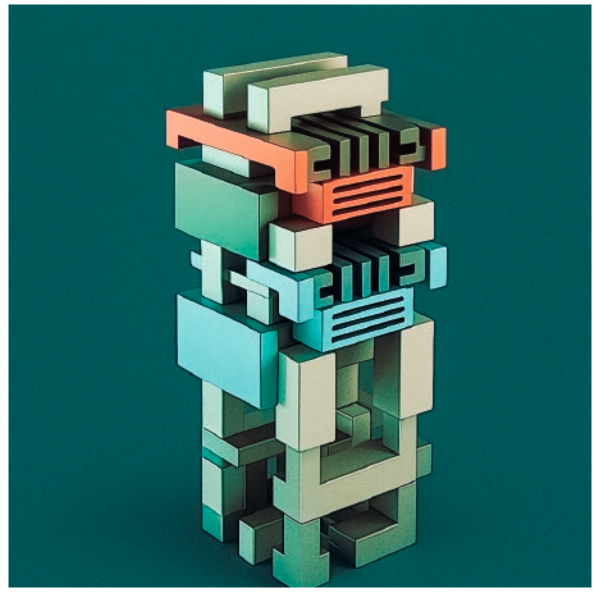
Why not use inexpensive glass instead of expensive silicon? Laser tech makes this possible.

Here, the question is how can manufacturers stack the chips in a reliable and efficient process? This is where the laser comes in: High-precision ultrashort pulse lasers bore so-called vias—holes from one layer to the next—through the substrate—technically known as an interposer—upon which each chip is mounted. These holes are then filled with metal to enable electrical contact between the chip layers.

The latest developments in laser tech also pave the way for a fascinating new option. TRUMPF has teamed up with the Schmid Group, a glass and electronics specialist from Freudenstadt in southern Germany. Together, they have taken a fresh look at an idea currently bouncing around the industry. Instead of using expensive silicon for the interposer, as is the industry standard, why not use inexpensive glass instead? Glass has pretty much the same thermal properties as silicon, and a similarly smooth surface, so nothing changes as far as computing performance is concerned. In practice, however, problems arise when trying to process glass. For this reason, the two partners have turned to complex wave optics—a field in which TRUMPF has vast expertise. Using a laser, it is possible to rapidly bore so-called through-glass vias (TGVs) of the highest quality through a glass substrate. Moreover, there are further advantages when glass replaces silicon.

So, let's all just take a break, as this is something that's easy to grasp: Microchips are square in shape—whereas silicon wafers are round, due to the chemical process by which they are grown. And when something square is built on a round base, there are always unused edges, which then get thrown away. Glass, by contrast, can easily be made square—just take a look at the nearest window. By using inexpensive glass rather than expensive silicon for the interposer, advanced packaging delivers the same quality, along with savings in three areas: cheaper material, higher yield, practically no waste. ■

03



Die Magaziniker & AI

near future

3D ARCHITECTURE FOR TRANSISTORS—ADVANCED LASER METROLOGY

When it comes to drawing up precise plans for the future, nothing can quite compare with the semiconductor industry. These road maps—blueprints for new types of microchips—often lie in the drawer for many years, each one building on the last. With each new step, the technology becomes increasingly complex. Each new leap lands a few meters beyond what was thought technically feasible before then. Right now, the industry is working on so-called nanosheet transistors, where the gate—i.e., the switch controlling the flow of electrical current—has contact on all sides of the current-carrying channel. The key point to understand here is that while this is not yet possible on a mass-produced scale, it will ultimately, as ever, make transistors smaller, more powerful and more energy-efficient.

This breakthrough is not on the cards until 2027. Yet, somehow, nanosheets are today, crazily enough, already old hat. That's because manufacturers and potential suppliers to the semiconductor industry are busy gearing up for the next-but-one chip generation. This is the complementary field-effect transistor (CFET), for which development is not expected to get seriously underway until mid-2030. The big question is who will win the race to develop the most reliable and productive fabrication process for CFETs, including all the steps before and after?

Once again, laser engineers have come up with a trick that sounds so off the wall that it's hard to believe.

In the CFET architecture, the two different transistor types—for the nerds: the n-doped and p-doped field-effect transistors—are vertically stacked on top of one another, thereby creating a space-saving 3D structure. In the past, these FETs were placed alongside one another. Now they form a kind of transistor tower—not to be confused with the chip stack described in the previous section. Alongside many other technical issues, experts are currently racking their brains over how to inspect the build quality of this tower—if, that is, it can only be viewed from above, so that merely the upper level is visible, with the transistors below remaining out of sight?

Quality control at each stage of the fabrication process is so sacred that the industry has its very own term for it: semiconductor metrology. With a product as paradoxical as the microchip—on the one hand, permanently at the edge of the physically possible; on the other, a mass-produced article for everyone—the yield per wafer is everything in economic terms. Painstaking metrology is the only way to prevent costly fabrication errors.

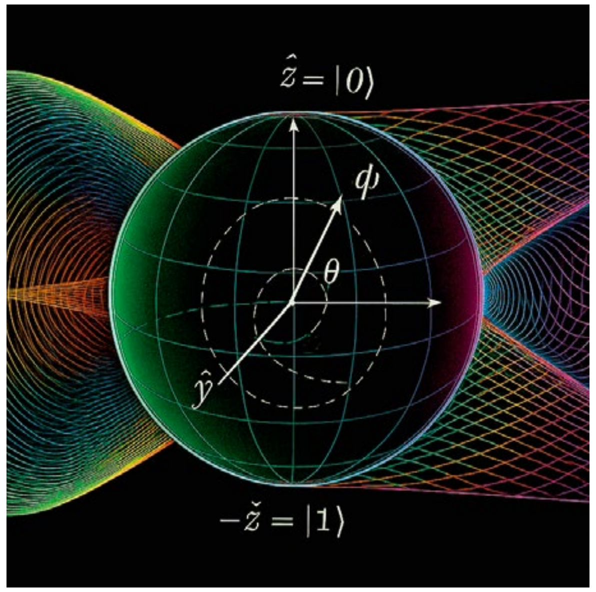
Among the various methods used, one is optical critical dimension (OCD) metrology. In simple terms, light of a broad range of wavelengths is shone onto the transistor structure from above. This light is scattered, producing a complex pattern that only a special algorithm can decipher and, on this basis, determine whether the chip fulfills the required specifications.

The problem is that today's OCD systems only work with light of a wavelength between 300 and 1,000 nanometers, which is way too long to be able to measure the features of future CFETs—critical dimensions that will be only around 20 nanometers. What's more, light at the wavelengths used today will be unable to penetrate the minuscule canyons between the transistor towers and thereby measure the structures below.

As a workaround, developers at TRUMPF subsidiary Active Fiber Systems in Jena have come up with a trick that sounds so off the wall it's hard to believe. They take an ultrafine infrared beam from a TRUMPF laser—at a wavelength of around one micrometer—and then use high harmonic generation (HHG) to produce a second beam with a much, much shorter wavelength of around 13.5 nanometers. This is small enough to penetrate the canyons of a CFET.

The physical explanation for this feat of magic is that the laser experts from Jena use HHG to produce the 77th harmonic of the infrared laser beam—musically speaking, this would be the 77th overtone of the beam. The three pioneers of this method were awarded the Nobel Prize in Physics in 2023. On the strength of this particular application, the team from Active Fiber Systems is highly confident of being in pole position to provide the metrology for CFETs come 2030. ■

04



future

COMPUTING WITH PHOTONS— LIGHT WILL SOON REPLACE ELECTRICITY

In less than ten years, microchips and laser light could well join forces in the ultimate symbiosis. Instead of aiding the chip industry in its quest to further shrink transistors, laser light could well take over the computing itself. Around the world, researchers and engineers are now working on photonic processors for everyday applications and on the development of optical quantum computers.

TRUMPF subsidiary Q.ANT launched its first commercial photonic processor, the Native Processing Unit (NPU), at the end of 2024. Essentially, this is a light-based processor, to which conventional computers in data centers can outsource particularly complex calculations. Instead of switching transistors by means of an electrical current, the NPU uses electric fields to modulate light and thereby perform calculations. The underlying method here is known as electro-optic modulation. Photonic components can perform complex mathematical operations, such as calculating the sine or even Fourier transform, in a single step—unlike classic transistors, which perform this operation successively in a large number of steps. This makes the NPU much, much faster. One optical element can replace millions of transistors. Tests show that even the first photonic NPU generation reduces the number of necessary computing steps to a tenth of what was formerly required. The Q.ANT processor is designed to meet the demand unleashed by the intensive use of neural networks for artificial intelligence. At the same time, it will help remedy an acute problem in the sector: The photonic NPU requires only one-thirtieth of the energy consumed by electrical transistors to deliver the same performance.

Photonic processors require only one-thirtieth of the energy.

The developers of quantum computers are heading in a similar direction. Here, too, ultrafast quantum processors will soon be undertaking the particularly big or complex operations that today's computing systems find difficult to master. At the heart of a quantum computer is the qubit. In quantum mechanical terms, the qubit is the equivalent of the transistor. And the more qubits that can be connected, the greater the processing capacity. There are several ways of generating qubits. Of these, two of the most important are the superconducting and the optical method. With the superconducting method, a quantum processor must be cooled to a temperature just short of minus 273 degrees Celsius. Developers are now able to get hundreds of qubits working together until they lose their quantum state. This is known as the coherence time and only lasts for a few hundred microseconds. The processing operation must be completed within this minuscule time span.

An optical quantum computer does not have this problem. In simple terms, an ultraprecise laser sends a photon packet into a maze made up of mirrors, beam splitters, phase shifters, nonlinear crystals and other optical elements. By nature, photons tend to ignore one another. But once they have entered this optical labyrinth, developers can use sophisticated quantum mechanical tricks to make them interact. This converts them into information carriers that can be used to perform arithmetical operations. The number of "switchable" photon qubits that can be generated in this way remains rather modest, at around 20. However, they make up for this deficiency with a high coherence time of several seconds. In other words, photon qubits remain operational for a length of time several orders of magnitude greater than their supercooled, superconducting counterparts.

The main advantage of the optical quantum computer will be everyday practicability, as it does not demand immense, energy-intensive cooling to a temperature of near absolute zero. Instead, it works at room temperature with ordinary air as a medium. Researchers anticipate that optical quantum computers will be fully developed by around the mid-2030s.

And then we will be able to count with light.

Die Magaziniker & AI

Laser applications in microchip manufacturing

Laser technology plays a role before, during and after almost every single step in chip manufacture. Each manufacturer and processor has their own process chain featuring the use of lasers at one point or another. Turn the page for an overview of the technologies used.

The most important processes and laser applications in semiconductor manufacture

01 *Front end*

From silicon crystal to a wafer with finished chip structures – this process takes place in large front-end manufacturing facilities known as foundries.

It all begins with **single-crystal silicon** grown as a cylindrical ingot.

These process steps are repeated for each layer of the wafer.

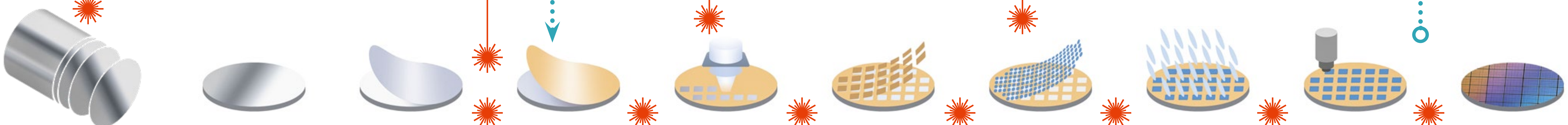
Ingot slicing – A laser gently cuts single-crystal silicon into extremely thin wafers.

Via drilling – Laser beams drill tiny vias into insulation and semiconductor layers. These provide, for example, vertical connections between layers of circuitry in 3D chips.

DUV/EUV exposure – A laser is used to produce deep ultraviolet (DUV) or extreme ultraviolet (EUV) radiation for photolithographic exposure.

Laser annealing – The laser heats precise areas of the wafer close to the surface for a few nanoseconds. This repairs crystal defects and activates dopants.

Laser-assisted etching – The laser heats certain areas so as to accelerate localized etching. This is particularly useful for complex shapes.



Ingot slicing
Ultrathin slices are cut from the silicon crystal.

Bare wafer
Semiconductor structures are created on the bare silicon wafer.

Deposition
A thin layer of material (e.g., for insulators or conductors) is applied to the wafer. This forms the basis for transistors and connections.

Photoresist coating
The wafer receives a photosensitive coating. This means that specific areas can then be exposed to light and thereby processed.

Photolithography
Light is projected through a photomask onto the coating, thus creating the minuscule patterns for what will become integrated circuits.

Developing
The exposed areas of the photoresist coating are chemically removed. This creates a mask that reveals certain areas for further processing.

Etching
The revealed areas are chemically or physically etched, thereby creating trenches, vias and conductor paths in the wafer.

Ion implantation
Dopant atoms are fired into the silicon at high speed. This modifies its electrical properties, enabling the transistors to switch.

Chemical-mechanical polishing (CMP)
This gives the wafer a smooth, flat surface, enabling the creation of a multilayer structure for advanced microchips.

Processed wafer
The wafer now contains all the front-end layers and structures and is ready for back-end processing.

Inspection and metrology – At almost every step in the foundry, noncontact laser measurement and detection of defects delivers quality assurance and process control.

02 *Back end*

This is where the microchips are detached from the wafer and transformed into a product. These steps are often carried out by smaller processing companies.

Laser-assisted soldering – The laser heats tiny solder joints that connect the chip and substrate.

Laser microwelding – A laser beam melts ultrafine wires at specific points to create contact points.

Laser beam-assisted bonding – A laser applies precise heat in order to create a thermocompressive bond between the chip and substrate or package.

Temporary bonding/debonding – A laser enables temporary bonding or debonding of chips and substrates during processing.

Grooving – A laser cuts fine grooves into the wafer or substrate material. This reduces mechanical stress during subsequent dicing and thereby increases the yield.

Laser dicing – A laser beam dices the wafer into individual chips (dies) in a particle-free process. In particular, this is used to dice very thin wafers.

PCB/substrate drilling – Lasers drill tiny holes in printed circuit boards and substrates to create electrical connections, especially in high-density chip assemblies.

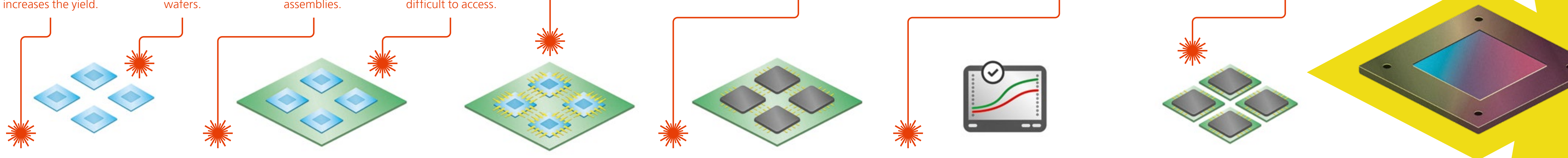
Laser-assisted confined ablation – A laser precisely removes surface material in order to reveal, for example, contact points that are difficult to access.

Redistribution layers (RDL) – A laser textures a metal layer known as the RDL. This carries signals from the chip to external output connections and serves to bond several chips together.

Marking – A marking laser applies serial numbers, data matrix codes or logos to the chip and package.

Laser depaneling – A laser beam separates individual chips, modules or printed circuit board components from a larger panel.

The **microchips** are now ready for installation in electronic devices.



Dicing
The wafer is separated into so-called dies. Each of these dies will become a microchip.

Die attach
The individual dies are physically attached to a substrate using adhesive or solder.

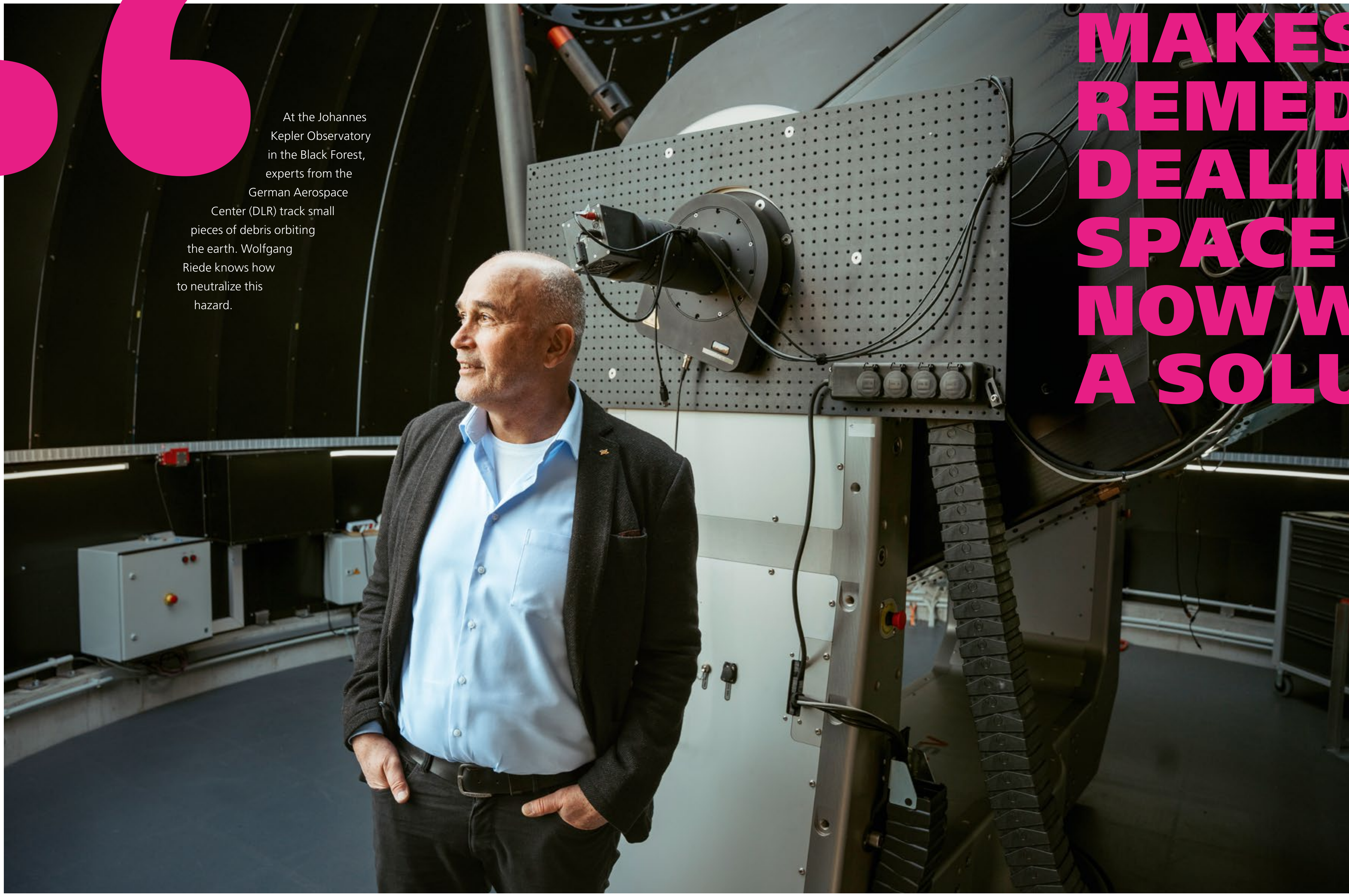
Wire bonding
Ultrafine wires connect the chip electrically to the contact points of the package, giving it connectivity with the outside world.

Encapsulation
The chip is encapsulated in plastic or ceramic. This protects it from damage, moisture and dirt.

Testing
Each chip is electrically tested – initially for functionality; later under load and temperature.

Depaneling
Multiple chips on a panel are cut and separated into their final form.

“UNTIL NOW, WE ONLY HAD MAKESHIFT REMEDIES FOR DEALING WITH SPACE DEBRIS. BUT NOW WE’VE FOUND A SOLUTION!”



At the Johannes Kepler Observatory in the Black Forest, experts from the German Aerospace Center (DLR) track small pieces of debris orbiting the earth. Wolfgang Riede knows how to neutralize this hazard.

Jeannette Petri

Things are getting crowded in the earth’s orbit. With all the space debris up there, somebody needs to find a way of preventing collisions with satellites and space stations. Wolfgang Riede plans to use lasers for this problem. In principle, an easy task, he says.

Wolfgang Riede, how big a problem is space debris in the earth’s orbit?
At present, there are some 13,000 metric tons of non-maneuverable scrap permanently orbiting Earth. That’s a volume of around one and a half times the size of the Eiffel Tower. The earth’s orbit is filling up with satellite infrastructure at an ever-increasing rate. We expect the total mass of scrap and satellites to double or even triple by 2030. That’s just five years from now!

What exactly is space debris?
Objects ranging from the size of a grain of sand to really large pieces of debris. There are around 50 large objects up there. This includes all the rocket stages jettisoned during 68 years of space travel. And then there’s Envisat, the European Space Agency’s huge earth observation satellite, which gave up the ghost in 2012 for unknown reasons. There are also numerous small satellites that are no longer operational. Added to this is a collection of around 40,000 small pieces of scrap measuring over ten centimeters, which we can track from Earth. Plus, there are millions and millions of smaller bits of debris. And for most of these, we don’t even know where they are.

The rocket stages and the broken satellites—that makes sense. But where do all the small pieces of scrap come from?
They’re caused by collisions, both controlled and uncontrolled. →

"THE PHOTONS IN LASER LIGHT EXERT PRESSURE. THIS IS MINIMAL. BUT IT CAN MAKE ALL THE DIFFERENCE TO AN OBJECT IN ORBIT."

Many are the result of anti-satellite weapon tests. In the days of the Cold War, both the Americans and the Soviets wanted to show the other side that they were capable of using a rocket to shoot down a satellite. That's still going on today. In 2007, China shot down one of its own satellites. Russia did the same in 2021. Both of these explosions left huge clouds of debris in the earth's orbit.

Well, I guess there's plenty of room up there …

There's plenty of room, but this stuff is flying around the earth at a speed of up to 28,000 kilometers per hour. Remember, that's almost eight kilometers per second! And each piece of debris moves along its own orbit. In other words, the debris is not flying synchronously, like the matter in the rings of Saturn, but in a wild, confused carousel. At the same time, each piece of debris rotates and therefore continuously alters its orbit ever so slightly. It can therefore happen that the International Space Station or one of the many functioning satellites is on a collision course with a piece of scrap metal. Were they to collide, this would release an immense amount of energy that is almost impossible to recreate on Earth. Laser technicians will understand what's involved here: A collision in orbit with a particle of just one millimeter in diameter—in other words, tiny—generates an energy of 70 joules per square millimeter. That's a lot! A satellite involved in such a collision would either be pierced by the particle or would completely disintegrate. Millions and millions of euros go up in dust. And back down on Earth, the infrastructure we rely on stops working. That's the problem!

Whew! And what can you do about it?

There are two options. First, if we spot a collision in advance, the satellite must then take evasive action. The ISS does this all the time. But it gets refueled, whereas satellites don't. Satellites are limited in the evasive action they can take. And when they do, this always impacts the overall service life, so it ends up costing a lot of money. Secondly, there are regular missions to clean up space. Vessels with robotic arms grab medium-sized pieces of scrap and hurl them down, as it were, into the earth's atmosphere, where they burn up. But that's expensive and out of the question for most pieces of scrap. In other words, both these options are only a make-shift remedy. What we need is a proper solution!

And you believe you've found the right one?

I think so. Laser momentum transfer—or what we at the German Aerospace Center affectionately call "laser nudging." Our team at the DLR has come up with a concept for how this can function. The principle is really easy to understand: The photons in laser light exert pressure. This is known as "light pressure" and is minimal. But when applied to a fast-moving piece of scrap in orbit, it can make all the difference. If we hit this piece of scrap frontally with a high-power laser, we can slow it down. And if we hit it from behind, we accelerate it. This means: If it slows down, it falls; if it speeds up, it rises. In other words, we can nudge it away from a collision path, from down here on Earth.
(See graphic, right)

But there must be a problem, right?

We don't need one laser station, we need ten—spread right across the globe.

Why's that?

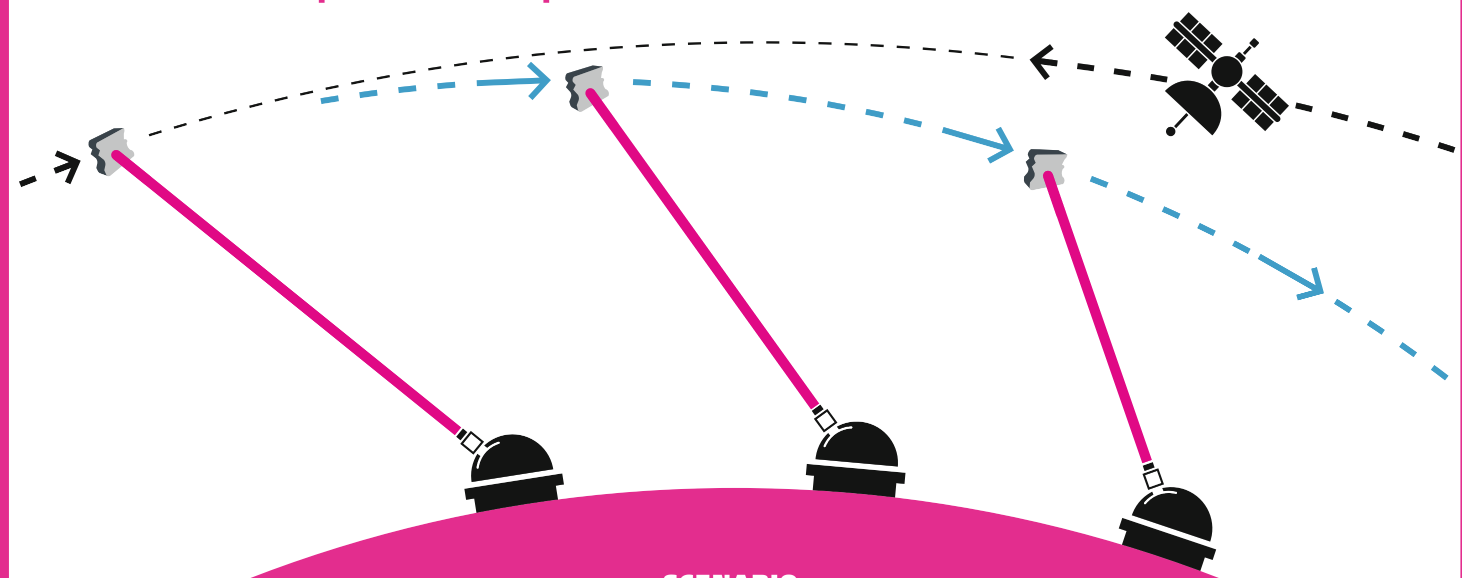
The light pressure exerted by the laser is minimal. We can only alter the speed of the pieces of scrap by ten micrometers per second. This means we have to apply the laser for a long time to achieve a significant effect. Imagine the target object appears on the horizon. At an overflight speed of eight kilometers per second, it remains visible for around ten minutes until it disappears below the far horizon. But we can't fire the laser as soon as it appears on the horizon. That's because the angle is still too flat and because the beam would have to travel through a lot of airspace. We're only allowed to use airspace closed to civilian traffic, and that means only within a certain radius around the ground station. So, we have to wait, until it gets closer. Then we have to hit the object either frontally or from behind, since we want to either slow it down or speed it up. This halves the period available once again, so that we end up with a contact time of just two to three minutes. And that's too short to deflect it enough. The method only works if there are ten ground stations each successively targeting the object over the course of ten overflights—a laser battery, as it were.

I see. But how can you even hit such a small thing in orbit?

That's not a problem. The space industry has been using ultraprecise lasers over such distances for a very long time—for example, to detect pieces of scrap in the earth's orbit. The tricky part lies elsewhere.

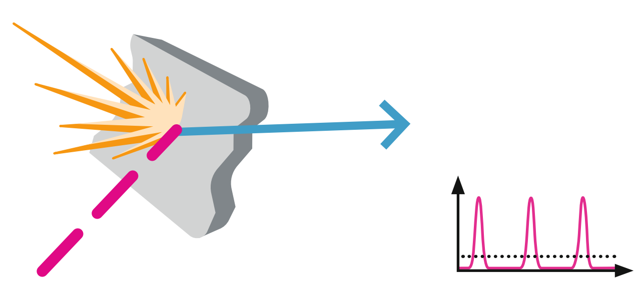
Preventing collisions in orbit with a laser

Deflection of a piece of scrap



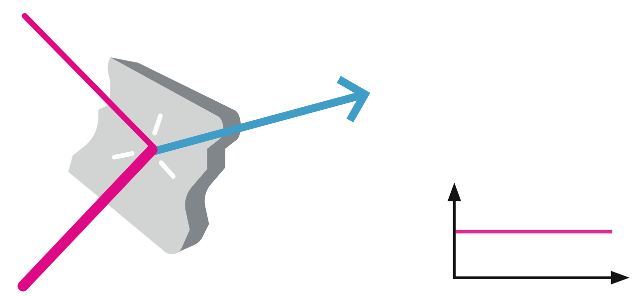
SCENARIO:
A piece of scrap metal in orbit is on collision course with a satellite and threatens to damage or destroy it. Back on Earth, ten ground stations successively target the piece of scrap with a laser and thereby divert its trajectory so that the satellite is spared.

Option 1: Ablation



A pulsed laser beam hits the object so hard that a plasma plume is created, thereby deflecting the object.
Advantage: One overflight is enough, so less advance warning is required.
Disadvantage: There is a risk that the object will disintegrate, producing more hazardous pieces of scrap.

Option 2: Photon pressure



A continuous laser beam applies photon pressure to gently nudge the object into a different orbit.
Advantage: There is no danger of the object disintegrating.
Disadvantage: Up to ten overflights are needed before sufficient deflection has been achieved. More advance warning is therefore required.

Christoph Kalscheuer

Wolfgang Riede is a laser physicist and heads the Department of Active Optical Systems at the Institute of Technical Physics at the German Aerospace Center in Stuttgart.

"IF ALL GOES SMOOTHLY, WE WILL DELIVER THE PROOF OF CONCEPT IN FIVE YEARS."

What's the problem then?
The problem is how far in advance you can accurately predict a collision. That's not an easy task. Like the weather, it becomes more difficult the further ahead you want to look. Our stations would need a few days' advance warning. But we're already working on this problem.

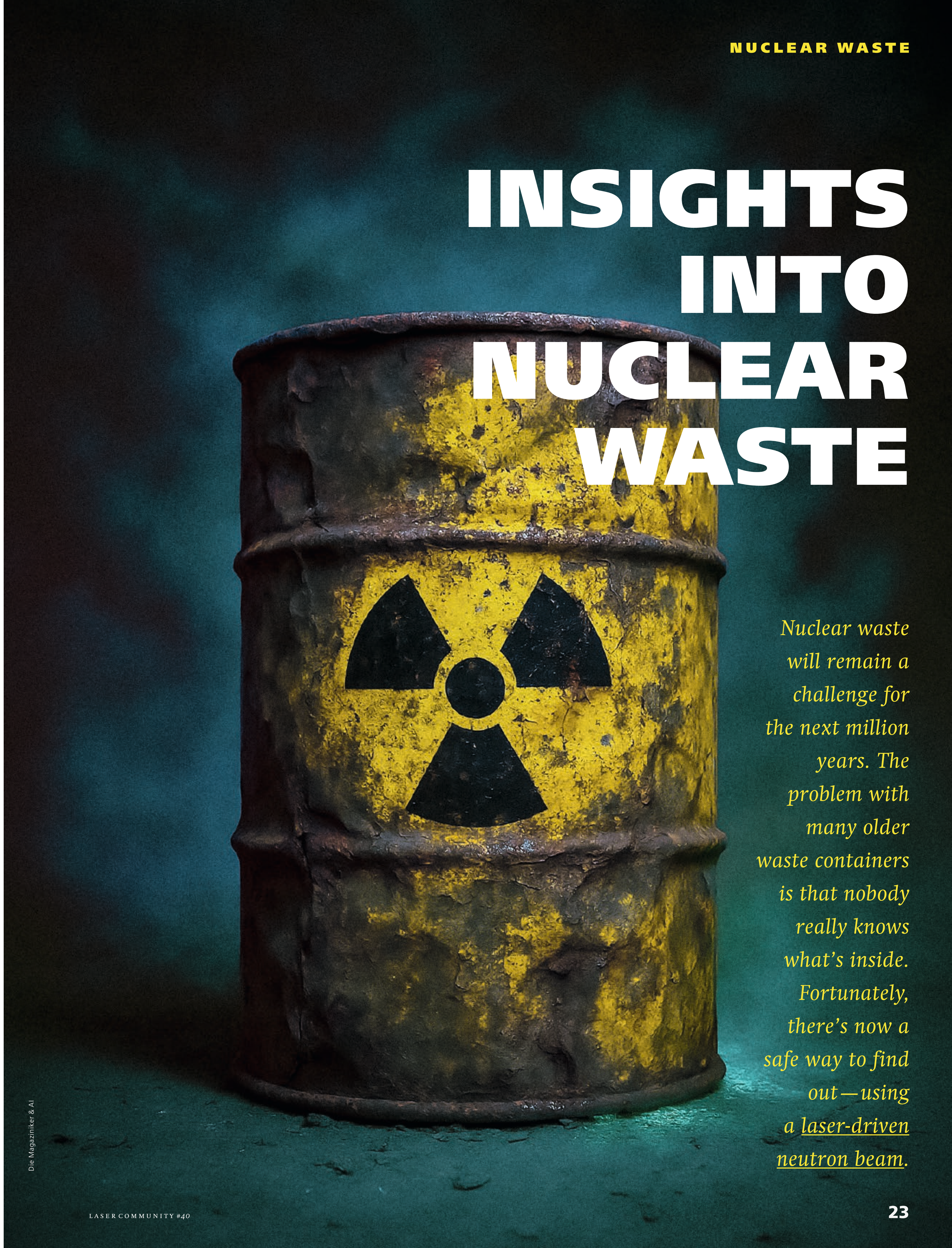
Has laser nudging been proven in practice?
We've never tried it in real life, but that's normal for a space project. In addition to the ground stations, we will also need two satellites in constellation. These work in tandem to measure the impact of the laser beam and then report back to us. We don't have these satellites yet.

Then everything we've been talking about so far is purely theoretical …
Not at all! In fact, I'm surprised at how fast our DLR project is now moving. ESA has commissioned us to design a ground station. We've been able to secure TRUMPF Scientific Lasers as a partner for the beam source. If all goes smoothly—financing, construction, choice of ground stations—we will deliver the proof of concept in five years. Okay, there are likely to be problems on the way. But we're still talking here about a reasonable time frame to realization.

How do you explain the sudden surge of interest in your project?
As I said, there's going to be a massive expansion of satellite infrastructure in orbit—the Starlink network, for example, to provide mobile web services. Space debris is a big issue here. And it's likely to get worse by several orders of magnitude because of this expansion, which in turn will generate more scrap. So, we're going to need some kind of solution sooner rather than later.

Who will pay for laser nudging?
ESA member states are kickstarting it through their contributions. But, ultimately, the plan is to market LMT as a service for private companies, organizations or states that want to protect their orbital infrastructure. Once stakeholders understand the scale of risk here, I think that funding the technology will be the least of any problems. Besides, in Germany we now have for the first time a federal minister with space travel in their portfolio, so we're also expecting political support on the national level. ■

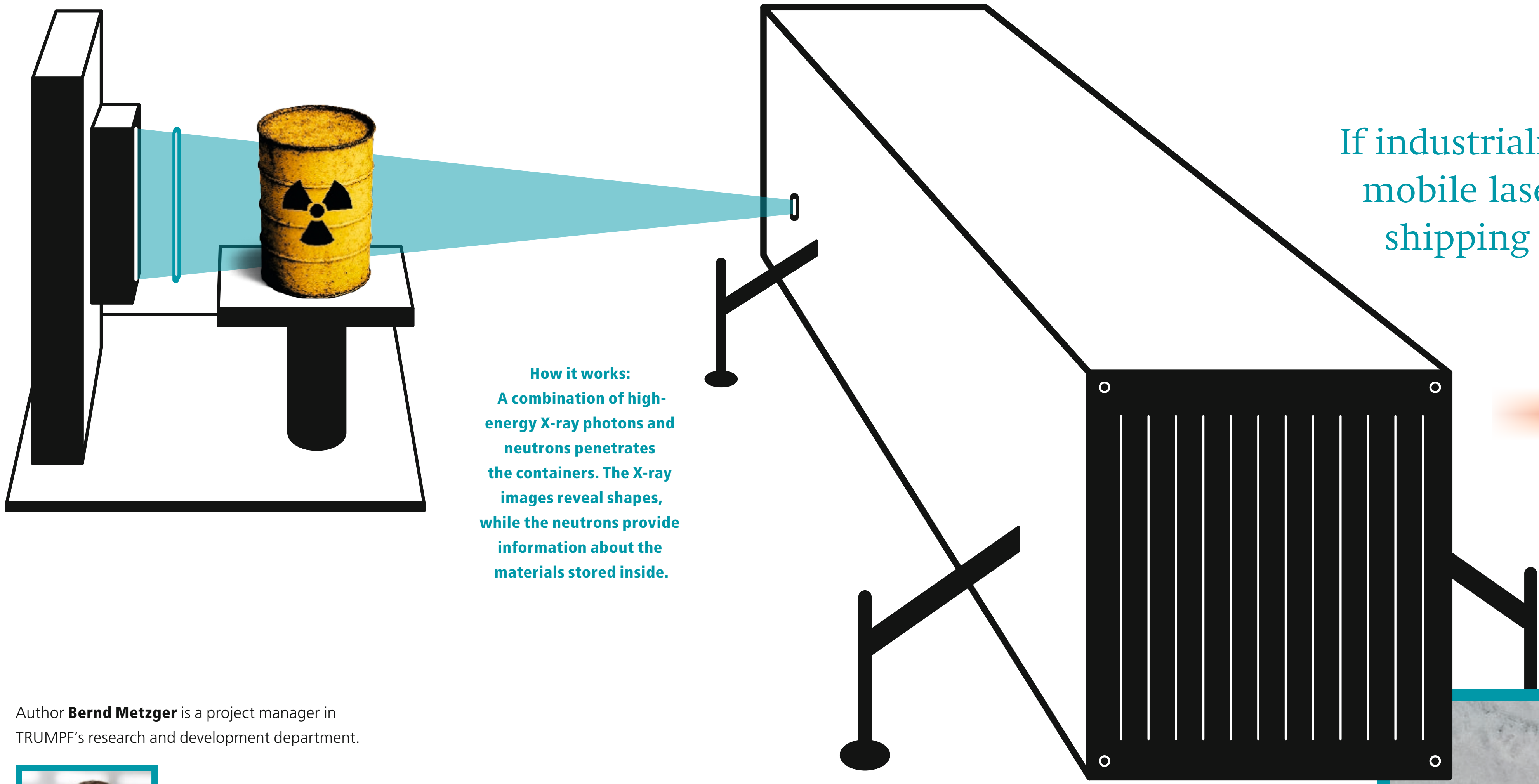
Jeannette Petri



INSIGHTS INTO NUCLEAR WASTE

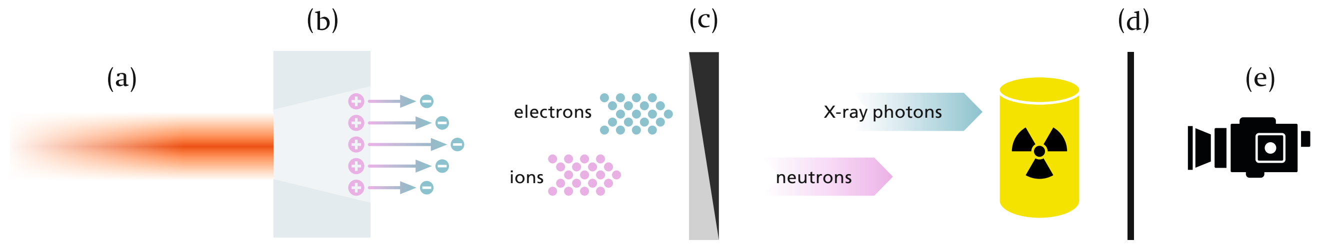
Nuclear waste will remain a challenge for the next million years. The problem with many older waste containers is that nobody really knows what's inside. Fortunately, there's now a safe way to find out—using a laser-driven neutron beam.

Die Magaziniker & AI



How it works: A combination of high-energy X-ray photons and neutrons penetrates the containers. The X-ray images reveal shapes, while the neutrons provide information about the materials stored inside.

> If industrialization goes smoothly, the entire mobile laser-neutron source will fit into a 12-meter-long shipping container.



The process begins with each laser pulse (a) punching electrons and ions out of a thin film of water (b). These highly energized particles are then directed into the converter (c), where they generate X-ray photons and release neutrons. A detector (d) captures the emitted particles, and a high-speed camera (e) records the images they produce.

Author **Bernd Metzger** is a project manager in TRUMPF's research and development department.

Asse, the famous salt-mine repository in the German state of Lower Saxony, is home to almost 126,000 containers of nuclear waste. Dumping of the waste began in 1967, and for decades water has been seeping into the unstable mine shafts, raising real concerns that the waste could contaminate the surrounding area.

Now, plans are underway to retrieve every last one of these barrels and containers. The problem is that nobody knows what many of them contain, how they were packed, how radioactive the material is—and how long it will continue to emit radiation. Without that information, it's impossible to say with a clear conscience how and where the barrels and containers could be stored in the future. In some cases, X-ray imaging can provide answers. But often the only option is to cut the containers open, particularly the heavily shielded ones that standard X-rays can't penetrate. But opening them up is only half the story: Each batch of waste must then be repackaged under strict conditions to prevent radiation exposure and environmental contamination. All this comes at a price. Current estimates for the Asse site alone—before any actual retrieval or in-depth inspection has taken place—already stand at some 4.7 billion euros.

LASER PULSES INSTEAD OF BEAMLINES Imagine a kind of super X-ray vision that could peer through concrete, iron and lead-shielded waste containers quickly, easily, nondestructively and relatively affordably. This dream of an all-seeing eye is now within reach thanks to a technology known as laser-driven radiation sources (LDRS). Developed by laser-fusion specialist Focused Energy in Darmstadt, the process combines high-energy neutron and X-ray beams. By exploiting their complementary penetration properties, LDRS delivers a clear, all-around view of the material.

To generate neutron beams and ultra-high-energy X-rays, you need something that can continually accelerate tiny particles along the same trajectory. The problem is that conventional particle accelerators with electromagnets positioned along endless tunnels are huge, immobile and cost hundreds of millions, if not billions, of euros—not exactly the best choice for this scenario. Fortunately, there's a new, alternative method of accelerating particles that uses ultrashort, high-intensity laser pulses to spark a cascade of particles over a distance of just a few millimeters, simultaneously generating both extremely hard X-rays and a neutron beam.

This new type of accelerator has been operating in laboratories for some time. Although it produces more than enough X-ray and neutron flux per pulse, it has previously required pauses of several minutes, or even hours, between pulses. The mobile LDRS device for nuclear waste sites is designed to deliver up to a hundred pulses per second, using a new generation of high-power ultrashort pulse lasers and a laser amplifier specially developed by TRUMPF.

CLARITY WITH NEUTRON IMAGING Inside the LDRS system, laser pulses are focused on an ultrathin, constantly refreshed film of water. Electrons in the water molecules absorb the energy of the laser photons and accelerate to near light speed, dragging protons along with them or, in the case of heavy water, deuterons (nuclei composed of a proton and a neutron). These particles then smash into a converter, typically made of beryllium, releasing high-energy X-ray photons and knocking neutrons out of the atomic nuclei. The resulting neutron and X-ray beams are aimed at a test object, such as a radioactive waste container. A detector screen known as a scintillator sits behind the object. When radiation strikes it, the screen emits light, creating grayscale images.

Because neutrons travel slightly slower than light-speed X-ray photons, the X-ray images appear a fraction of a second before the neutron images. A camera with a very high time resolution separates the two exposures for independent processing. Neutrons penetrate even lead and steel to identify the hidden materials, while X-rays map the relative density of those materials. By combining these datasets, the LDRS system can categorize the substances inside a container as specific materials.

The specially developed disk amplifier head boosts the pulse power.

PILOT PLANT IN GERMANY Since 2024, research and tests funded by the German Federal Ministry of Education and Research (BMBF) have been underway at the decommissioned Biblis nuclear power plant (see info box), with energy firm RWE providing the necessary facilities. The government-funded project aims to demonstrate the technology's effectiveness by 2028 or 2029, with a relatively modest investment of 27 million euros. If industrialization goes smoothly, the entire mobile laser-neutron source will eventually fit into a 12-meter-long shipping container—ready for deployment at Asse. ■

RESEARCH PARTNERS INVOLVED IN THE PROJECT

The PLANET project aims to develop a laser-based neutron source for the nondestructive testing of industrially relevant objects. Individual components are being developed by the following partners: the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Focused Energy GmbH, the Fraunhofer Institute for Laser Technology (ILT), Photonis Germany GmbH, the Institute for Nuclear Physics at the Technical University of Darmstadt, and TRUMPF Laser SE.

www.photonikforschung.de/projekte/lasertechnik/projekt/planet.html Official funding reference codes: 13N16946 bis 13N16951

WHEN I FIRST HEARD ABOUT LIDAR, I KNEW RIGHT AWAY: THIS CHANGES EVERYTHING!

Lidar technology is revolutionizing archaeology, giving researchers like Marcello Canuto a whole new insight into Mayan civilization.

Bryan Tarnowski

Mr. Canuto, news broke last year that one of your students had discovered a previously unknown Mayan city in Mexico. What's the story here?
Via a simple Google search, a student of mine, Luke Auld-Thomas, stumbled upon lidar data that had been posted online by a Mexican environmental organization. From an archaeological point of view, the data was not really ideal, as it was recorded to map vegetation rather than terrain structure. And it was of an area that we wouldn't have selected. But we scrolled through the images for an hour or so. And then suddenly, we thought: "What on earth is that?"

What did you see?
As I said, the images weren't all that great, but we could identify structures that were obviously not of a natural origin. And what we saw was that settlement density—i.e., the number of buildings per square kilometer—in the Mayan lowlands was also very high. In fact, it was considerably higher than in regions further south that we'd already taken a look at a little while before. And even there, we were surprised at how densely populated it must have been. We thought: "Wow, that's really interesting!"

Does this mean a rewrite of Mayan history?
In part, yes. At first sight, the discovery might not seem so spectacular. Valeriana—as we're calling the new site in the state of Campeche—is not a huge ancient city like Tikal in Guatemala, which draws in masses of tourists. It's really just a medium-sized site. But the exciting thing is, we weren't searching specifically but just happened to look at a small area and immediately found something big. In other words, there are probably a whole lot more medium-sized sites like this. And this discovery confirms something we've been seeing over the past ten years thanks to lidar. Wherever we use this mapping technology, we find evidence of Mayan settlements.

So how has lidar changed our understanding of Mayan civilization?
For the past 150 years, the research consensus has been that complex societies could only arise in dry regions intersected by rivers, such as in Egypt, Mesopotamia or the Indus Valley. The tropics, by contrast, were considered incapable of supporting advanced civilizations. But lidar shows this to be totally false. It reveals not only a high population density but also a level of infrastructure quite unlike anything we'd previously imagined. The number of fortifications, roads, canals and reservoirs all tell us that the Maya had a massive impact on their environment. And that, in turn, required a high level of organization and a functioning administration. In other words, Mayan civilization was much more complex than we have previously acknowledged. Decipherment of the Mayan script in the 1980s was a huge breakthrough. And now lidar has given us a similar boost.

Does this remove the need for excavations?
Not at all. We'll still need to check whether what it is that lidar has revealed actually exists at the field site. It's what we call "ground truthing." And excavations are also essential to find out more about how, for example, people lived. What lidar does is to make archaeology much more efficient: We now know much faster where we need to dig. In the past, we had to fight our way through the jungle to map new sites. Often, you couldn't see what was right next to you! It must have been around 2012 that I read about the archaeologists Arlen and Diane Chase using lidar for the first time, at the Caracol excavations in Belize. I knew right away: This changes everything! That's when I decided that I was going to stop conventional mapping. It's just a waste of time! Previously, we needed maybe 100 years to map 1,000 square kilometers—and all on foot! Using lidar, we've covered 10,000 square kilometers in just ten years.

What other secrets can lidar reveal?
More and more archaeological teams around the world are working with lidar—not only in Central America but also in South America and Southeast Asia. We're definitely going to see more discoveries over the next ten years. I also predict that lidar will tell us a lot more about the Amazon region. I can't say exactly what, but it will be a big surprise! ■

PROF. MARCELLO A. CANUTO Ever since childhood, archaeologist Marcello A. Canuto has been fascinated by the Mayan civilization. He is currently Director of the Middle American Research Institute and Professor of Anthropology at Tulane University in New Orleans, USA. He says that lidar has made his work richer and more exciting.

MAPPING THE JUNGLE To scan the landscape with lidar ("light detection and ranging"), a plane flies over the jungle and fires millions of laser pulses at the ground. Only about 5 percent actually make it through the canopy. Yet with the help of special software, the reflections from these pulses suffice to render visible any human-made structures on the ground below.

SENSATIONAL DISCOVERY Using lidar technology, archaeologists have already unearthed a number of formerly unknown Mayan settlements. The discovery in 2024 of Valeriana, a Mayan city in the state of Campeche in Mexico, was particularly spectacular. With additional funding for lidar mapping by plane, more sensational finds could well follow.

THE ROAD TO SUCCESS

Up to 400 bipolar plates are stacked alternately with membrane assemblies to form a fuel cell.

Hydrogen and oxygen flow through the tiny channels in the plates.

EKPO supplies its fuel cells to customers all over the world. To keep up with demand, the company is outfitting a production line with fiber lasers.

High-precision fiber lasers play a pivotal role in the transition toward carbon-neutral mobility. The world needs zero-emission powertrains for everything from construction equipment, trucks and cars to trains, ships and eventually even aircraft. Based in Dettingen an der Erms in southern Germany, EKPO Fuel Cell Technologies is committed to providing the fuel cell technology that will drive this mobility transition and provide clean power. The company—a joint venture between automotive suppliers ElringKlinger and OPmobility, whose former name contributed to the acronym EKPO—has set the bar high: Rather than playing a background role, it aims to set the global standard for the entire fuel cell industry. A critical part of this mission is the ability to weld ultra-high-precision, gastight seams by the meter—a task perfectly suited to fiber lasers.

A SINGLE FLAW EQUALS FAILURE Holding a bipolar plate in his hand, Arno Bayer, Head of Industrial Engineering Joining at EKPO, explains the vital functions that bipolar plates perform in every fuel cell: connecting, distributing, conducting and cooling. Each plate consists of two ultrathin metal layers, typically just 75 to 100 micrometers thick, welded together in such a way that coolant can flow between them. Bayer points to a multitude of channel structures stamped into both sides of the plate: On one side of the finished product, hydrogen will flow; on the other, air (i.e., the oxygen required for the reaction). “Bipolar plates require a tremendous amount of expertise,” Bayer says. “But, at the same time, they have to be mass produced. We need up to 400 plates per fuel cell, which are then assembled into what we call stacks,” he explains, gesturing toward the completed fuel cells at the back of the EKPO facility, each roughly the size of a beverage crate. “The real challenge is making sure that every single seam on the bipolar plates is welded with absolute precision to be completely gastight. If even one plate leaks, then the entire stack—the whole fuel cell—fails.”

Tobias Gerber

12,000 KILOMETERS A YEAR EKPO therefore needs a laser that can weld high-precision, reliably gastight seams at lightning speed. In this case, lightning speed means operating near the so-called humping limit, the maximum welding speed achievable before undesirable bead-like humps start to appear on the seam for physical reasons. The weld seam is 0.1 millimeters wide and roughly 0.15 millimeters deep, and each bipolar plate requires a seam about three meters long. This means the laser at the Dettingen facility must lay down approximately 12,000 kilometers of weld a year—the equivalent of sailing from Hamburg to New York and back. “A single-mode fiber laser is the only laser in the world that we can rely on to get the job done,” says Bayer. “That’s why we chose the TruFiber, because its beam quality and process reliability are second to none.” Following successful welding trials and the development of an innovative clamping and handling system for the bipolar plates, EKPO decided to build a high-throughput production line. First, the laser fuses the two halves of each bipolar plate into a single, gastight unit. Next comes rigorous conductivity and leak testing, before the bipolar plate is ready for stacking—and ready to power the mobility revolution. ■

Contact: Arno Bayer, Head of Industrial Engineering Joining at EKPO Fuel Cell Technologies GmbH, phone +49 07123 724 9189, arno.bayer@ekpo-fuelcell.com

South Korea

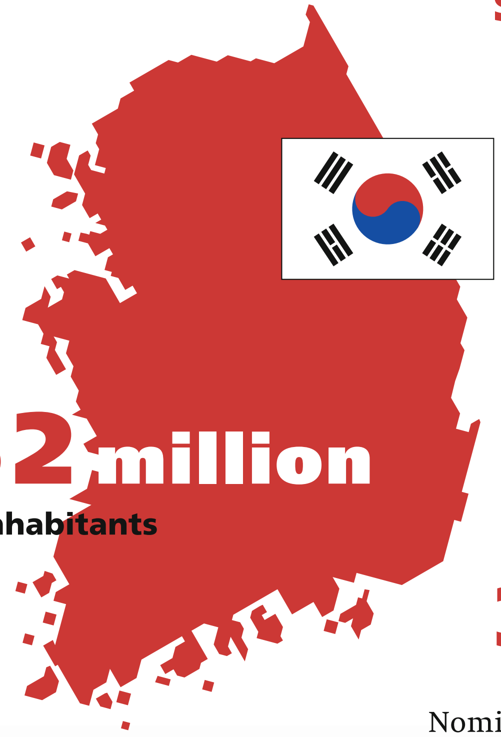
OVERVIEW OF THE ECONOMY

Industrial enterprises in South Korea are constantly investing in future-oriented technologies such as **digitalization and automation**.

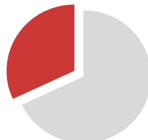
The nation's economy is particularly competitive and innovative in sectors such as **semiconductors, electronics and battery technology**.

South Korea is also embracing **digitalized agriculture**. This sector is highly productive and a key driver of economic growth.

WELCOME TO SOUTH KOREA, LAND OF LASER TECH!



52 million
Inhabitants



32%
Industry as a proportion of GDP

36,024
US dollars
Nominal GDP per capita

LASER LAND

The country has an important **battery industry** that relies heavily on precision laser welding and cutting.

In **display manufacturing**, lasers boost resolution and performance for screens of all sizes, driving high output.

To address the constant military threat it faces, South Korea is currently exploring the use of laser technology for **missile defense**.

Samsung/squadkid42, Shutterstock

WHERE'S THE LASER?

Around Real Madrid: Home to the most successful club in Spain and Europe, the name "Bernabéu" echoes like thunder in the world of soccer. The stadium's exterior also needed to reflect the club's regal splendor, so Real Madrid decided to completely redesign the facade. The architect came up with an envelope of gently curved diagonal metal louvers that create a sense of translucency. What this lyrical vision meant for the manufacturer was that no two louvers would be exactly alike. To tackle this huge production run of one-off pieces, Madrid-based metal specialist Lasercor turned to its 12-kilowatt TruLaser 5030 fiber machine. Featuring six different surfaces that reflect light in different ways, the louvers have become a major draw for Bernabéu fans in their own right. ■

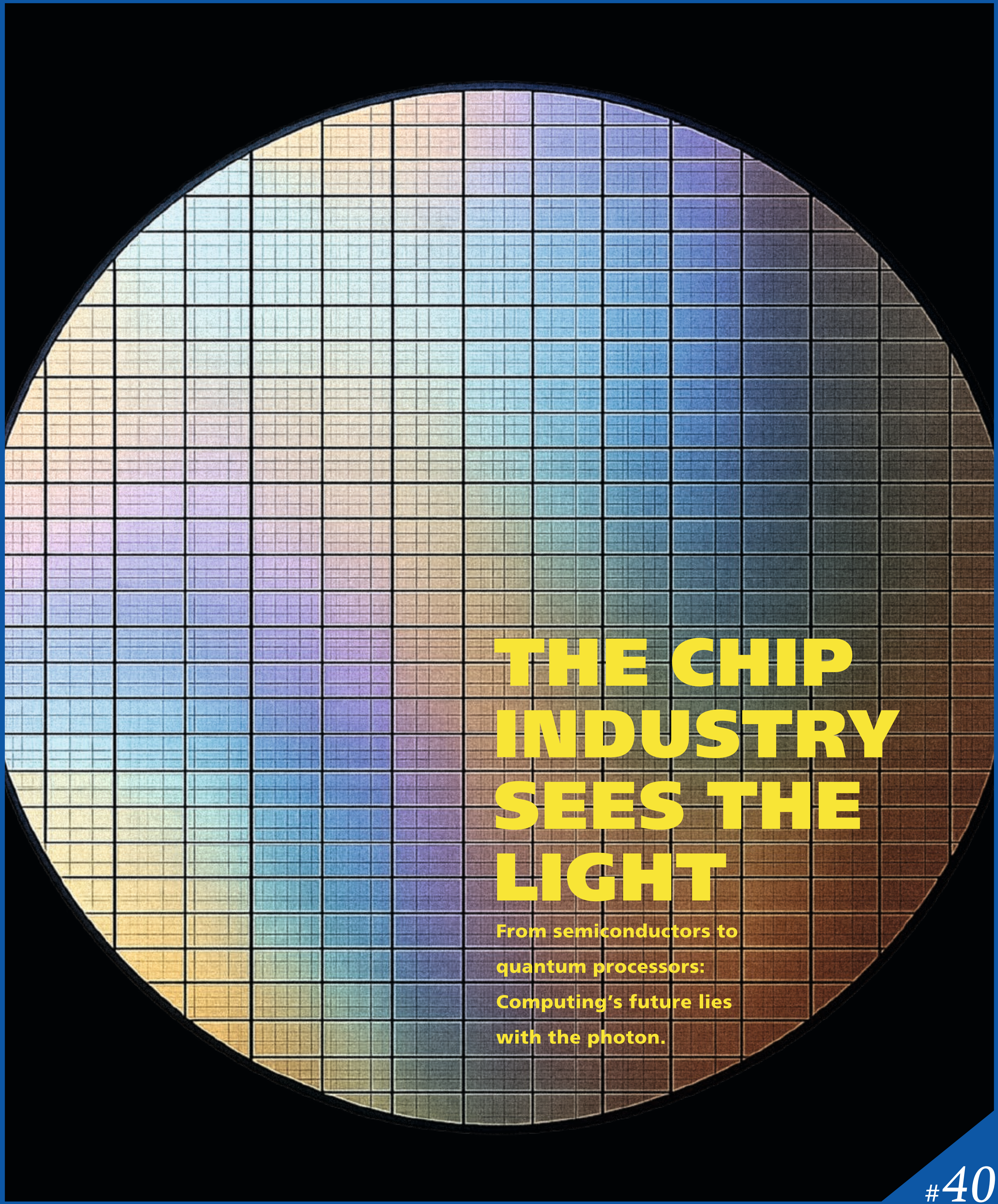
AdobeStock/Davidbenito

1 nanometer

Scientists at Stanford University have observed the smallest dance the world has ever seen: a synchronized dance of electrons twirling around a tiny particle. It was previously considered practically impossible to observe movements smaller than 10 nanometers. The Stanford experiment managed to break this barrier: Pulses from an attosecond laser — each with a duration of just 10^{-18} seconds — lit up the subatomic chorus dance, barely a nanometer across, making it visible for the first time.

LASER COMMUNITY.40

LASER COMMUNITY.
Of people and photons



THE CHIP INDUSTRY SEES THE LIGHT

From semiconductors to quantum processors: Computing's future lies with the photon.

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