LASER COMMUNITY.
Of people and photons

A new era in beam generation

Secondary beam sources induced by laser will trigger a raft of new applications in industry and medicine.

#35

LASER COMMUNITY. *#35*

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Gernot Walter

The dawn of a new age

Each year, I eagerly await to see who has won the Nobel Prize in Physics. This fall, the award went to an international research trio of Alain Aspect, John F. Clauser and Anton Zeilinger for their groundbreaking work in quantum mechanics. Although the fundamental insights of these three brilliant physicists remain beyond the grasp of many people, the impact of their truly amazing research will be felt by all of us. In announcing its decision, the Nobel Committee for Physics had the following to say: "Being able to manipulate and manage quantum states and all their layers of properties gives us access to tools with unexpected potential." By this, they mean ultrafast quantum computers, absolutely secure quantum communications and quantum sensor technology. I, for one, am convinced that quantum technology is about to unleash a new industrial age in which photonics will play a key role.

With laser technology, we are seeing, once again, that the best is yet to come—in the field of quantum technology certainly, but also, and especially, in relation to secondary beam sources. Firing laser pulses at certain materials makes them emit various forms of radiation, which can then be exploited in all kinds of ways. As our cover story explains (page 12 onward), scientists are now using lasers to generate a whole variety of beam sources. The principle here can be illustrated in terms of a game of pool. To pot each of the 15 balls, you need to ensure that the white cue ball hits the colored object ball at exactly the right angle and exactly the right speed. In a secondary beam source, the laser is the equivalent of the white ball, and the colored ball represents an induced beam of electrons, protons or neutrons. These new sources of radiation have the potential to revolutionize medicine and industry. For example, the use of laser-driven electron or proton beams as a form of noninvasive tumor therapy may well transform cancer treatment. Secondary beam sources can also shed light on other problems. EV battery manufacturers, for example, might use laser-induced electron beams to monitor distribution of the electrolyte as it flows into the cells—virtually in HD-video quality. Combined with the right software, this can also be used to predict battery life. Read about this development on page 16.

In this area, too, TRUMPF has played a leading role, with the world's first commercial breakthrough for the principle of laser-driven secondary beam sources, back in 2017. Since then, the microchip industry has been using extreme ultraviolet (EUV) radiation to photolithographically print circuitry on semiconductor wafers. Today, the production of high-power lasers for EUV lithography machines is a key line of business for TRUMPF.

Each day, smart minds around the world are busy pushing back the frontiers of physics. In the coming years, it will therefore be fascinating to see who ends up winning the Nobel. Readers of the latest edition of *Laser Community* can also discover some of the magic of physics. I wish you all a lot of fun in doing so!

DR.-ING. CHRISTIAN SCHMITZ
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Wham!

It is not easy picturing something that the human eye will never see. We therefore asked the AI text-to-image generator DALL·E to create an image from the following description: "Laser beam exceeds threshold and becomes particle beam." Turn to our cover page to see what it generated: **page 1.**

Woof!

As anyone in labor studies knows, a company dog does wonders for the workplace atmosphere. At Alpine Laser in Minnesota, this is Emma's role. Right now, she's guarding a TruMicro. To find out what her coworkers are up to, turn to **page 6**.

Wow!

How do you generate a proton beam? What can you do with neutrons? Stephanie Dierolf offers a colorful introduction to this fascinating subject. Although pressed for time, Stephanie was determined not to miss out on this project. Her great illustrations can be seen from **page 12.**

DALL-E / Florian Burkhardt, Stephanie Dierolf, Ackermann + Gruber | Fotogloria

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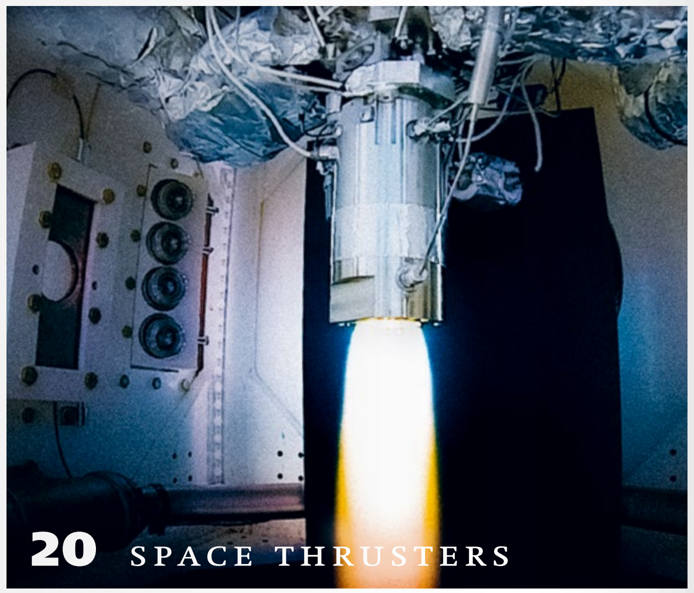
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A new light cable for USP lasers means company cofounder Joe Kempf can make his machines more modular and compact than those of market rivals.

REBOOT FOR STENTS

Stents save lives. These are the flexible, laser-machined tubes used to widen blood vessels and nerve conduits. With demand on the rise, conventional manufacturers are struggling to serve the market. What better time to shake up the industry with the launch of a disruptive start-up!

Joe Kempf sits comfortably in a swivel chair in the functionally furnished conference room: “The team and I have spent years developing a specialized laser cutting platform specifically for medical tube cutting. Every aspect of the workstation has been optimized to make the machine as efficient and fast as possible, while addressing the technology and usability gaps present in the legacy product offerings.” Confident words from an engineer who quit his regular job in the med-tech industry, scraped together his savings and, together with a partner, founded the start-up Alpine Laser. That was back in 2019.

A CAPACITY BOTTLENECK With an eye for an opening, Kempf saw a golden opportunity for a new manufacturer of the machines used to make stents and interventional tubular components. Stents are the semi-elastic wire-mesh tubes that surgeons insert into constricted blood vessels to hold them open. In industrialized countries with rapidly aging populations, minimally invasive surgical procedures like these are becoming more and more common and replacing riskier methods. In the U.S. alone, over two million stents are implanted yearly—a number that is growing all the time. What’s more, new therapies are coming to market each year that utilize laser cut tubular components.

Yet Kempf’s plan to produce a machine for manufacturing stents faced a major hurdle: entry into the medical manufacturing market is not an easy process. The medical device market is strictly controlled by regulating bodies around the world. Understandably, the laws and regulations governing quality and certification are extremely rigorous. As a result, the major manufacturers of stent cutting machines have carved up the sector among themselves. “Now the

In reality, only two and a half millimeters in diameter and absolutely life-saving: In the U.S. alone, over two million of these semielastic tubes are fitted each year.

established manufacturers can't keep up with the rising level of demand, and it's created a bottleneck," Kempf explains.

SMALLER, FASTER Kempf and his team know the medical manufacturing industry. For decades the team at Alpine Laser have been users and operators of this type of equipment. They understand what works, what doesn't, and what the machines need to do. Over the course of the last 18 months, they have benchmarked their laser cutting system against nearly all other systems on the market. The design of any such machinery always involves a key trade-off: on the one hand, the machine should be easily scalable and thereby allow inexpensive manufacturing; on the other, it should be highly customizable and configurable to individual user requirements. "We realized that a modular design was the only way of combining these two goals," says Kempf. Alpine Laser came up with a design for a system that would micromachine high-quality components between two and five times faster than conventional machinery. One reason is that extensive effort has been placed in developing robust and flexible tooling—setting up the machine with new part holding and aligning the optics, for example—takes less than five minutes. That's significantly faster than all previous systems. What's more, with a footprint measuring a mere 1.2 × 0.7 meters, it is the smallest stent-making machine in the business.

Of course, one configuration of the machine is fitted with an ultrashort pulse (USP) laser: without a femtosecond laser, it would be impossible to achieve the required smooth edges and tiny struts for tubes with a diameter of 0.25 millimeters and a wall thickness of as little as 0.5 millimeters. Yet, as Kempf explains, USP lasers are not known for being especially flexible: "That could have caused issues with our strategy of developing a modular platform where we can utilize a majority of common system components across all machine configurations; including both USP Lasers and Pulsed CW Fiber Lasers."

A FIBER DELIVERED USP LASER Kempf then discovered that TRUMPF was working on the world's first fiber delivered USP laser. "We immediately realized that this was key to a modular design." The new laser light cable is made of a hollow-core fiber. This delivers the USP laser pulses from A to B without any loss in stability. "That meant we could separate the laser source from the cutting optics without having to mount a bulky laser head unit near the processing area," Kempf explains. "This makes the machine significantly more compact and allows us to standardize our machine design for both USP and Fiber lasers."

Alpine Laser contacted TRUMPF. The two companies then got together on the development of Alpine Laser's Medicut Pro. This is the first ever machine to use a USP laser with hollow-core fiber delivery for production on an industrial scale. What's more, the beam quality delivered by the TruMicro yields a further benefit. "Ultrafast lasers can deliver such clean-cut edges that our customers can produce parts that require, in many applications, no postprocessing with aggressive chemicals," Kempf explains. "And that removes one significant barrier for device manufacturers; people don't want to work around hazardous chemicals."

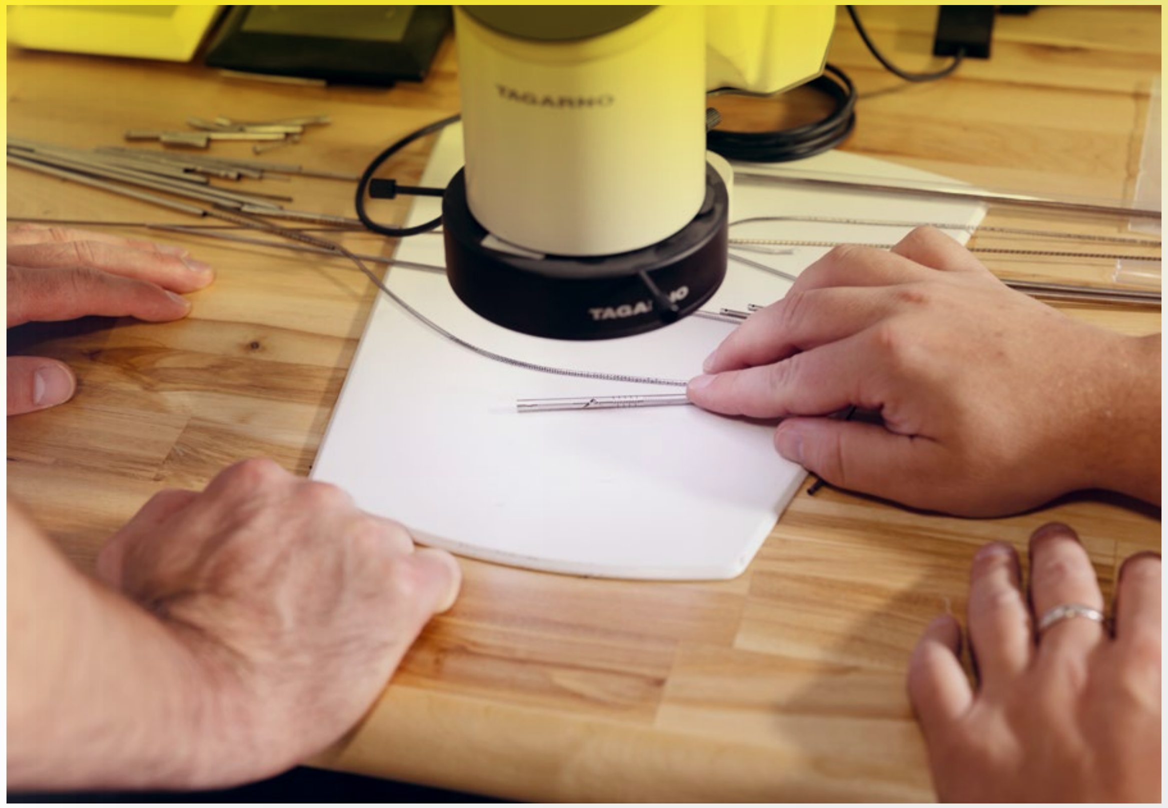
BOOSTING OUTPUT Having initially hoped for a modest and steady ramp in sales with the launch of this new machine, Alpine Laser has been blown away by the demand. Bolstered by this experience, Kempf is now turning his attention to new USP flat sheet cutting systems for complex laser cut catheter delivery systems. Kempf says, "We feel our job is far from done—we're just getting started. We have a large list of products in our pipeline that stand to benefit from an Alpine revamp—updating old industry designs with new, more advanced technologies. The team at Alpine will continue to investigate and implement the latest technologies, ensuring that our machines continue to outperform market offerings for years to come."

Contact: Alpine Laser, Joe Kempf,
Phone: +1-651-353-4376, joe@alpinelaser.com

"USP lasers cut with such clean edges that our customers can now produce parts that no longer need any post-processing with aggressive chemicals."

Gernot Walter

Ackermann + Gruber | Fotogloria



Top: Joe Kempf and his team assemble a modular machine for microprocessing stents.
Center: Clamping devices for machine retooling.
Bottom: Inspecting a stent.

POWER

Rehearsing for real maneuvers on the red planet: the Rosalind Franklin Mars rover.

LASER SEEKS LIFE

A new space mission seeks to determine whether life once existed on Mars. Key to this quest is a small but extremely robust solid-state laser.

The size of a mere quarter, yet this diode-pumped solid-state laser can handle extreme conditions.

Sadly, it is highly unlikely that anything could today exist on the surface of Mars. The aridity and punishing radiation would kill off even the hardiest of life forms. Yet conditions were different two to three billion years ago. Back then, water was plentiful on Mars, and the climate warm and humid. A good number of scientists postulate that life may very well have evolved around the same time as it did on Earth. Were this the case, the remains of such life forms should lie buried beneath the planet's crusty surface—in the form of fossils.

This is what the European Space Agency (ESA) aims to find out. To this end, it will dispatch a small drilling rig and analytics lab to the red planet. All this gear will be packed into a Mars rover some two meters high, two-and-a-half meters wide and weighing a mere 310 kilograms. The rig will drill to a depth of two meters in search of rock samples. Back inside the rover, an array of analytic devices will examine these samples for biomarkers—traces of past life. One of these instruments is a Raman spectrometer. This shines a green laser beam onto the surface of a rock sample. The spectrometer analyzes the scattered light and, on the basis of changes in wavelength, determines the molecular properties of the material examined.

The beam is generated by a diode-pumped solid-state laser that has to meet highly challenging specifications: it must be lightweight, extremely compact and capable of enduring savage cosmic radiation as well as working reliably across a massive temperature range of minus 130 to plus 24 degrees Celsius. And, last but not least, it has to withstand the huge vibrations and jolts during rocket launch and touchdown on Mars.

Researchers at the Fraunhofer Institute for Applied Optics and Precision Engineering (Fraunhofer IOF) worked for seven years to develop such a laser. The full module is the size of a quarter and weighs a mere 50 grams—despite delivering a power of 100 milliwatts. To ensure the requisite robustness, the Fraunhofer team made use of a special laser-soldering technique to assemble all the various parts of the ultrasensitive laser resonator and other optical components. Such joints are strong enough to withstand severe mechanical and thermal stress.

Originally planned together with Russian state space corporation Roskosmos, the second leg of the ExoMars program was scheduled to take off in 2022. However, in the light of the current political situation, this collaboration has been put on ice and the launch postponed, provisionally to 2024. ■

Fraunhofer ILT, ESA, Gernot Walter

GLORY

THE WORLD'S FIRST LASER SURGEON

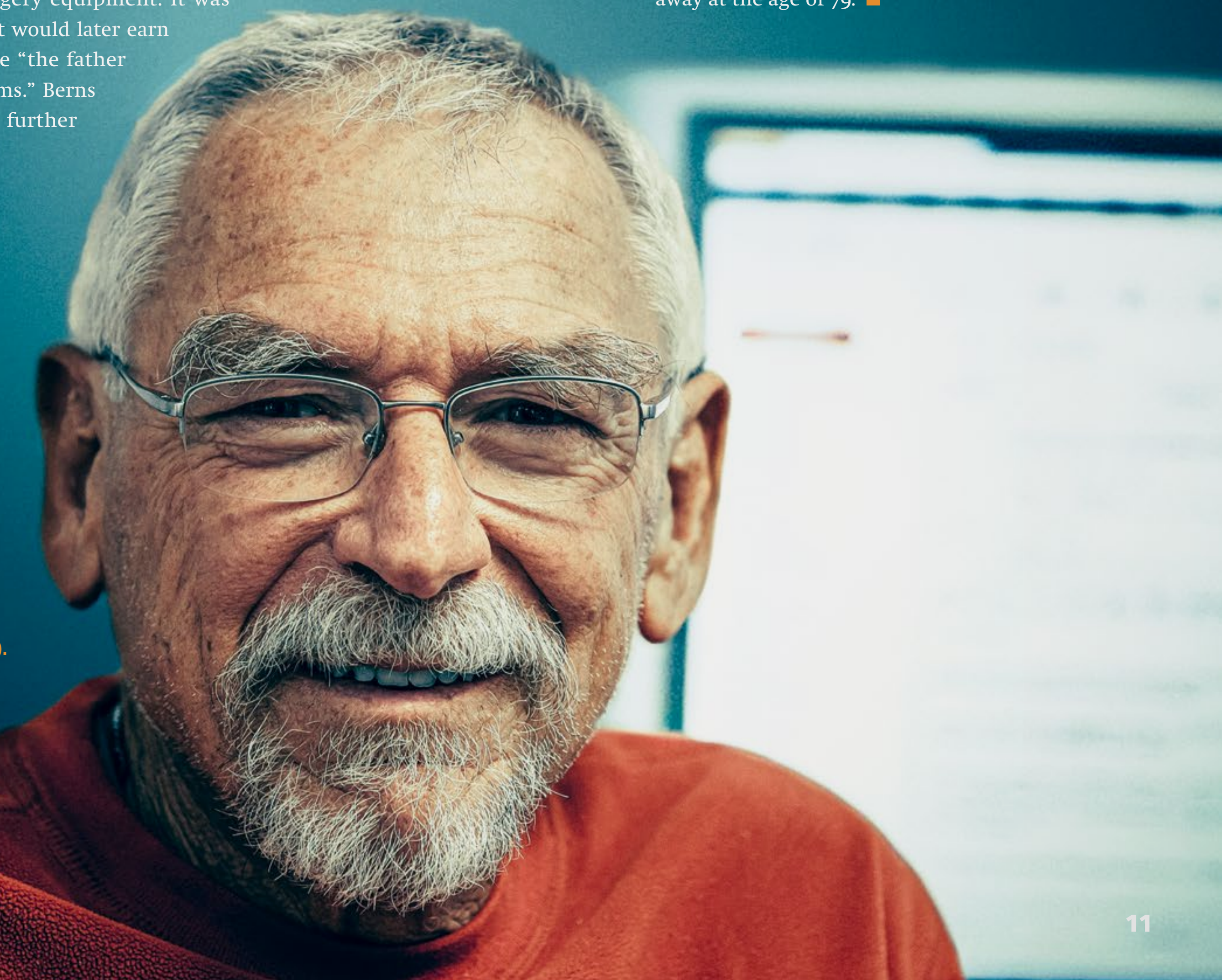
Michael Berns, who brought laser technology to the fields of biology and medicine, has been posthumously awarded the SPIE Gold Medal by the International Society for Optics and Photonics.

"It was 1966. All I knew about lasers was that Goldfinger was going to slice James Bond in half!" These were the opening words to a conference paper that Michael Berns delivered mid-2022. "Then one of my professors told me that the department had purchased a small ruby laser but did not know what to do with it." Berns soon came up with a couple of ideas.

Born in Vermont, Berns originally studied biology before branching out into research of how cells and tissue react to laser light. It was a move that would lay the foundations for laser surgery. Berns was the first person to manipulate individual chromosomes and perform subcellular surgery—to repair nerve cells, for example. In addition to doing the biomechanical spadework for this type of surgery, he also developed new laser therapies to treat conditions of the skin, eyes and vascular system. At the end of the 1970s, he set up the Laser Microbeam Program, dedicated to the development of laser surgery equipment. It was work like this that would later earn him the nickname "the father of laser microbeams." Berns went on to found further biomedical bodies—including, in 1982, the renowned Beckman Laser Institute & Medical Clinic at UCI.

Apart from science, Berns nurtured several other interests. In his spare time, he was also a painter, avocado farmer and spy thriller novelist. In 1979, when traveling to deliver a lecture on biomedicine at Moscow State University, he was interrogated by KGB agents for 12 hours after being caught smuggling Jewish prayer books inside a false-bottomed suitcase. Berns was banned for life from entering the Soviet Union. This incident would later inspire his first nonscientific work, *The Tinderbox Plot*, a spy novel published in 2021.

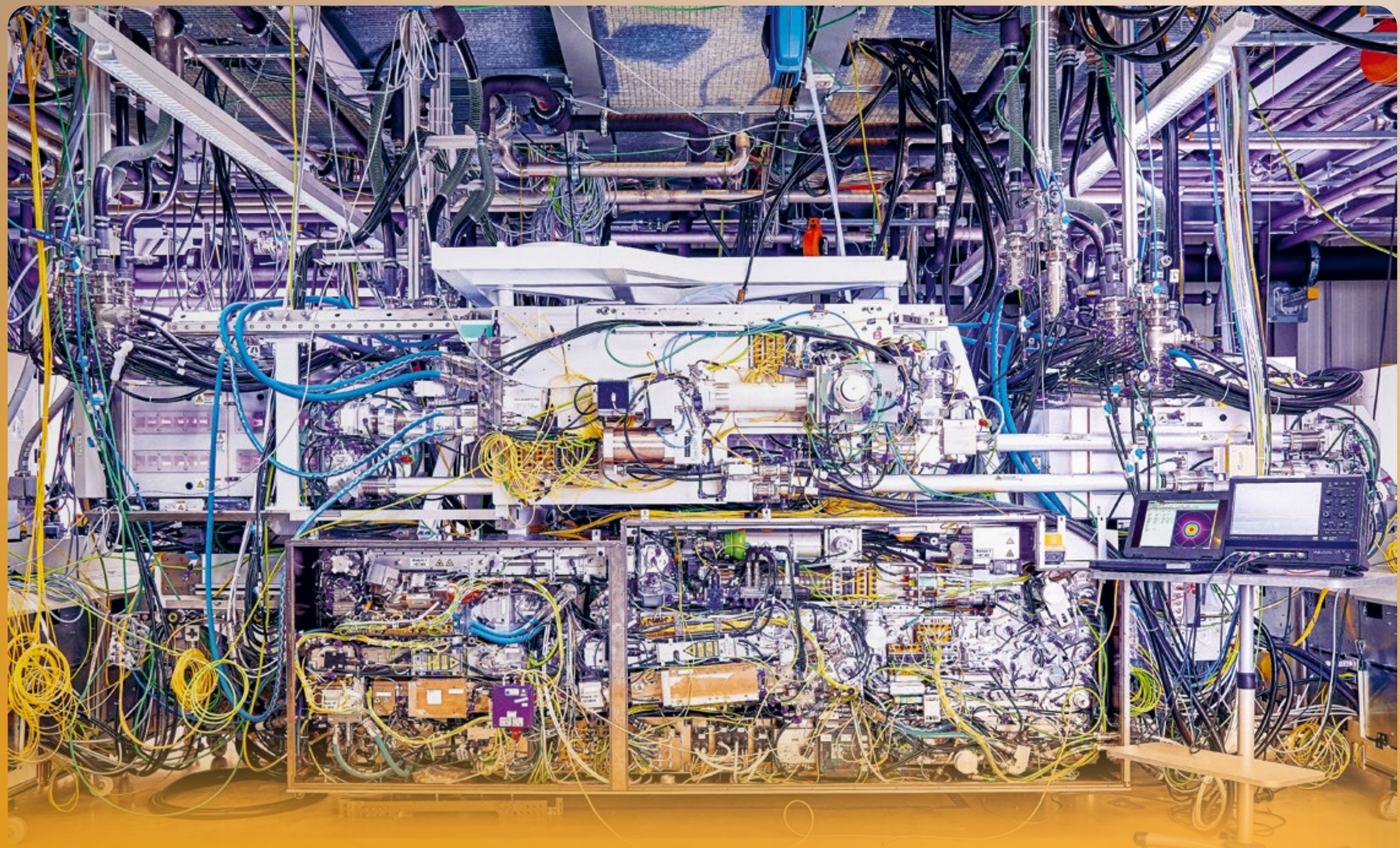
In 2022, the SPIE international society for optics and photonics announced that it would award Michael Berns its top prize in recognition of his work in introducing laser technology to the fields of biology and medicine. Only a few days before the award ceremony in August, Michael Berns passed away at the age of 79. ■



Laser pioneer and thriller writer Michael Berns (1942–2022).

Beckman Laser Institute & Clinic

SECONDARY SOURCES
Secondary beam sources are created when laser pulses are fired at certain types of material, thereby generating a further form of useful radiation—e.g., light in the X-ray spectrum or a particle beam. The origin of this principle lies in the use of extreme ultraviolet (EUV) light for the production of microchips. Future beam generators could well look something like this seed module for an EUV lithography machine.



TRUMPF

Breakthroughs in USP laser technology will provide industry and medicine with easy access to hard X-rays and high-energy particle beams. A host of new applications will follow.

THE AGE OF THE BEAMS

For many years, ideas lay dormant on the drawing board – but new USP lasers are now turning them into concrete applications.

Just imagine you want to scan a whole bridge and see whether the concrete inside is still okay or starting to crumble. No problem! All it takes is a neutron beam. And for that you simply need to build a 100-meter-long proton accelerator plus a nuclear reactor to generate the neutrons—all at a cost of around a billion euros. What's more, you would have to build them right next to the part of the bridge that you wanted to inspect. Alternatively, you could always just wait until laser-driven particle accelerators become available in sufficient numbers, at a price of a couple of million euros. These will fit on a truck that you can drive along the entire length of the bridge. And then on to the next bridge!

The coming years are going to see a massive increase in the availability of hard X-rays and of electron, proton and even neutron beams. Thanks to technology that will simplify the production and radically reduce the cost of such beam sources, scientists and engineers are now busy brainstorming new ideas about how best to use them (see pages 16 and 17). These ideas have the potential to revolutionize medicine and industry. So what's behind this new trend?

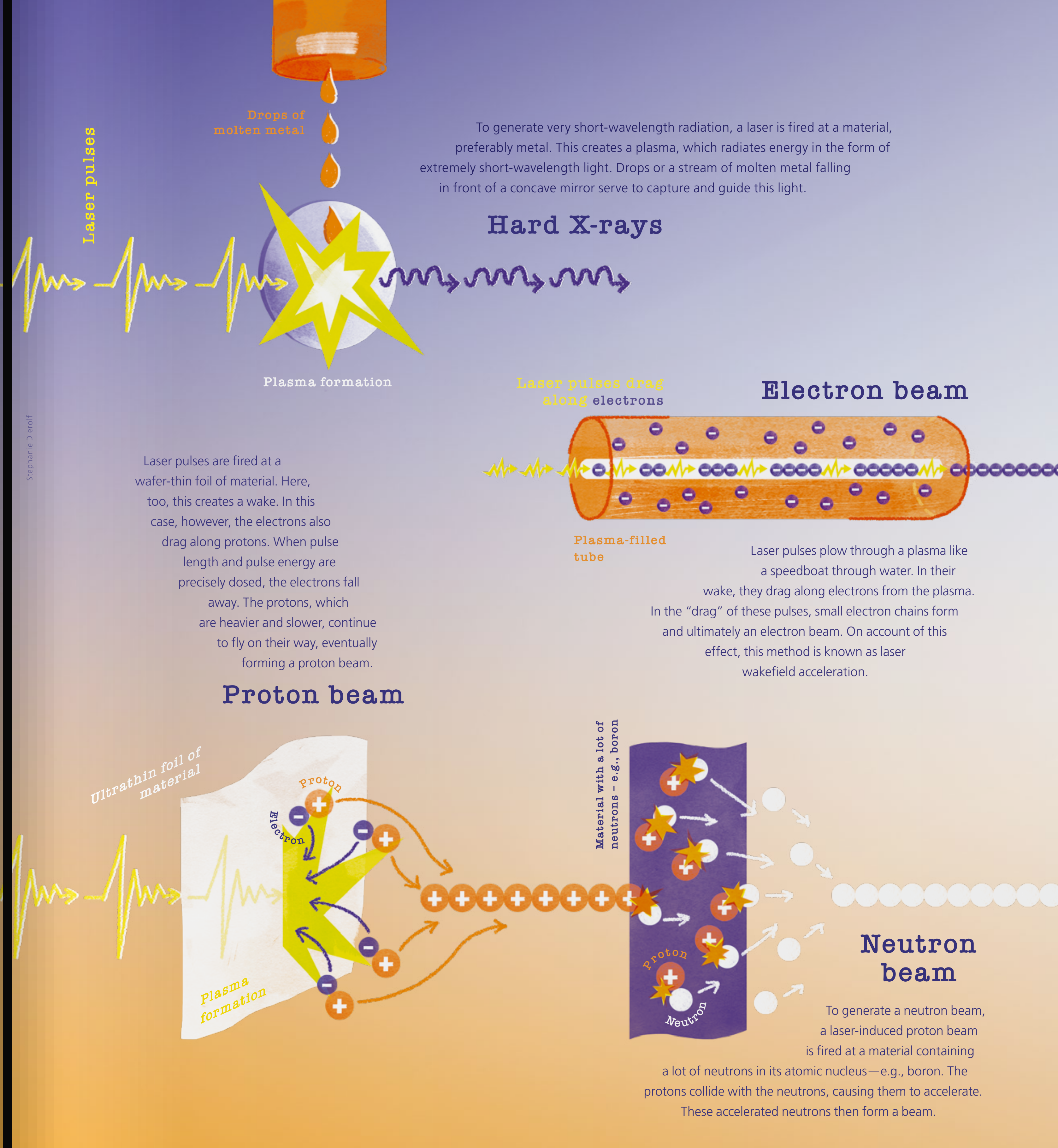
THE USP BREAKTHROUGH What's behind this trend is the ultrashort pulse (USP) laser. Until now, it has only been possible to produce on a widespread scale X-rays and particle beams with comparatively low particle energies—for the purposes of simple X-ray images, for example, or electron microscopy and electron-beam welding. Producing high-energy beams, by contrast, requires a huge electromagnetic input. Take an electron beam: the conventional method is to arrange the electrons into a powerful, reasonably ordered beam and then accelerate them. This involves the use of a long beam pipe, either straight or ring-formed. Electromagnets and accelerating sections positioned along the beam pipe are activated in fast, finely coordinated succession, thereby bringing the electrons up to speed.

The minimum length of beam pipe is 100 meters. This will ensure that the electrons attain the requisite velocity somewhere in the region of the speed of light.

For decades now, there have been ideas about how beams might be generated in a simpler and more compact manner. One of these was to use packets of photons, produced by a laser, to accelerate particles. The problem here was the lack of a laser beam source capable of meeting these requirements.

But no longer. It is about ten years since USP lasers made the leap from the lab to industry. This shift has given the technology a powerful boost. For in order to adapt it to this challenging new world, USP pioneers such as TRUMPF have pulled out all the stops to improve performance and reliability. Two priorities have been to increase pulse energy and average power—i.e., the number of pulses per second. In the last five years alone, the average power of USP lasers from TRUMPF has grown from 50 to 200 watts. On a number of occasions, company engineers have also succeeded in demonstrating an average power of more than 1,000 watts.

In other words, it's time to leave the drawing board and start developing some of these dormant ideas. This baptism of fire in industry has given rise to a new generation of UKP technology—one in which laser-driven particle acceleration is now very much a reality. What once required 100 meters of tunnel now needs an acceleration path of only a few millimeters. The hardware for this fits in a garage or on the back of a truck. In the case of an electron beam, this works as follows: powerful, precisely timed femtosecond pulses are fired into a plasma tube. If this is done correctly, the laser pulses simply drag the electrons along with them. Here, a distance of ten millimeters is sufficient to achieve the required electron velocity (for more details on the individual concepts, see right). A magnetic system compresses the electrons into a beam and guides this to the desired spot. That's why laser-driven particle accelerators are so much smaller and cheaper than larger, tunnel-based variants.



Generate your own beam …

THE LASER AS BEAM GENERATOR On the face of it, this new generation of particle accelerator has to fulfill extremely demanding requirements. The minuscule photon packets must hit a spot only a few micrometers in area with exactly the right energy and at exactly the right moment—to within the nanosecond. If not, the acceleration process will fail to start or falter and peter out. Yet users of the latest USP technology know better. After all, mode-locked oscillators have a temporal precision within the range of a few femtoseconds. On the other hand, laser enthusiasts may well experience a certain letdown. For, in the end, the immensely powerful laser pulses serve merely as a means to an end. In lab jargon, this is what is known as a laser-driven secondary beam source. It's like the power socket and the kitchen microwave: I want to heat up my lunch, but instead of directly using electrical energy for this, I use the power to generate microwaves, which then warm up my bowl of soup. In this analogy, the laser beam is the electricity—a precious form of energy—but the real aim is to generate other types of beam. In other words, the laser is the beam generator.

THE COMMERCIAL BREAKTHROUGH TRUMPF has been pursuing this idea for quite some time now. The first commercial breakthrough for the principle of laser-driven beam generation came in 2017. This was the use of very soft X-rays—extreme ultraviolet (EUV) radiation—to photolithographically produce semiconductor circuitry on silicon wafers. TRUMPF supplies the high-performance laser system used in the lithography machines supplied by ASML to the chip-manufacturing industry. The TRUMPF system fires laser pulses at a waterfall of tin droplets. This causes the plasma to emit radiation of 13.5 nanometers—exactly the right wavelength with which to create even the smallest of transistor circuitry in the wafer. The ASML lithography machine produces 100 chips per hour. This new generation of microchip is found in cellphones and a host of other devices.

It is hoped that many more successful commercial applications of laser-driven beam generation will follow over the next few years. Many of them are still at the trial stage. Experts estimate it will take another five to ten years before most of them have found widespread usage in industry and medicine. But the potential is huge—as is the resulting boost for laser technology. Each leap forward in the—as yet—exotic field of laser-driven secondary beam sources is like a new development in Formula One racing: whatever proves its mettle there will one day find a way into normal production vehicles. In the case of USP lasers, that means advances in the field of material processing. We are seeing the dawn of a new age, one in which the ready availability of coherent subatomic particle beams will become the most normal thing in the world. As with all inventions, a technological and social transformation did immediately result from the very first successful application of this technology. That came a number of decades ago, with the development of the electromagnetic particle accelerator. Instead, the real revolution only begins when a technology becomes cheap, simple and widely applicable. In the case of laser-driven particle accelerators, this is about to happen. And, with this type of radiation readily available, everybody will soon be beaming. ■

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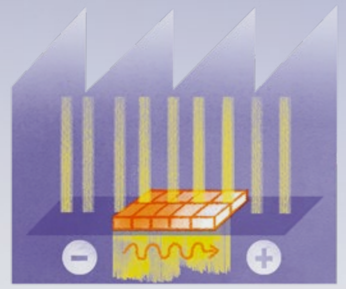
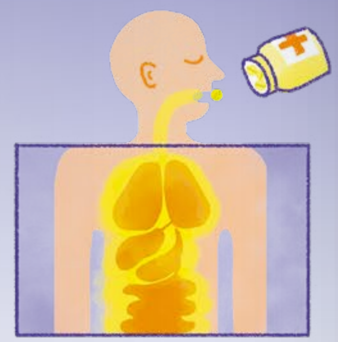


Quality control

When it comes to quality control and fault diagnosis, there is nothing quite like being able to actually look inside objects without destroying them. Hard X-rays and electron beams enable this type of noninvasive scan. An X-ray system to automatically inspect minuscule transistor circuitry is now approaching industrial maturity. Similarly, maintenance engineers can examine turbines or additively manufactured components with inner structures in this way. An electron beam penetrates even very solid materials such as metals, thereby making it possible to look inside very large structures or components in situ. There are also interesting applications in battery manufacture: laser-generated beams have such a high temporal resolution that it is virtually possible to make a video of how the electrolyte is distributed when batteries are filled. Software then checks the functionality of the battery batch and even predicts its expected life.

Detection of explosives and drugs

When an object is scanned with a neutron beam, its atoms give off a characteristic fluorescence, which reveals exactly the nature of the material under examination. This also applies to organic substances, including drugs and most explosives, which are invisible to X-rays. A neutron beam is so powerful and broad in scope that it can be used to scan an entire shipping container. One idea would therefore be to scan every container arriving at a cargo port—just like baggage screening at an airport. Special software would then be used to detect the presence of explosives, drugs or embargoed goods.



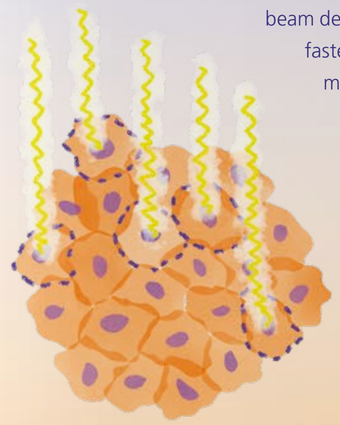
Drug development

While it is easy to determine whether drugs work, it is often much more difficult to say how they do so. With hard X-rays and electron beams, it is possible to image and monitor drug activity within the body—as in a video. In the future, as this form of radiation become readily available, it will be much easier for scientists to observe the folding of individual proteins or the docking mechanism of viruses. In other words, laser-driven beam generation could provide the next boost for the development of new drugs and vaccines.

Stephanie Dierolf

Noninvasive tumor therapy

For many years, conventional practice has been to treat cancer cells with repeated doses of radiation until they—hopefully—disappear. As a rule, X-rays or gamma rays are used for this purpose. Recently, electron beam therapy has also joined the mix. Yet radiotherapy is often an ordeal for patients—and, in the case of electron beam therapy, the equipment is large and expensive, meaning that it is not widely available worldwide. Low-cost, laser-driven electron beams could change this. In addition, because of their charge, electrons can be magnetically focused and therefore applied more precisely than conventional X-rays and gamma rays. As a result, this form of therapy destroys less tissue around the tumor, making it more tolerable to patients. In addition, an electron beam delivers much more energy much faster, thereby destroying the tumor more quickly and effectively. Proton beams are even more powerful. They can also be focused better at depth within the body. This means they only act where they are needed and do not destroy any tissue in front of the tumor. Recently, researchers successfully treated a mouse with proton beam therapy.



Bridge scans

Until recently, the idea of generating neutron beams with a mobile system would have seemed ludicrous. Conventionally, you would need a nuclear reactor to do this. With the laser method, however, no reactor is required, and the entire system will fit on a truck. This could help solve a serious problem: the timely diagnosis of so-called concrete cancer. Over time, moisture can make concrete porous and instable—a worrying phenomenon, particularly in bridges. Here, water sparks a reaction between alkaline cement and silica, the two main components of concrete. With a mobile neutron source mounted on a truck, engineers could examine a bridge's massive concrete pillars to a very high resolution and thereby determine its structural condition. Initial concepts of this type are currently being developed in Japan. This system could also be used on other objects and structures. Even the casks used to store nuclear waste—which are themselves radiation-proof—could be scanned with a neutron beam for structural integrity.

→ … and how to use it!

FISHING FOR MICROPLASTICS

Hazardous microplastics are everywhere, even in treated water. But Andrea Lanfermann has netted a solution.

Dominik Asbach | Fotogloria

Ms. Lanfermann, you've declared war on microplastics. Don't the wastewater treatment plants already take care of them?
Sadly, no. In fact, a key problem here is the lack of a clear directive telling the treatment plants what they have to do.

What do you mean by that?
At present, microplastics are merely defined as particles smaller than five millimeters. That's a very open-ended definition, given there are also plastic particles on the nanometer scale. It's unclear down to which size particles have to be filtered and below which they are allowed to pass through. We're now aiming to filter down to a particle size of ten micrometers.

How will you do this?
We've teamed up with partners to develop a cyclone filter with a ten-micrometer mesh. This removes particles from the water by means of centrifugal force and a filter unit. Initial tests at a wastewater treatment plant were very promising. We were able to filter out almost all particles of plastic down to a size of ten micrometers.

That's a very fine mesh.
Correct. To create such a fine mesh, we use an ultrashort pulse laser. Our project partner Laserjob used a TruMicro 5225 to cut the mesh for the filter unit in our prototype. It took two weeks. That's because they had to drill 59 million holes with a single laser beam.

How can that be economical?
It isn't, but now we've developed a process for multibeam drilling. This uses the TruMicro 5280 Femto Edition to drill tiny holes in a sheet of stainless-steel foil only 100 micrometers thick. A special optical system creates a matrix of identical laser beams. This splits the laser beam into 144 individual beams, meaning we can drill 144 holes at once. This slashes the processing time. But there are still difficulties. Splitting the laser beam means less energy for each individual beam. Nevertheless, the system still has to be capable of drilling precisely positioned holes. And because we are also heating a larger area, there is greater thermal distortion. With multibeam drilling, it's therefore vital to monitor the process and the quality. That way, we can better understand and control these thermal effects. Here, at the institute, we've developed simulation software for laser drilling, which is also backed up by optimization software from our partner OptiY. This enables us to calculate the shape of the drill hole and thermal stresses and to choose the correct parameters to prevent distortion. We're aiming to produce a filter unit with as many holes as possible.

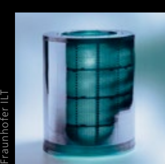
Why is that?
Our filter lets through 33 liters a minute, which is way too little for a wastewater treatment plant. And there's another thing: the geometry of the laser beam creates conical holes, which take up more space. A ten-micrometer hole has an upstream diameter of 30 micrometers. This reduces the number of holes that can be cut in the filter—and thereby the rate of flow. Currently, only 2.5 percent of the area of each drilled sheet of foil is actually perforated. Increasing this will be one of the key tasks for future research.

What other goals do you have?
We want to laser-drill holes as small as 500 nanometers in even thinner sheets of steel foil and make the process suitable for industrial use. Our partner LUNOVU has created an interface where users can enter the size, area and configuration of the holes they want to drill. That saves us the time-consuming business of having to plan the process manually. And it also means filters can be made for other purposes.

And what might those be?
Local water treatment. This means the filter is installed right where microplastics are produced. That might be a PET recycling facility, which would filter its own wastewater before it went to the treatment plant. Apart from that, there are also applications beyond microplastics. One idea is to equip filters with a biological component. After mechanical filtration, nanoparticles would then be combined with enzymes or proteins in order to break them down. That would be a way of removing trace substances from water. There's heaps of potential. We're only just getting started. ▪

THE ADVERSARY Our water is contaminated with microplastics. According to a study by the Alfred Wegener Institute, water filtered by a typical wastewater treatment plant still contains over 700 particles of microplastics per cubic meter. Each year, that amounts to as many as 5.3 billion minuscule and potentially harmful particles ingested by animals and humans.

THE PARTNERS The joint project SimConDrill had expert input from partners KLASS-Filter GmbH, LaserJob GmbH, LUNOVU GmbH, OptiY GmbH and the Fraunhofer Institute for Laser Technology (Fraunhofer ILT).



Fraunhofer ILT

THE FILTER In the SimConDrill cyclone filter, wastewater is circulated around a centrally mounted drum to which a laser-pore filter unit has been welded. A hydrodynamic scraper ensures that no particles get stuck in the filter pores.

REIGNITING THE RACE FOR SPACE

Right across the space industry, operators are in search of the same vital quantity — thrust. Whether for rockets, satellites or lunar landers — makers of the requisite hardware are now opting for 3D printing.

Durango, Colorado It's early morning and Charlie Garcia's inbox is full—queries of the kind: "We're planning a moon shot …"; "We're looking to orbit Venus …"; "We're going for a Mars landing …" Garcia is chief engineer for special projects at Agile Space Industries in Colorado. His previous employer was SpaceX, which is where he gained his expertise in a hot commodity required for every space mission: thrust.

MARKET LEADER FOR MOON LANDINGS "Spaceflight has become cool once again," he says. "There's now a boom in civil and commercial missions. Year on year, we have more and more customers; year on year, they're ordering more and more of our hardware." What they purchase from Agile Space are thrusters—spacecraft propulsion systems. Thrusters come in different types, depending on their function. There are thrusters to keep satellites in their proper orbit, for example, and there are classic thrusters that propel rockets into space. One of Agile Space's specialties are the kind used for lunar landers. "We're market leader for moon landings," Garcia explains.

The attitude control thrusters for a lunar lander are about the size of a 0.5-liter beverage can. The housing features a system of inner ducts to transport a bipropellant fuel and oxidizer. As the lunar lander descends toward the surface of the moon, the thrusters ignite to level the craft and ensure a soft touchdown. This special propellant combination combusts when it comingles and burns at a temperature of up to 3,000 degrees Celsius.

LIKE THROWING AWAY GOLD Agile Space has pioneered the use of 3D printing to manufacture its thrusters. It is only recently that the space industry has overcome its reservations regarding this technology—also known as additive manufacturing. In the past, it has preferred processes that have stood the test of time. After all, there's no one in space to send along a spare part when something goes wrong. "Around four years ago, the race for space reignited," Garcia explains. "By then, the attitude toward additive manufacturing had flipped. People realized that 3D printing was a perfect match for the space industry." By that, he means the need for ultra-lightweight, ultra-complex parts with inner ducting and fabricated of exotic alloys, often in very small or even one-off batches. "But what really clinched it was what we in the industry call the buy-to-fly ratio." This describes the weight of the material used to make a component compared to the weight of the material that actually ends up in flight. Additive manufacturing offers an unbeatable buy-to-fly ratio. →

Sinfully expensive space alloy Niobium 103.

Agile Space explorer Nick Gabrielli always comes up with new 3D printing strategies and gets more out of the machines than they than they are officially capable of.

Chandler Crowell | Fotogloria

3D-printed thruster for the attitude control during the moon landing.

“People have finally realized that 3D printing is a perfect match for the space industry.”

Charlie Garcia, Chief Engineer at Agile Space Industries

The specialist alloys used in the space industry are seriously expensive. The thrusters from Agile Space, for example, are made of the extremely heat-resistant alloy niobium C-103, which can cost as much as 1,600 U.S. dollars per kilo. “If you manufacture from a solid piece of material—i.e., turning, milling and drilling a metal blank—you may be buying as much as five kilos of niobium C-103 per thruster,” Garcia explains. “And then you end up with four-and-a-half kilos of waste, while the part itself only weighs half a kilo. It’s a bit like making a wedding ring out of a gold bar and then throwing the rest away.” With additive manufacturing, by contrast, Agile Space uses only as much of the expensive alloy as is actually contained in the finished product.

Mount Pleasant, Pennsylvania No wonder, then, that 3D printers are in big demand in the space industry right now. As are contract manufacturers who are able to max these machines out. That’s why Agile Space teamed up with the Pennsylvania company TroniX3D and then, in 2021, made it part of the corporate family, under the new name of Agile Additive. Cofounder Kyle Metsger and the rest of the TroniX3D team were quick to pinpoint how additive manufacturing could give Agile Space that decisive edge.

VALUABLE FEEDBACK FROM TESTING As Metsger recalls: “Agile Space was always good at identifying and eliminating the bottlenecks that occur in the development and testing of thrusters, which is lengthy process at the best of times. That’s their thing. Then we came along and said, we’ve got another idea, but we’re going to have to trust each other.” What Metsger needed was the data generated during hot and cold testing of the thrusters. With direct access to this, Metsger and his team could then combine it with its own production data from the machines. Agile Space agreed. “Almost immediately, we identified ways in which the process could be modified,” Metsger explains. This knowledge was implemented right away, with the result that development times have been slashed from several months to just a couple of weeks. Naturally, this gives customers of Agile Space a big boost in the current dash for space.

“We could do all of this,” Metsger adds, “because we were able to find a bold and innovative company to supply us with the machinery for additive manufacturing.” Right from the start, it was clear they were going to have to spend a lot of time experimenting with powders, alloys, machine settings and new designs. Metsger’s supplier of choice was TRUMPF. Once again, trust was a key factor. “It quickly grew into a partnership of equals,” he explains. “There’s been a lot more trust involved than is usual in business dealings, but we’re both benefiting from that. We’re doing things here that go way beyond the machines’ official specifications, but in turn this means that TRUMPF gets valuable feedback from a sophisticated user.”

Agile Space currently has one TruPrint 1000 and two TruPrint 2000 machines in action and, as of this summer, the even larger TruPrint 5000—the first of its kind in the U.S. There’s a simple reason behind this new acquisition: by building on its success with small parts, Agile Space is now using additive manufacture to produce bigger and bigger components. Likewise, it is also starting to incorporate formerly discrete assemblies within single components. This drives down weight and saves on assembly costs. Equally important, it also reduces complexity, which means there is less scope for things to go wrong. Before rocket launch, it cuts the cost of safety testing and certification; and, once in space, it boosts the chances of mission success. Over the past few years, Metsger has witnessed a fundamental shift: “To succeed in today’s space industry, you now have to be using additive manufacturing. Anyone not doing so is going to fall by the wayside.” ■

Contact: Agile Additive, Kyle Metsger, Phone: +1-724-260-8061, kmetsger@agileadditive.com

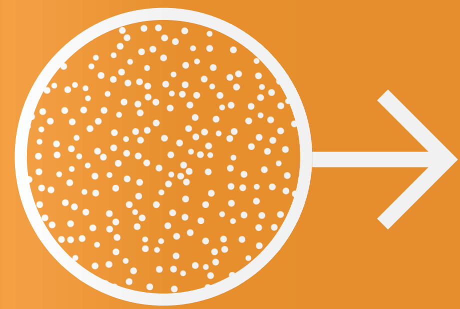
“To succeed in today’s space industry, you need to be using additive manufacturing.“

Kyle Metsger, Technology & Innovation at Agile Additive

Agile Space Industries

Magic Metals!

Metallic glasses have fantastic properties—if, in the past, few applications. This has changed with the advent of 3D printing. Four examples of products already in mass production.

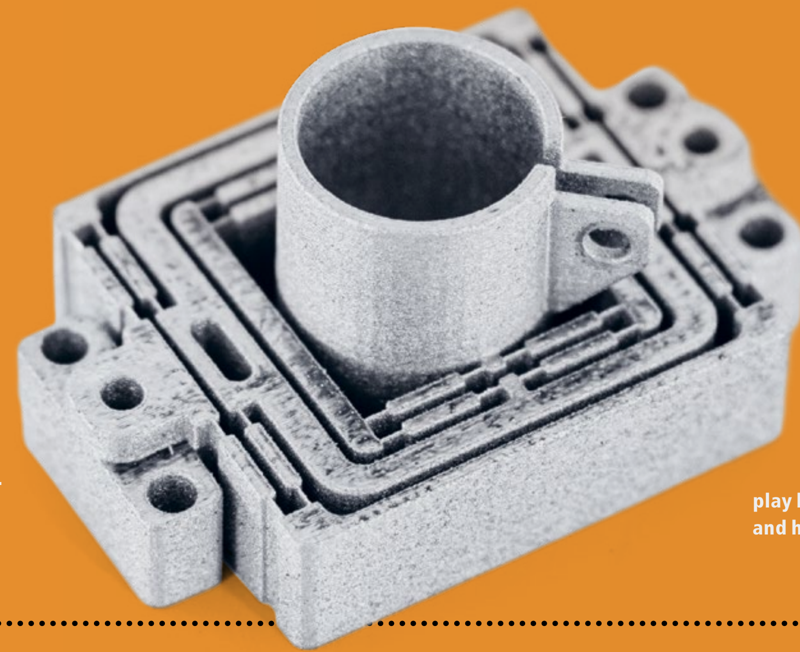


If molten metal solidifies very quickly, even fast-moving atoms do not have time to line up in a lattice. Instead, they form an amorphous, glass-like structure. These amorphous metals have special properties.

Low thermal conductivity
The atoms in an amorphous metal have less freedom to move. This is why they absorb thermal energy slowly and feel warm to the touch.

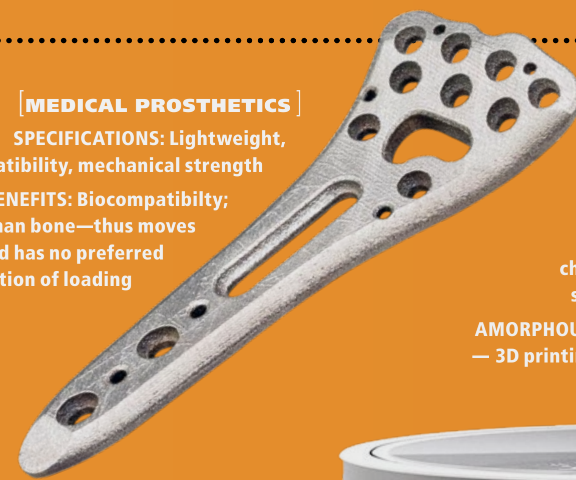
High resistance to corrosion
Unlike in a lattice structure, there are no freely moving electrons within an amorphous metal. This inhibits reactivity with other elements.

High mechanical strength
Because amorphous metals do not have a crystalline structure, they are equally resilient in all directions, but also hard and highly flexible.



[FLEXURE BEARING]
SPECIFICATIONS: High-precision guidance of spindle-mounted focusing mirrors in laser machines; multiple degrees of freedom between bushing and housing to prevent jamming; complex assembly and alignment.
MORPHOUS BENEFITS: Design and manufacture as a single component; slender, elastic ribs in housing allow for equalizing play between bushing and housing.

[EARBUDS]
SPECIFICATIONS: Quality acoustics from a small volume; complex shapes; mechanical strength to withstand dropping or scratching; biocompatibility for bodily contact; comfort in winter—cold metal in ear
AMORPHOUS BENEFITS: Enhanced formability, including cavities; hardness plus elasticity; resistance to corrosion; low thermal conductivity for warm feeling in ear

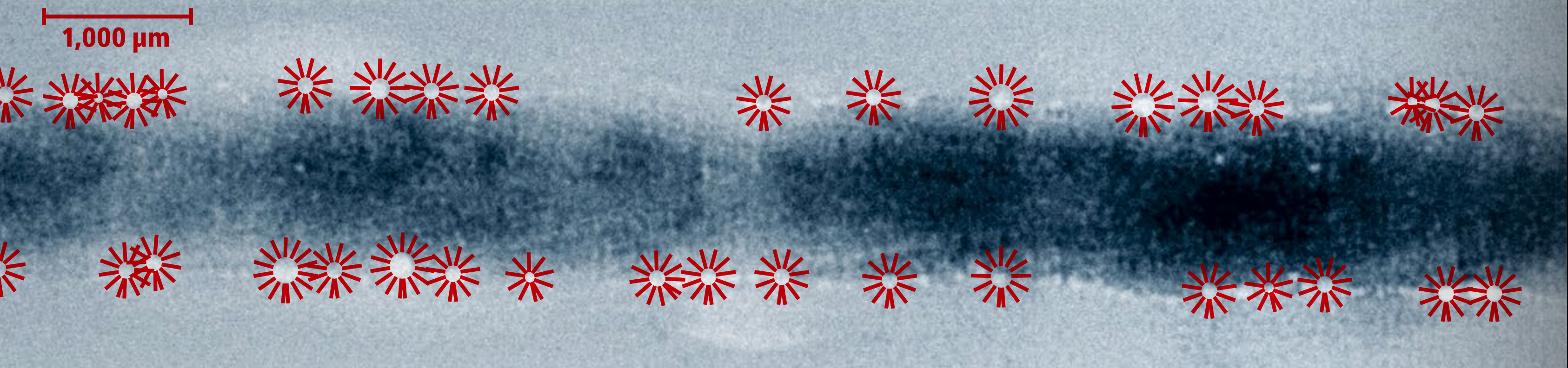


[MEDICAL PROSTHETICS]
SPECIFICATIONS: Lightweight, Biocompatibility, mechanical strength
AMORPHOUS BENEFITS: Biocompatibilty; more elastic than bone—thus moves with load and has no preferred direction of loading

[RESISTANT WATCHCASE]
SPECIFICATIONS: High mechanical strength and chemical resistance to shocks, scratching, water and sweat
AMORPHOUS BENEFITS: Flexible design — 3D printing; hardness plus elasticity; resistance to corrosion

Contact: Heraeus AMLOY, Valeska Melde, amloy@heraeus.com; TRUMPF, Jan Christian Schauer, jan-christian.schauer@trumpf.com

TRUMPF, Sennheiser electronic GmbH & Co. KG, Oskar Pascal AB



At last, a gastight weld with aluminum

A big problem with seal-welding aluminum is that you often end up with gas-permeable pores in the seam. Yet a quick glance into the fire and steam of the keyhole reveals that all it takes is a differently shaped laser beam—and the pores disappear.

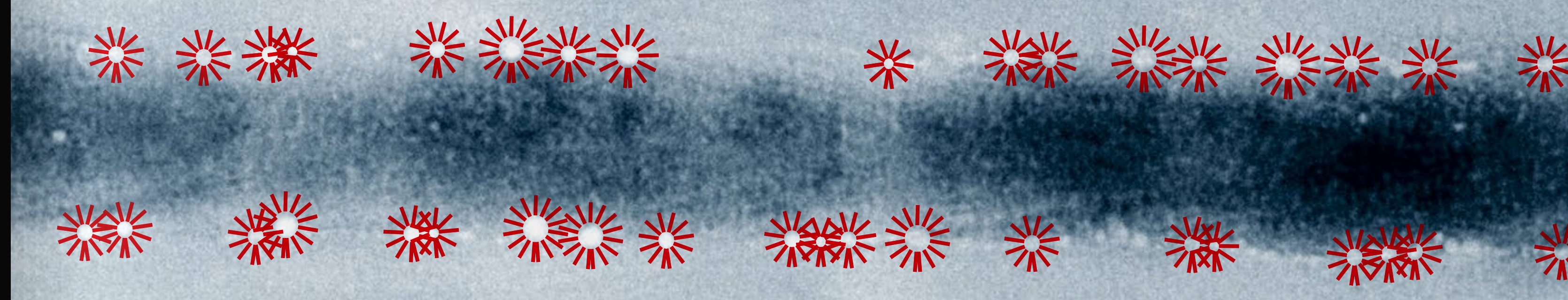
It is now very easy to laser-weld highly reflective aluminum, creating wonderfully strong seams at high speed. That these seams contain a few pores—gas inclusions—does not impact the mechanical strength of the weld. Things are different, of course, when a gastight weld seam is required. If the seam contains a lot pores, this leads to the formation of tiny channels through which gas can penetrate or escape.

A GASTIGHT DILEMMA Conventionally, there are two ways of creating a gastight weld: those who require a fast, high-quality, energy-efficient process favor a laser along with a high-cost material such as stainless steel; those who prefer to use aluminum need to solder in order to create a gastight joint—a process that not only is much slower but which also consumes a hundred times more energy and requires an area the size a basketball court.

Tomorrow's mobility will rely upon the ability to create millions and millions of reliable gastight welds. Ideally, these will be the work of a highly automated process that functions well with aluminum, as a cheap and lightweight material. This process will serve to produce casings for power electronics and the cooling plates found in electric vehicles. These carry water-filled cooling channels and shield the sensitive electronic components of the packed batteries from moisture and weather influences. The seals for these casings must be completely impermeable. This is what our development partner, automotive supplier Benteler, is looking to achieve. Together, we forged a plan to overcome the aforementioned dilemma and find a way to produce gastight laser-welded seams with aluminum. It was time to eliminate the pores!


Author: **Dr. Mauritz Möller** is a welding engineer and works for TRUMPF Automobile Sector Management. He was involved in the development of the multifocus welding system. Contact: +49-7156-303-34604, Mauritz.Moeller@trumpf.com

Top and bottom: X-ray images of weld seams



With a single focus, an aluminum keyhole regularly collapses and traps gas pores in the weld seam. These pores render the seam less gastight.

> *"EV manufacturers can now create gastight welds with aluminum."*

INTO THE FIRE AND STEAM Analyses with external R&D partners showed us the way forward. We examined the deep, narrow hollow that is created during welding as the metal melts and vaporizes under the heat of the laser. The resulting vapor forces the molten metal sidewards and downwards. This creates a deep, narrow, vapor-filled cavity known as the keyhole. As the beam travels through the metal, molten metal flows around the keyhole and solidifies in its trail to form a seam.

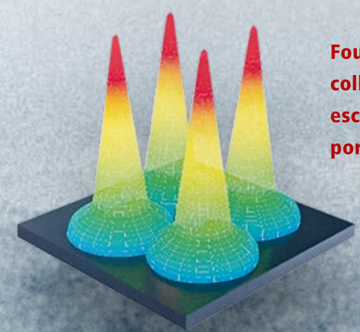
As long as the keyhole remains stable, everything is fine. However, any fluctuation in the degree of laser power on the inner wall of the keyhole leads to variation in the diameter of the aperture. Should this aperture become too small, the following occurs: some of the vapor can no longer escape and forms a protuberance on the back wall. In turn, this interruption in the gas flow creates negative pressure, causing molten metal to collapse into the keyhole and trap vapor. This leads to the formation of gas pores. This can happen with any material. But, with aluminum alloys, this occurs more quickly, easily and frequently than with steel, for example.

KEEPING THE KEYHOLE OPEN So what can be done when the keyhole becomes too small? Easy! Make it wider. And when fluctuations in laser power threaten collapse? The answer then is to ensure greater stability. In both cases, the solution starts with BrightLine Weld, our proven beam-shaping system. This delivers a much more stable process by splitting the laser light in the light cable between an inner and an outer fiber core, thereby optimizing power distribution for high-speed welding. Yet this is only the preparation for the real trick, which is performed by the optical system.

This splits the laser into four individual spots, which form a square and are arranged in such a way that their effective radii overlap. The aim, after all, is not to create four small keyholes, but a very large one. Because the laser has already been divided between the ring and the core, each of the four individual spots is able to make extremely efficient use of the available power. With laser power now distributed evenly across the entire area, the keyhole remains open and allows vapor to escape. As a result, no molten metal collapses into the keyhole, no vapor is trapped and there is no formation of gas pores.

In a clear sign of the success of the multifocus system, the keyhole area is now ten times as big. What's more, the dimensions of the melt pool fluctuate by only seven percent as opposed to 50 percent. As a result, the process is much smoother.

Tests and measurements show that the new multifocus system is almost 100 percent reliable when it comes to producing gastight seams. And it is also very fast. At present, we are operating at speeds of up to 15 meters a minute. In the lab, however, we are already running tests at 30 meters a minute. Our development partner Benteler is now looking forward to launching production on the basis of this patented technology. After all, demand for laser-welded aluminum casings for power electronics and battery cooling plates is set to be huge. ■



Four laser spots prevent keyhole collapse, so that all the gas can escape. The resulting seam is pore-free and perfectly gastight.

TRUMPF

“Sometimes it’s good to be small”

Gediminas Račiukaitis is president of the Lithuanian Laser Association. He explains how such a small country was able to build up such a strong reputation in this field.

Gediminas Račiukaitis feels at home in the streets of the Lithuanian capital, Vilnius. He hopes that laser technology will persuade young Lithuanians to make a home in their own country.

Tadas Kazakevičius | Fotogloria

Mr. Račiukaitis, are people surprised when you tell them about Lithuania’s laser industry?
Yes, it happens all the time.

Why is that?
We’re a small country of not even three million inhabitants, a former Soviet republic that joined the European Union less than 20 years ago. We’re used to people underestimating us. But we’ve had laser technology since 1966—longer than most other countries in the world.

Why so long?
Basically, Lithuania’s laser industry can be traced back to three students who were all sent

to Moscow in 1962 to study quantum electronics—and, with it, the emerging field of laser technology. They helped fire the first laser in Lithuania in 1966 and went on to found the Laser Research Center at Vilnius University and the Center for Physical Sciences and Technology—which is where I am now head of the Department of Laser Technologies. Anyone in Lithuania with anything to do with lasers has some sort of connection to at least one of these bodies, and usually to both of them. They're only 20 kilometers apart. Commercial lasers for science have been built in Lithuania since 1983.

What's the situation in Lithuania's laser industry right now?
We've more than 50 companies manufacturing lasers or optical components for lasers. Together, they employ around 1,400 people and generate annual revenues in the region of 176 million euros.

That's not a lot.
No, it's not. But if you have a mobile phone, you can be pretty sure it contains a part that was made by Lithuanian USP lasers. For certain high-tech systems, our small country can hold its own with the U.S., China or Germany.

What do these companies make?
We've always been a strong player in the field of scientific lasers. Right now, we're working on some of the most intense lasers in the world, as part of the Extreme Light Infrastructure (ELI) project, a European research initiative. It's around 15 years since the first Lithuanian companies began producing lasers and optical components expressly for the industry. Our market breakthrough was the commercialization of the USP laser—an area where we've played a strong role from the very beginning. These days, we've a whole spectrum of manufacturers producing lasers and laser-processing machines, or optical components such as coated lenses, or optical parametric oscillators. OPOs are used to convert and amplify laser light. Ninety percent of all OPOs sold worldwide are made in Lithuania. There are also a number of contract manufacturers operating here—companies with laser machinery who provide high-end laser-processing services such as glass cleavage. Right now, several companies are moving into medical engineering.

What is Lithuania's flagship product in the laser market?
If I had to choose an area, then it would be OPCPA, a technology that is used to amplify ultrashort laser pulses. Lithuanian companies have played a strong role in this field for a long time. In general, when it comes to USP lasers and their components, we're competing on even terms with the rest of the world. For me, that's great to see, because these are all cutting-edge technologies that will enable us to build lasers of ever-greater intensity.

"If you have a cellphone, there's every chance that some of the components were manufactured with a USP laser made in Lithuania."

And who do you sell all these products to?
They all go abroad. Sadly, there aren't many Lithuanian companies that use laser technology in their manufacturing. That's a drawback compared to Germany, for example, where there are lots of opportunities to meet up with companies and even take a look at their production facilities. That makes it much easier to sound them out and find out what they really need. Here, in Lithuania, we're also looking at ways of getting more feedback from end users. But since they don't come to us, we have to go to them. Right now, the Lithuanian Laser Association is organizing a visit to companies in Korea and Taiwan.

What's the secret behind Lithuania's success in laser technology?
That sometimes it's good to be small. It means that we all know each other personally. Most companies are spin-offs from the leading institutes, and most of the company founders and workforce are of the same age as the people from the other companies and the institutes and know each other because they all studied together. It's very common to move from academia to industry and back again. As a result, research and development at the institutes are strongly geared toward what companies actually require. In the laser community, we all trust each other—even across company boundaries. Sure, we're still market rivals, but companies here tend to work together rather than against one another. In the photonics world, I'd say that's pretty unique.

Profile: Gediminas Račiukaitis is head of the Department of Laser Technologies at the Center for Physical Sciences and Technology in Vilnius. His research interests include the laser-induced generation of high-energy electron beams and selective metallization by laser for applications in electronics. He is also president of the Lithuanian Laser Association and has been involved in the development and growth of the country's export-led laser industry from its earliest days.

Tadas Kazakevičius | Fotogloria

How does the country itself benefit from Lithuania's remarkable success in the photonics industry?
Well, first of all, in ways you might expect: it gives us a stronger economy, global prestige … But there's also something else, even more important: a home for my fellow Lithuanians.

What do you mean by that?
In Lithuania, when it comes to choosing a career, people often look abroad. Ideally, you study at Oxford—no matter the subject, no matter how successful—and then go on to work in Sweden or in Germany. For some people, that's great. But, in the process, you end up losing your roots, and many people are unhappy about this. The fact that Lithuania has a flourishing laser industry means that young people are now able to imagine having a bright future for themselves back home, complete with an exciting and well-paid job. That's the best way of stopping the brain drain. It's something I see year after year: the desire to stay at home, here in Lithuania.

Where do you see it?
Each year, 40 out of 50 of the new intake of physics students opt to major in laser physics or laser technology. Things are quieter in the corridors of the other physics departments because there is no collaboration with industry there. Of course, even without that, laser technology is still a great field. But primarily, it offers great prospects. And young people recognize that.

What does the future hold in store for laser technology from Lithuania?
Over the period from 2009 to 2021, our photonics industry grew year on year by 16 percent. That's huge growth, and I see it continuing at a similar level. In turn, this will mean tapping into more markets, so that there is an outlet for this growth. Our job, at the Laser Association, is to help make this happen. As for new applications of this technology, I see good opportunities in the fields of optical and quantum optical communication. In fact, I'm already seeing the first evidence of commercial activities in this direction. And, soon, there will be more on the way.

Do you have any advice for other countries?
If you don't use lasers in science and industry, then everything eventually grinds to a halt. Everything goes dark. ■

Thailand

VIEW ON THE ECONOMY

WELCOME TO LASERLAND THAILAND!

Thailand's industry is the **most powerful in Southeast Asia**. Companies in this sector are clustered in and around the capital, Bangkok. Other parts of the country are not heavily industrialized.

The major sector is the **automotive industry**. Specifically, Japanese OEMs (Toyota, Honda, Mitsubishi, Nissan) manufacture here, as do Ford and Chinese automakers, with a combined output of around **2.5 million vehicles** a year.

Thailand boasts a correspondingly healthy **automotive supply industry**, with the Thai Summit Group as the largest player.

Nominal GDP per capita

7,168
U.S. dollars

45%

Industry as a proportion of GDP

70m
inhabitants

LASER TECH IN THAILAND

Among automakers and suppliers alike, demand is high for **3D laser-cutting machines** — to produce bodywork parts, for example.

In Thailand, **EV production** is now being ramped up. Mercedes-Benz manufactures batteries here, and BMW assembles five different plug-in hybrid models, both of which will boost demand for certain kinds of laser machine.

Companies in Thailand are primarily investing in **high-power laser** machines.

nukul2533 / AdobeStock, Ford, Gernot Walter

WHERE'S THE LASER?

In a strong back. Netflix and all the other streaming services are the couch potato's best friend—and natural enemy of a healthy back. And there's also nature to contend with: from the age of 30 onward, disc degradation sets in—and, with it, all kinds of back ailments. Regular workouts are a big help here. But be wary of doing too much, too soon! Rushing into training unprepared can cause major injury. Fitness equipment such as Smart Strength from EGYM is great for workout newbies. These machines adapt to the training requirements of each user and feature onscreen animations to show whether the exercises are being correctly performed. The frame is made by specialist metal fabricator Steinhart from southern Germany, using laser tube-cutting and combination punch-laser machines. So, get off the couch and get down to work with your very own smart personal trainer! ■

Olesja Sidorenko / AdobeStock

OPTICAL MICROPHONES have a greater dynamic range than conventional mics. How? A combination of laser diode and interferometer accurately measures even the smallest vibrations of a silicone membrane—all without any self-noise from the microphone itself. Produced by Norwegian company sensiBel, this technology takes up a mere cubic millimeter in volume and is perfect for cell phones, headsets and similar devices. Now you can record street concerts, conversations and video soundtracks in studio quality for all eternity.

Felix Koutchinski / unsplash