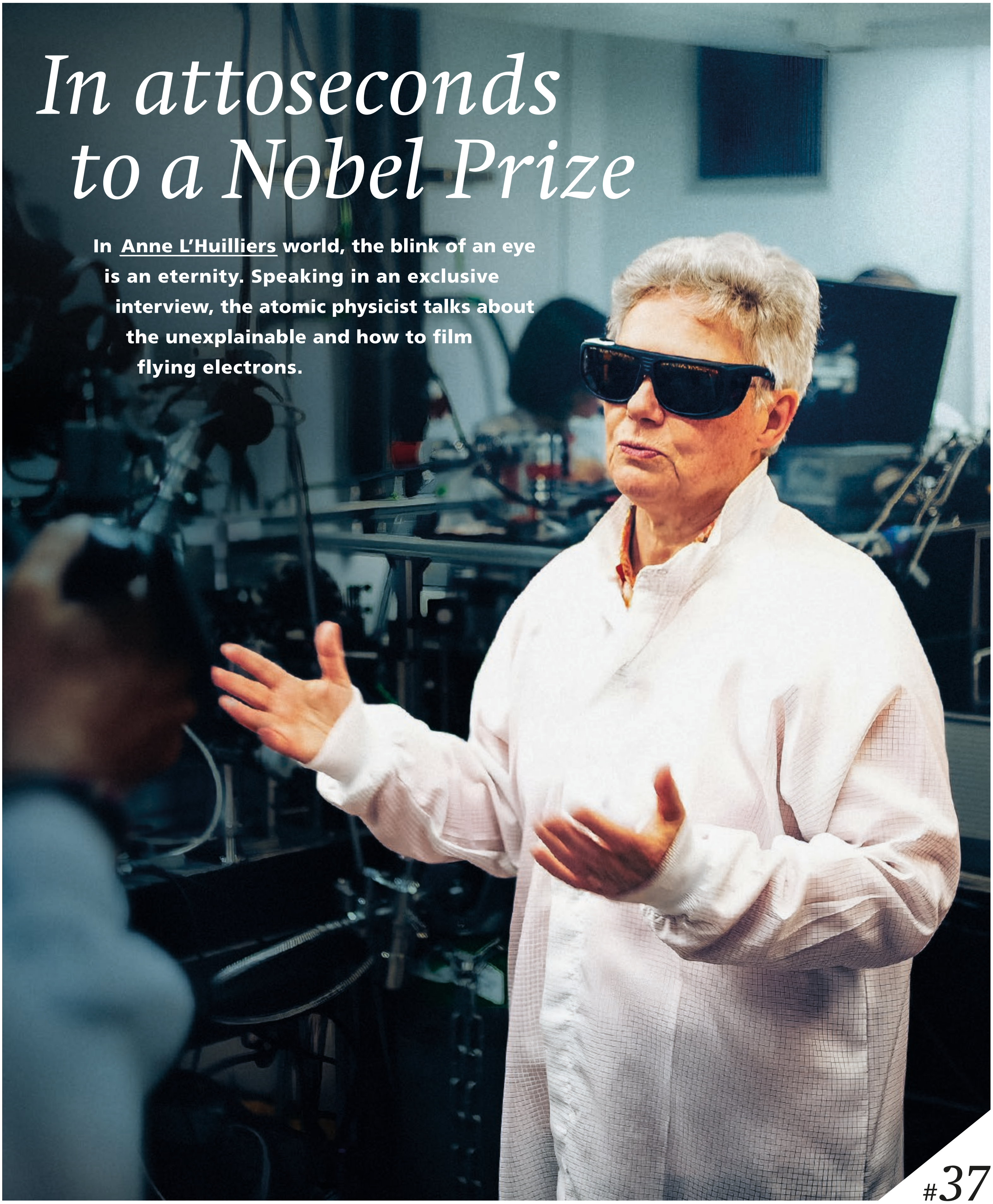
LASER COMMUNITY.

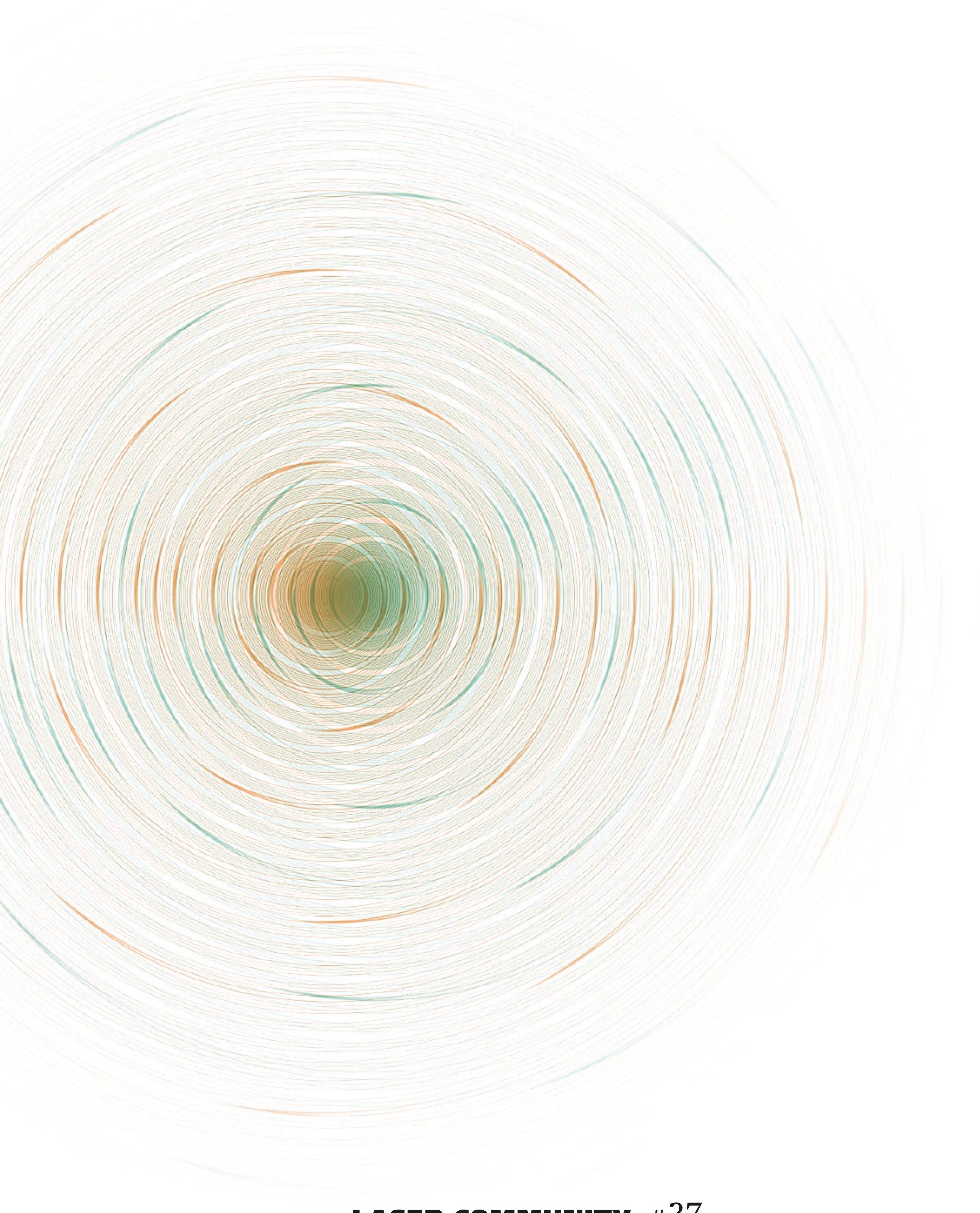
Of people and photons



In attoseconds to a Nobel Prize

In Anne L'Huilliers world, the blink of an eye is an eternity. Speaking in an exclusive interview, the atomic physicist talks about the unexplainable and how to film flying electrons.

#37



LASER COMMUNITY. *#37*

ISSUE Autumn 2023 **PUBLISHER** TRUMPF SE + Co. KG, Johann-Maus-Strasse 2, 71254 Ditzingen, Germany; www.trumpf.com
RESPONSIBLE FOR CONTENT AND EDITOR-IN-CHIEF Gabriel Pankow, phone +49 7156 303-31559, gabriel.pankow@trumpf.com
DISTRIBUTION Gabriel Pankow, phone +49 7156 303-31559, gabriel.pankow@trumpf.com, www.trumpf.com/en_INT/newsroom/customer-magazines
EDITED BY Die Magaziniker GmbH, Stuttgart, Germany; Florian Burkhardt, Martin Reinhardt
CONTRIBUTORS Florian Burkhardt, Thilo Horvatitsch, Martin Reinhardt, Maria Seidenkranz, Sebastian Stamm, Sue Strickrodt
PHOTOGRAPHY AND ILLUSTRATION Fiumu, Tobias Gerber, Jan Hosan, Florian Jaenicke, Maximilian Schlosser, Marta Soul, Gernot Walter
DESIGN AND PRODUCTION Die Magaziniker GmbH, Stuttgart, Germany; Gernot Walter (AD), Martin Reinhardt **TRANSLATION** Apostroph Group, Hamburg **REPRODUCTION** Reprotechnik Herzog, Stuttgart, Germany **PRINTED BY** W. Kohlhammer Druckerei GmbH + Co. KG, Stuttgart, Germany

Cover page: Maximilian Schlosser; illustration page 2: Gernot Walter

Dear Readers,

Who isn't fascinated by the night sky? Constellations of stars, the Milky Way, the moon. Thanks to the technological advances of recent decades, such as research satellites, the depths of the universe seem closer than ever. With their light, stars now reveal many exciting physical properties, like their temperature or chemical composition. The innovation of German researchers Hartmut Grote, Henning Vahlbruch, and Benno Willke now makes it possible to gain an even more detailed insight into space. These three laser physicists enabled the measurement of gravitational waves, thereby demonstrating the existence of black holes for the first time. We report on this pioneering development *on page 23*.

On page 26, you can read about a possibly even more spectacular breakthrough in the field of laser physics. In 1925, the famous scientist Werner Heisenberg posited that it is not possible to observe the position and orbitals of an electron within a hydrogen atom. The electrons are simply too fast, moving at a speed of attoseconds. For many years, no one doubted this theory until Anne L'Huillier achieved the impossible. In 1987, L'Huillier discovered the "overtones" of light, which appear when infrared laser light passes through an inert gas. Research into this phenomenon enabled further experiments and breakthroughs and the generation of ultrashort pulses of light. Although her work did not make it possible to visualize the exact position of electrons, it did allow us to see the dynamics of electrons within atoms and molecules. In recognition of her outstanding research, L'Huillier was awarded the Nobel Prize in Physics in 2023, together with Pierre Agostini and Ferenc Krausz—what a phenomenal lifetime achievement! I am delighted that the freshly crowned Nobel laureate agreed to talk to us about her work in an exclusive interview.

This issue is, however, also full of examples of practical laser applications. Take, for instance, ElringKlinger, a company that uses our femtosecond lasers for surgical applications to process endoscopic tubes made of Teflon. Or automotive supplier Webasto, who has put its trust in green wavelength lasers when welding copper parts for electric vehicles.

Whether you are exploring the boundaries of physics, using laser technology to make safe and suitable products for everyday use, or simply wish to immerse yourself in the fascinating world of photonics, I hope you enjoy reading this issue.

DR. RER. NAT. HAGEN ZIMER

Chief Executive Officer Laser Technology

Member of the Managing Board of TRUMPF SE + Co. KG

Film

To mark the award of the Berthold Leibinger Zukunftspreis to laser physicist Anne L'Huillier, a video has been made about her research. *Laser Community* was there to witness—and photograph—the shoot. The film can be viewed at: **you.tubeGazhEf8tcf0**, and the article read here: from **page 26**.

Camera

Looking for a photographer for our story in South Yorkshire, we came across Marta Soul. Photo art is more her thing. Luckily for us, she agreed to try her hand at industrial photography. Judge the results for yourself on **page 24**.

Image

We asked Vahid Babaei if color laser marking could also be used to recreate the cover of the last edition of *Laser Community*. "Sure!" he replied. We've therefore hung him a digital version on the wall—see **page 20**.

Max-Planck-Institut Saarbrücken, Marta Soul, Maximilian Schlosser

LASER

Die Magaziniker & KI, Fotogloria | Tobias Gerber

CONTENTS

COMMUNITY.

FEATURE

10 YOU HAVE A MATCH!

On the hunt for new partners, more and more automotive suppliers are hooking up with med tech manufacturers. No wonder—thanks to laser technology, they've got exactly what the other's long been looking for.

6 Three cheers for a warm EV

Webasto uses three high-tech laser processes to create the optimal heating system for EVs.

17 Safer disposal of unexploded bombs

Lasers help clear the hazardous remnants of war.

18 AHEAD

A new software has now enabled color laser marking.

20 Putting the brakes on particulate matter

Advances in high-speed laser metal deposition (HS-LMD) save money and reduce abrasion of brake disks.

22 POWER

3D-printed copper can give CERN cheaper particle accelerators.

23 GLORY

Using squeezed light, three German researchers have helped astronomers see more of space than ever before.

24 Working-class hero

Peter Brown has big plans for an AM job shop—and his very own 3D-printing empire in the UK.

26 *"The easiest way to picture an attosecond?—You can't."*

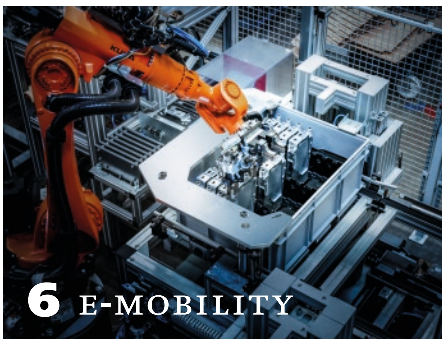
Anne L'Huillier, recently awarded the Nobel Prize in Physics, explains how research with the world's shortest laser pulses can help advance knowledge.

30 LASER LAND

Laser tech in Ireland.

31 WHERE'S THE LASER?

In the leap of a mountain bike.



6 E-MOBILITY

17 BOMB DISPOSAL

26 LASER PHYSICS

FIUMU, Gernot Walter, Maximilian Schlosser

3 CHEERS FOR A WARM EV

One of Webasto's laser tricks: scanners use ultrashort laser pulses to ablate material from a thin layer of metal.

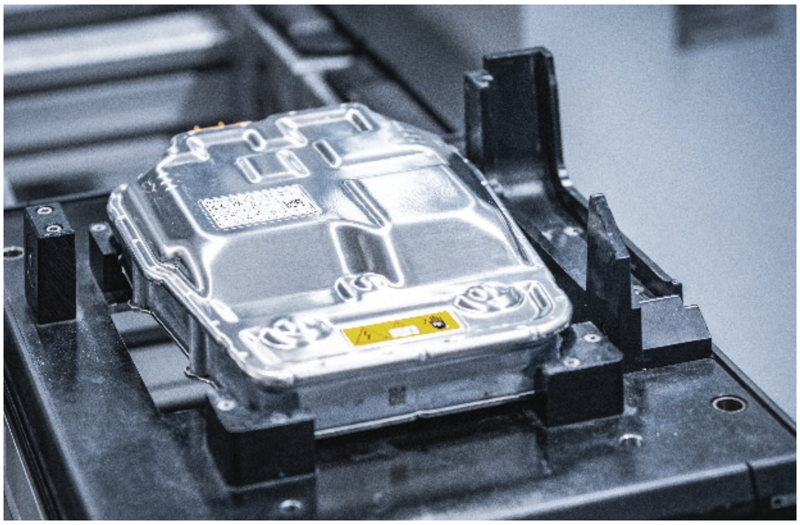
FIUMU

The heating system in an electric car is a complex feat of engineering and crucial to the vehicle's performance. By using three high-end laser applications, the German automotive supplier Webasto has taken this vital component to a new level.

When you're buying a new electric vehicle, you never give a second thought as to whether the heating works. You take it for granted. The heater in an EV is not only there to provide a warm and cozy interior, or to clear the windows of frost and condensation in the winter. Equally important, it also enhances the efficiency of the battery, which operates best within a certain temperature range.

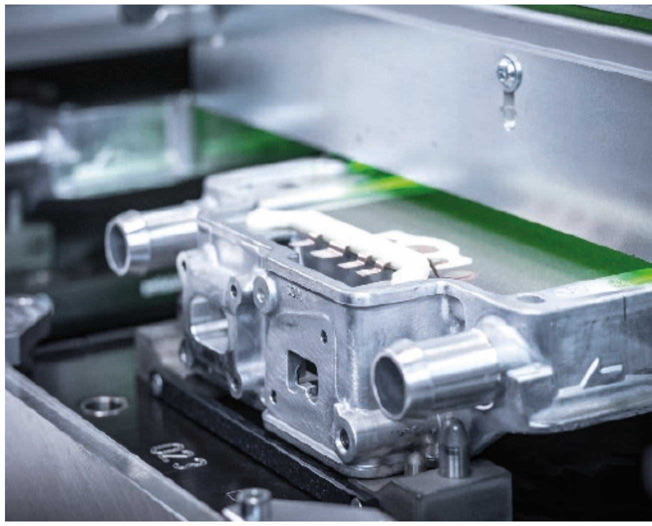
Unlike an internal combustion engine, an electric motor does not produce any waste heat. An EV therefore requires an auxiliary heating system equipped with sufficient power. This uses electricity from the battery to heat a medium—either conventional coolant or battery oil—and thereby deliver warmth. As with any other EV component, the same golden rule applies to the heating unit: the lighter, the better; the smaller, the better. Leading the way on both these counts is Webasto, the market leader in automotive heating technology.

With its new high-voltage heater, the German manufacturer has now turned the dial a further notch. Designed to function with various EV system voltages and offering continuously adjustable power, this new development also helps stabilize the onboard electrical system. The innovative design and outstanding features are the result of three laser applications. →



“When it comes to welding copper, we only use green lasers. Nothing else.”

Jörn Schmalenberg, Webasto



LASER 1

GAS-TIGHT ALUMINUM WELDING

Jörn Schmalenberg is head of production engineering for the manufacture of electric heaters at Webasto’s factory in Neubrandenburg. This facility produces 95 percent of the heater components that the company makes for both ICE and electric vehicles: millions of units manufactured with reliable high-performance lasers and then shipped globally. “An EV heater works like any other heater: you warm a liquid via a heat exchanger and then feed it through pipes. Liquids and high voltages don’t mix. It’s therefore vital to ensure that the housing is as tight as a drum.” For this purpose, Webasto uses a lightweight housing made of die-cast aluminum. One way of creating gas-tight welds with this material is to use conventional electron-beam welding in a high vacuum. This is too expensive, however, as well as far too slow. Instead, the company uses a disk laser, which can be operated under atmospheric pressure and without a shielding gas. Ideally, this must operate as quickly and as powerfully as possible, the aim being to create a weld seam free of pores. If the laser dawdles at low power, this can cause pores to form in the material as it melts, with the result that the housing will not be gas-tight. “By using the 16-kilowatt TruDisk laser, we’re going for the sledgehammer effect, so that there isn’t any time for gas bubbles to form in the first place.” It is crucial that the laser creates as big a keyhole as possible. “A lot of laser power gives you a stable keyhole. The more you use, the better it is,” Schmalenberg explains. Webasto is very happy with the results right now but is also looking at the new Multifocus optics for this application. This splits the laser beam into four individual spots, which form a square in such a way that their effective radii overlap, thereby creating a very large keyhole. The laser power is spread evenly across the entire area of action, so that the keyhole stays open, without collapsing, and there are no pores.

LASER 2

CONNECTING COPPER WITH A GREEN LASER

Once the housing has been gas-tight welded, Webasto then connects up the heating elements. As a good electrical conductor, copper plays a key role here. “The mating parts, along with the copper, are highly reflective, which makes laser welding much more difficult,” Schmalenberg explains. Moreover, as with battery cells, the weld seams for the Webasto heating unit must not penetrate too deeply. Otherwise, this could damage the layers below. “We have to be able to precisely regulate the welding depth of the laser. A conventional infrared laser is of no use here.” TRUMPF’s green laser has a wavelength that is well absorbed by copper. Using the right pulse sequence, extremely accurate welding depths can be consistently achieved—free of spatter and without the need for a shielding gas. The TruDisk Pulse does this with a power of four kilowatts and pulse durations in the millisecond range. “We haven’t had a single defect in several million components,” Schmalenberg says. “That makes everything much more relaxed. We don’t use anything else for welding copper now—just a green pulsed laser. Infrared is passé.”

FIUMU

LASER 3

ULTRAPRECISE ABLATION

Once Webasto is satisfied with the copper welds, attention turns to the actual heating elements. This is where the company's very own thin-film technology comes into play. Rather than attaching separate conductors, Webasto simply etches them directly into a thin layer of metal. This makes the heater as flat as possible. "Extreme precision is required when etching the material, so that the laser doesn't go to deep and damage the layers below," says Schmalenberg, who uses a TruMicro ultrashort pulse laser for this purpose. "The aim is clean ablation and precise edges. It's vital to avoid any melting, as this can cause defects. The USP lasers take the material directly from a solid to a gaseous state. Without them, we'd be unable to achieve such a flat product design."

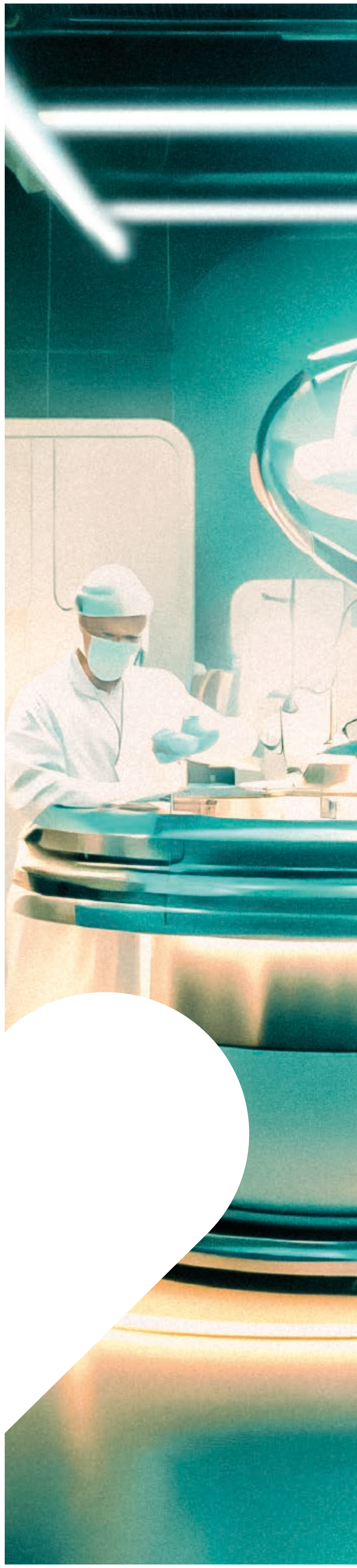
→ Making the heating unit super flat means it can be installed very close to the components that carry the coolant. "This proximity ensures an extremely fast response time when heating the coolant. What's more, the special design means that heating power can be almost continuously regulated—both at 400 and 800 volts. We were the first to offer this," says Schmalenberg proudly. During voltage peaks, the heater also functions like a small capacitor and therefore helps stabilize the onboard electrical system.

Manufacturing in a high-wage country like Germany demands a high degree of automation and innovation. For a company like Webasto, that means using advanced laser technologies. As Schmalenberg explains, this makes Webasto a preferred partner worldwide: "It's safe to say that not many of the EVs produced around the world roll off the assembly line without featuring first-class electrical components from European manufacturers like us." ■

Contact: Webasto Group, Jörn Schmalenberg,
Manufacturing Enigineering, phone: +49 395 5592-276,
joern.schmalenberg@webasto.com

Jörn Schmalenberg and colleague Knut Hoffmann can afford to look happy: they make the best heating systems for electric vehicles.

WEBASTO manufactures and markets a range of components for the automotive industry. The company is a long-established player in this sector and operates from over 50 locations worldwide. With a 70 percent market share in Europe, Webasto is the world market leader for heating systems for ICE vehicles and for innovative roof systems. It has been supplying the e-mobility market with EV heaters, batteries and charging solutions since 2012. To ensure a steady stream of new ideas that swiftly make their way to market, Webasto collaborates on various projects with the Schweißtechnische Lehr- und Versuchsanstalt (SLV) and with Fraunhofer IGP in Rostock.

Die Magaziniker & KI

YOU HAVE A MATCH

Traditional automotive suppliers are looking for a new, long-term market. Med tech manufacturers are looking for someone who's reliable and understands their needs. Thanks to laser technology, they're a perfect match.

Were there a Tinder dating app for industry sectors, then automotive suppliers would be seeing an uptick in matches from med tech manufacturers. After all, the medical technology sector offers everything the supplier's heart desires: high growth, big profit margins, robust forecasts for the coming years, stable revenue streams. By contrast, the giant automakers—their traditional end customer—are in the midst of a major transition to e-mobility. Right now, they're more concerned with developing new onboard software than securing a supply of enhanced brake hoses. For the established suppliers, that poses a number of uncomfortable questions: What will they still be selling to the OEMs tomorrow? And at what price? Little wonder that the automotive suppliers and ancillary engineering companies are busy looking for a secure source of revenue for the coming years. So, when a potential partner from the med tech sector appears on the dating-app screen, some are quick to swipe right!

AUTOMATION AND PRICE PRESSURE Med tech, for its part, is not averse to a new date—a new partner that understands its needs. Any potential mate must be able to handle complex development processes as well as plenty of documentation and regulatory compliance. And they need to deliver products with a long life cycle as well as guarantee maintenance and spares availability over the coming decades. Automotive suppliers have mastered this art from many years of experience in their core business.

Automation and volume production are becoming more and more important in med tech, where faster development cycles and booming demand have prompted a rethink. At the same time, recent years have seen an influx of new players with low-cost products. For the established companies, this means unit price has become a key factor in the fight to secure market share. High volume combined with efficient production—who better to provide this than seasoned automotive suppliers?

HIGHLY RELAXED Stephan Kowalski, from the newly established Center of Excellence Medical at Grob-Werke, a manufacturing system and machine tool provider with major customers in the automotive industry, thinks the same: "We know all about med tech's stringent requirements regarding product safety and availability. With all our years of supplying the automotive industry, we've a whole range of methods up our sleeve for essentially eliminating machine downtime—the nightmare of any carmaker." And, thanks to his experience with projects in the safety-critical aerospace industry, Kowalski is highly relaxed about being able to meet med tech's requirement for comprehensive documentation and 100 percent product quality. "That's why we began taking a closer interest in this sector around two years ago."

What Grob needed back then was a strong business case and an equally strong partner. That's how it came to team up with TRUMPF. The idea was to create a fully integrated production line—comprising 3D printing, milling and laser marking—for the highly efficient manufacture of artificial knee joints.

NEW LASERS FOR SUPERFINE TUBES In the town of Bietigheim-Bissingen, some 200 kilometers away, Fabian Kopp, a product development manager at ElringKlinger, had a similar plan. His idea was to use laser technology to make med tech products cheaper to manufacture and also to add new laser-generated features.

Like Grob-Werke, ElringKlinger is a major automotive supplier. Its core products are components for drive, transmission and thermal-management systems. "Here, at the plastics technology group, we've supplied medical technology manufacturers with various hoses in the past, but we've never actively pitched our own product ideas," Kopp explains. "But we intend to change that." This comes in response to the growing use of endoscopy in healthcare procedures. Here, the surgeon inserts into the body of the patient a long thin tube containing the various surgical instruments required to perform the operation. Such a procedure avoids the need to cut open the patient and thereby speeds recovery times. This is already common practice for abdominal and intestinal operations. And now surgeons are beginning to employ the technique for procedures in narrow blood vessels, nerve pathways and even the brain. The tubes for this have to be much thinner than the ones used in gastrointestinal surgery—so thin, in fact, that it is impossible to produce them mechanically. Like Kowalski, Kopp went looking for a suitable partner; and, like Kowalski, he ended up at TRUMPF.

TWIN PROCESS FOR NEW KNEES Back at Grob, Kowalski was busy working on his artificial knee joint. His idea? To use a 3D printer to batch-produce the basic form of the joint out of a cobalt-chrome or titanium alloy. This is then transfered to a 5-axis milling machine. As Kowalski explains: “With artificial joints, surface quality and efficient manufacture are vital. The surface quality has to be perfect, so that the artificial joint doesn’t cause discomfort and lasts as long as possible.” For this purpose, a team at Grob has developed, together with partners, a special concave barrel cutter. This mills the functional surfaces to a surface quality better than anything achievable with rival processes. What’s more, it takes only half as long—only 30 minutes per knee joint.

“Our customers are reacting to price pressures in the industry. In China, for example, there’s a new group purchasing organization that has pushed down implant prices by around 80 percent. That’s why all the mainstream med tech manufacturers are looking to introduce new processes and cut unit costs!” says Kowalski with a grin. “We’re well used to dealing with such demands from the automotive industry. We know that we can deliver.”

REVERSING TEXTBOOK WISDOM At ElringKlinger, meanwhile, Kopp was busy explaining to experts from TRUMPF the specifications required for his superfine endoscopic tubes. Some of these tubes

CONTINUED ON PAGE 16

“The price of prosthetics has fallen by as much as 80 percent in recent years! Mainstream med tech manufacturers are therefore looking to cut unit costs. We’re well used to dealing with such demands from the automotive industry.”

Stephan Kowalski, head of medical technology at the engineering company Grob-Werke in Mindelheim

Fotogloria | Florian Jaenicke

The new art of laser therapy: an increasing use of laser technology in the medical arena is improving both diagnostics and treatment. Six examples of the present and future.

SEED LASERS FOR KIDNEY STONES

Industrial seed lasers happen to have a wavelength that is very efficiently absorbed by water. This opens up interesting surgical applications, including the treatment of kidney stones. Using an endoscope, the surgeon guides a laser fiber to the kidney stone. A laser flash vaporizes the liquid around the stone, thereby creating a precisely localized pressure wave that destroys it.

MARKING LASERS FOR TISSUE ANALYSIS

In combination with a precision scanner, a femtosecond laser is used t o remove tissue samples directly under a scanning electron microscope. This tissue removal is contact-free and can be either fine or planar in any geometry. This makes it faster and easier to retrieve tissue samples for examination in the life sciences and for diagnostic purposes.

VCSELS FOR MEASURING BLOOD SUGAR

So-called VCSELs—tiny laser diodes on a semiconductor—are a common component of smartphones. Placed on the skin, they can also detect glucose molecules in the blood and thereby measure blood-sugar levels. For diabetes sufferers, that means no more pinpricks. Such devices will soon be so small that they can be worn on the wrist like a watch.

ALREADY HERE

COMING SOON

LASER IONIZATION FOR BREATH DIAGNOSIS

Using the MALDI technique, a laser can ionize specific molecules in the air and thereby make them measurable. Work is underway on devices capable of detecting molecules indicative of certain diseases. All the patient will need to do is briefly blow into the device. Mobile applications are also considered feasible.

LASER-INDUCED RADIATION FOR CANCER THERAPY

Laser-driven proton accelerators are much cheaper than conventional ones—and small enough to be installed in every hospital. The radiation effectively targets cancer cells without the risk of patients suffering severe side effects of radiation therapy, as may still be the case today.

QUANTUM SENSORS FOR NERVE-CONTROLLED PROSTHETICS

Laser-driven magnetic field sensors based on quantum physics are so sensitive that they can measure even the smallest changes in a magnetic field—including electrical nerve signals. The technology already works, and now tests are being carried out to use measured nerve signals to control prosthetics.

Die Magaziniker

have to be thinner than one millimeter in outside diameter but still contain inner channels for a camera and surgical instruments. In addition, the tubes require tiny holes in the walls, through which the surgeon can spray medication and the like. “The difficulty here,” says Kopp, “is that you can’t drill holes fine enough without also damaging the partition wall that separates the three inner channels.” And there’s another problem with mechanically drilling the holes: “It leaves rough edges that cause the tube to snag when it’s being fed through narrow blood vessels or nerve paths.” Kopp’s answer here was to try lasering the holes—an idea by no means as evident as it would be to a metalworker. “All the manuals say it’s practically impossible to laser polymers,” Kopp explains. “Either nothing happens, or the polymer burns uncontrollably.”

The polymer in question is PTFE, better known under the brand name Teflon. This is the only plastic suitable for this type of endoscopy—essentially because of its nonstick, nontoxic properties. The team at TRUMPF promised to take another look at lasering polymers. Soon after, they asked Kopp to drop by. “I was blown away by the results—that’s how good they were,” he says. By using stable femtosecond pulses, TRUMPF reversed textbook wisdom. With a wavelength that is well absorbed by PTFE, a femtosecond laser produces incredibly precise, burr-free holes with smooth and rounded cutting edges. “That was the moment I knew we could do amazing things with lasers and shift from being a component supplier to becoming a technology partner to the med tech industry.”

One of Kopp’s ideas is about how best to make the bendable sections in endoscopic tubes. Conventionally, this is achieved by wrapping the entire tube in a metal mesh except for the parts where it has to be able to bend. “Using a femtolaser, we can now ablate material from the surface of the PTFE tube at the point where it has to be bendable,” he explains. “In future, we might be able to dispense with the metal mesh entirely—which is anyway an additional risk factor in surgery. It would also make the product less expensive as well as better for the patient.”

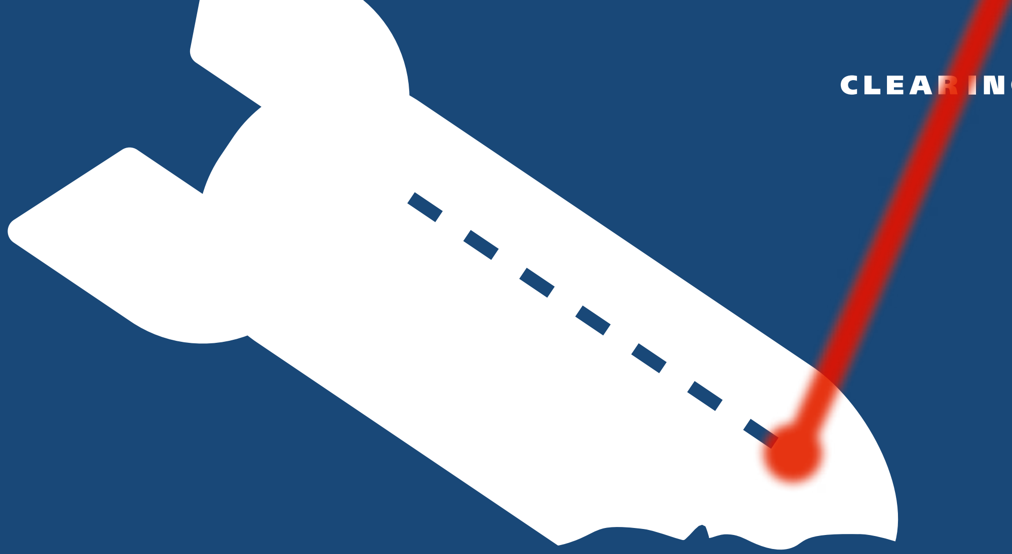
Grob and ElringKlinger are both confident that innovative laser power can help them deliver the very best for their new customers. Indeed, it looks very much as if the current fling between automotive suppliers and med tech manufacturers might grow into a long-term thing.

Contact: Bernd Block, Industry Manager Medical Technologies at TRUMPF, phone: +49 7156 303-35903, bernd.block@trumpf.com

“I was blown away by the results. That was when I knew we’d be able to do amazing things with lasers and become a technology partner to the med tech industry.”

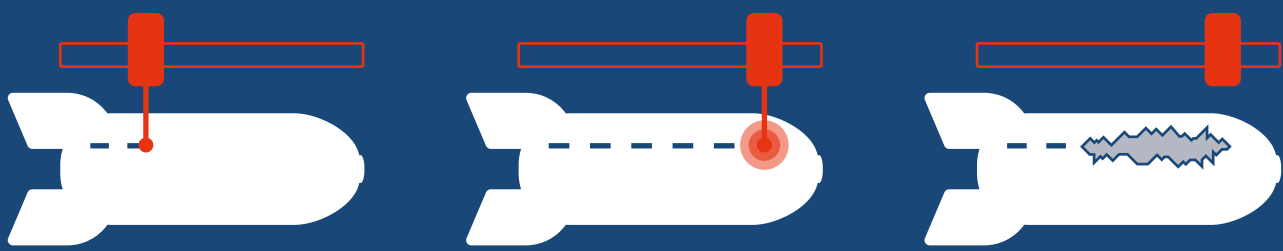
Fabian Kopp, development manager at ElringKlinger Kunststofftechnik in Bietigheim-Bissingen

Fotogloria | Tobias Gerber



Safer disposal of unexploded bombs

In the aftermath of military conflict, unexploded bombs can lie undetected and remain a deadly hazard for many years to come. Now, lasers are being used to defuse these bombs more easily and more safely than was previously possible.



01

Weaken the bomb casing

Bomb disposal experts use a linear-guide carriage to position the laser cutting head against the bomb. If the bomb is under water, this is done with a diving robot. The laser beam cuts a long groove in the steel casing—as deep as possible but gaged so precisely that it does not penetrate through to the explosive charge within or detonate it on account of the excessive heat input. The creation of a predetermined breaking point in the bomb casing substantially reduces its explosive power.

02

Trigger deflagration

At the end of the axis, the laser beam now penetrates the casing. This heats the explosive within so quickly that the gases thereby produced rapidly combust rather than detonating, in a process known as deflagration. The resulting pressure wave is thereby reduced and dissipates mainly via the predetermined breaking point created by the laser. Underwater, in particular, bomb disposal experts try to control this process so precisely that only part of the explosive burns and the detonation chain is interrupted. This further reduces the pressure wave.

03

Dispose of harmless bomb fragments

All that remains is the split casing, which has been ruptured in a controlled manner, plus traces of the burnt explosive. The process is safer because no one needs to risk their life trying to remove the detonator in advance of a controlled explosion. And it is easier because the pressure wave in laser-induced deflagration is much lower than in a controlled explosion. This reduces the scope and cost of the protective measures required to accompany bomb disposal.

Gernot Walter

WE HELP LASERS DISCOVER THEIR ARTISTIC SIDE

Vahid Babaei has developed a software that enables color laser marking.

Mr. Babaei, will your laser soon be holding an art exhibition?
Well, that's certainly a possibility! We can already use it to paint—or "mark"—very nice images on metal.

Painting with a laser—how does that work?
We've known for a long time that metals such as stainless steel or titanium change color under the application of heat. This can be used to create a number of colors. After all, a laser is nothing more than a targeted heat source. If the laser is properly calibrated, you can use it to paint an image on metal.

**Sounds logical, in theory.
But why isn't it already common in practice?**
The calibration process for color laser marking is very time-consuming. There's a lot of trial and error involved. You set the laser and then do a test. The results give you an idea of the calibration you need, and so you readjust the laser accordingly. You then carry on repeating this process until you get the color you want. For the next workpiece, however, you have to start all over again, because the parameters are now completely different. It's all very laborious, which is why it's not been economically feasible so far.

THE INITIATOR was initially at MIT in Boston before moving to the Max Planck Institute. In 2023, he was awarded the Curious-Mind-Forscherpreis. This recognizes scientists under the age of 40 whose work combines academic excellence with key impulses for the future German economy.

THE ENABLERS TRUMPF has been on board from an early stage, providing Babaei and his team with equipment and know-how. As a young company fresh out of the field of research, Oraclase is also a member of the federal German government's startup program EXIST, which provides funding of 800,000 euros.

AHEAD

An algorithm determines the correct parameters and automatically calibrates the laser accordingly.

But now you've developed algorithms for the job?
That's correct. It was a buddy of mine in Boston who gave me the idea. He was wild about a blue-colored motorbike exhaust pipe and asked me if there were any other colors available. That got me thinking: like a CMYK printer [editor's note: the standard color model for four-color printing], you really need only a handful of colors and a software capable of converting the desired image into these colors. And you should be able to do that with a laser. I then looked around to see if anyone was already doing this—there wasn't. In this area, at least, the paths of information technology and industrial manufacturing have barely crossed. So, my team at the Max Planck Institute and I developed algorithms for precisely this.

What do your algorithms do exactly?
First of all, an evolutionary exploration algorithm takes care of the trial-and-error part. It gets the laser to mark the workpiece on the basis of randomly selected parameters. It then evaluates the result and adjusts the parameters for the next run. This is done with the help of our sorting algorithm, which orders the process parameters for the colors according to which performs best with respect to specific characteristics such as resolution or saturation. The exploration algorithm then incorporates the best-performing parameters in its calculations and, on the basis of this incrementally optimized result, launches the next trial. The two algorithms repeat this process until no significant improvement is registered and the result is as close as possible to the original color.

And they can do this faster than human specialists?
Yes and no: depending on the level of difficulty, they are maybe just as fast or even slightly faster than the specialists. But, in the end, they are more precise and deliver better results. What's more, this means that the specialist can devote time to problems more complex than merely the laborious process of trial and error.

Is industry set to profit from this?
Color laser marking is only one example. I'm sure there's big potential for numerous other laser applications—cutting, welding, you name it. In principle, every application and every user can benefit from having a custom-developed algorithm to handle or assist with the calibration process. That's why we've set up own company, called Oraclase, to do further research into our algorithms and identify potential market partners. So far, things are looking good, and we've got big plans for the future! ■

Jan Hosan

THE TEAM The Max Planck Institute in Saarbrücken is one of the world's leading research institutes for computer science. With a focus on areas such as machine learning, visual computing, databases and programming, its researchers are taking computer science to new heights.

Author **Marco Göbel-Leonhäuser** works for Business Development Surface Technologies at TRUMPF and is spearheading the rollout of HS-LMD for brake disks.

Putting the brakes on particulate matter

The EU has launched a crusade against particulate matter produced by vehicle braking systems. With the automotive industry eager for a solution, TRUMPF has a key technology to hand: advanced high-speed laser metal deposition. This will make brake disks not only more ecological but also more cost-effective to manufacture.

It sounds absurd, but it's true: anyone who brakes often while driving is harming the environment and ultimately themselves. In one kilometer of a standardized test cycle, the brake pads of today's passenger cars abrade up to 40 milligrams of particulate matter from the coating of the brake disk. These particles are smaller than 10 micrometers in diameter (PM10), penetrate very deep within the lungs, and are extremely harmful to health. With figures for 2019 showing around 300,000 premature deaths a year in Europe from particulate matter emissions, the EU has now slammed on the brakes itself. The planned Euro 7 emissions standard aims to restrict particulate matter from brake abrasion to seven milligrams per kilometer—ideally, from July 2025.

But how can automakers best meet this new limit? The automotive industry is currently testing a highly promising solution: high-speed laser metal deposition (HS-LMD) to provide brake disks with a protective coating that reduces wear. TRUMPF has now advanced its version of this technology to industrial maturity and tested it together with development partners. The results show that brake abrasion and particulate matter emissions fall below the required limit. How has this been achieved? So much can be revealed: part of the secret is actually no secret at all—and TRUMPF literally conjured the rest out of a top hat!

Let's begin with the open secret: laser metal deposition offers an ideal approach. It has long been used to provide metal parts with a protective finish to guard against wear and

TRUMPF, Die Magaziniker & KI

corrosion. Here, a laser beam is used to generate a weld pool on the surface of a metal workpiece. Nozzles then spray a fine metal powder into this weld pool. The powder melts in the light of the laser and bonds indissociably with the base material. When finishing brake disks, this powder usually consists of a mix of stainless steel and ceramic or cemented carbide grains. With this coating, there is far less abrasion during braking. In its conventional form, however, the process itself is too slow for the production of millions and millions of brake disks.

FROM 0.5 TO 100 PER MINUTE The high-speed version of this process is much, much faster: here, the laser heats the powder immediately after it exits the nozzle, while on its way to the workpiece. This accelerates the process enormously, increasing the feed rate from less than one meter to over 100 meters per minute.

As important as line speed is to automakers, they also want a top-quality and cost-effective product. And this brings us to the second part of TRUMPF's secret: the efficient application of just the right amount of laser energy to an expensive metal powder. If the LMD machine applies too much energy—and does so in an uncontrolled manner—this can cause excessive temperatures in some areas of the material. This is very bad news for quality.

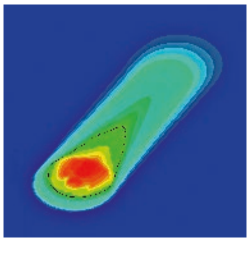
Beam shape determines the thickness of the coating and powder consumption.

Temperature peaks lead to cracks in the layers and to high residual stresses, which can even cause the brake disk to warp. Manufacturers do grind the disks at the end of the production process in order to correct any slight deformations. To facilitate this, however, the coating has to be a little thicker than is actually necessary. This in turn uses more powder, which drives up costs and reduces efficiency. The application of additional layers also introduces extra heat into the workpiece and increases the risk of deformation. Should the additives in the steel powder then melt, the coating can quickly become brittle and may even flake during braking.

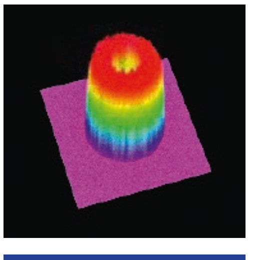
Some of these risks can be limited by using a specific beam profile that is known as a top hat on account of the three-dimensional representation of its energy-density curve. This beam profile applies the energy very evenly, without temperature peaks. This is already very good news. Even better, however, would be the ability to control the energy distribution within this top-hat beam profile.

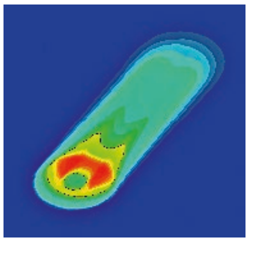
To achieve this, TRUMPF has refined the top-hat profile through the addition of an adjustable ring. With this patented beam-shaping technique, it is possible to apply different levels of energy per unit of area, both within the core and surrounding ring of a laser beam applied via a 2-in-1 delivery fiber. Furthermore, the level of energy per unit of area can also be freely controlled within these two zones. In other words, the amount of energy applied can be precisely increased or reduced according to what is required. As a result, productivity increases, while the risk of warping and cracking decreases. With the TRUMPF process, a thinner coating is therefore required—around 25 percent thinner than the market average. This in turn reduces powder use—a saving that TRUMPF has further increased with its patented high-performance nozzle complete with robust laser optics to ensure ultra-efficient powder feed and processing.

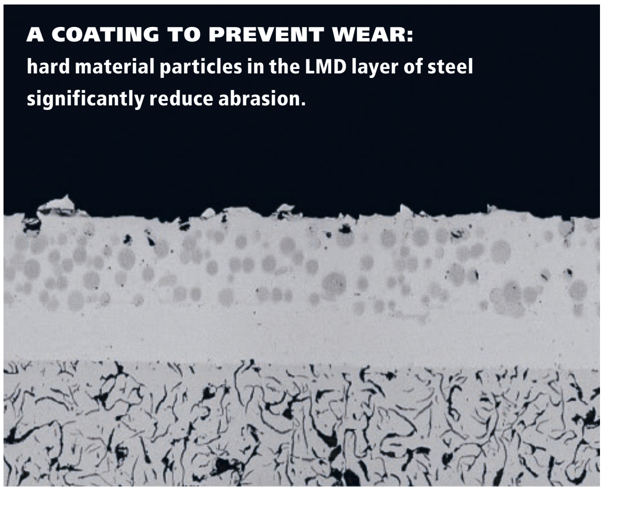
MILLIONS IN SAVINGS TRUMPF's process has won a host of awards and not only meets the new limits for particulate matter emissions but also reduces the risk of disk warpage to almost zero. Moreover, because the expensive metal powder makes up the lion's share of production costs, brake manufacturers can save millions of euros per year. And, last but not least, the environment profits too. ■



LEFT: The standard beam profile in high-speed laser metal deposition. **RIGHT:** Modified beam profile from TRUMPF with a 2-in-1 delivery fiber creating a controllable ring around the core. This provides enhanced control of temperature distribution in the workpiece, thereby preventing or minimizing welding errors (bottom right).







A COATING TO PREVENT WEAR: hard material particles in the LMD layer of steel significantly reduce abrasion.

TRUMPF

POWER

A radio frequency quadrupole in 3D-printed copper

GREEN LIGHT FOR CERN

Particle accelerators offer a key to learning more about our world and solving some important human problems. Yet they are also expensive. I.FAST, a project coordinated by the European Organization for Nuclear Research (CERN), is hoping to change that. Its secret weapon? A green laser.

At the European Organization for Nuclear Research (CERN), near Geneva, researchers use the most powerful particle accelerators in the world.

Researchers and engineers at CERN are looking for new ways to make particle accelerators more efficient and affordable. It is clear that there is now a big need for cheaper particle accelerators. They not only play a key role in fundamental research but also enable some of the wonderful advances that impact our everyday lives. In the field of medicine, for example, they are used in cancer therapy and diagnostics. Likewise, they help industry produce better semiconductors. At the same time, there are many other areas that no one has ever really considered on account of the still-astronomical costs.

The CERN project is focusing on a core component: the radio frequency quadrupole (RFQ). This highly complex piece of equipment accelerates the particle beam to almost the speed of light. At present, it takes a whole series of production steps to fabricate such a component, including milling, brazing and heat treatment. Not only is this laborious and expensive, but it also stands in the way of new and innovative designs. The ability to incorporate intricate surface structures, internal cavities and new forms of cooling channel would seriously enhance RFQ design. In other words, just the job for a 3D printer. That said, there are two problems with this approach. Firstly, the newly designed RFQ is made of pure copper, which is an excellent conductor but also a difficult material to use with laser-based 3D printing. Secondly, the part is approximately 40 centimeters in length—bigger than anything that has ever been additively manufactured from copper. The researchers turned to TRUMPF, which had just unveiled a large 3D-printing machine that uses a green laser. A green laser has a relatively short wavelength that is efficiently absorbed by copper. In other words, the copper powder absorbs enough of the laser energy for the machine to be able to print large parts with intricate structures at a uniformly high level of quality. For the first time ever, a RFQ was produced in a single piece. At the same time, researchers were finally able to implement their new design ideas. Furthermore, manufacture is much cheaper and faster. Are we therefore about to witness a particle accelerator boom? At present, there are around 30,000 particle accelerators in operation worldwide. Printed RFQs could soon help boost this number. ■

GLORY

THE LIGHT-SQUEEZERS

Three laser physicists from Germany enabled the measurement of gravitational waves and thereby the first ever demonstration of the existence of black holes. The next target? Dark matter. Just another day at work!

Squeezed light? What's that? I'm sorry, there isn't time to go into that right now! Please refer to a laser physics textbook. Our task is to tell you what can be done with it: for a start, measuring things that could otherwise never be measured.

Science has been talking about black holes for around 100 years now. Yet it was only in 2015 that the physical proof of their existence was made. The Laser Interferometer Gravitational-Wave Observatory (LIGO)—two huge observatories located far apart, one in the east and one in the west of the U.S.—succeeded in measuring the merger of two black holes, 1.3 billion light years away. This measurement was made on the basis of the first ever detection of gravitational waves—a twin breakthrough for the field of astronomy!

These breakthroughs were made possible by, among other things, ultraprecise beam sources developed by three German scientists in Hannover: Hartmut Grote from Cardiff University, Henning Vahlbruch from the Max Planck Institute for Gravitational Physics in Potsdam and Benno Willke from the Leibniz University Hannover. At the heart of LIGO are extremely sensitive laser interferometers several kilometers in length. These are able to detect gravitational waves on the basis of minuscule compressions of space-time. Here, even a couple of extra photons can render a measurement worthless. The answer is to use incredibly stable lasers. "These lasers have to be extremely powerful, exceptionally stable and incredibly reliable," Willke explains. "It's a unique combination. We really do have the most stable lasers anywhere in the world." It took years of basic research and development, numerous prototypes and a trial run lasting a full 12 months before the laser was ready to be shipped from Germany to the U.S.

One of the secrets behind this special beam source is squeezed light. "In squeezing light, we manipulate its quantum nature and thereby break into a whole new world of laser sources," Vahlbruch explains. It is then that phenomena that had previously escaped detection become measurable—such as gravitational waves.

This might even include dark matter, one of the biggest remaining mysteries in the world of physics. Grote is currently working on this problem with the help of technology from Hannover: "Who knows whether we'll discover anything. But, if we did, it would be sensational!"

In September 2023, Hartmut Grote, Henning Vahlbruch and Benno Willke were jointly awarded the Berthold Leibinger Innovationspreis for their heavy treatment of light.

Putting the squeeze on light: Hartmut Grote, Henning Vahlbruch and Benno Willke.

Maximilian Schlosser

WORKING CLASS HERO

Marta Soul

Peter Brown has worked his way up the ladder. Having founded Laser Additive Solutions, his dream is now to build his very own AM empire in the UK.

It's a powerful vision that has driven Peter Brown all these years: the evening sun bathes the windows of his manufacturing facility in a soft orange light. Inside, row upon row of 3D printers work busily away, fusing metal powder into high-tech components. In 2015, Brown left his position at the UK's Welding Institute to set up his own company, Laser Additive Solutions. This specializes in the repair of parts made of difficult-to-machine materials such as tungsten for the nuclear and aerospace industries and for nuclear fusion research.

HARD-EARNED CAPITAL A born entrepreneur, Brown faced considerable challenges at the outset of his journey. "Ever since my first job, I've dreamed about setting up my own company," Brown explains. "But I come from a working-class background, so I didn't have the necessary capital." Hard work was the answer: "To get the money together, I bought houses, did them up in my spare time and then sold them on at a profit."

Then, in 2015, he saw a second-hand welding machine on eBay. It seemed like a golden opportunity to reinvest some of his hard-earned cash. "If not now, when?" he thought. He therefore bought it, along with a brand-new 2-kilowatt disk laser as the laser source. With this welding machine and the disk laser, he built his first laser cell. It was Brown's entry into the world of LMD. "I still had contacts in industry and ended up landing some great orders—in the main, valves for power plants and parts for aircraft engines and turbines," he says. As business grew, Brown took on more people and invested in another machine. At the same time, his thoughts turned to diversification—using the lasers not only for LMD but also for standard welding jobs. "We played around a bit and discovered that we could also use the laser cells for welding," he explains. "We just had to deactivate the powder feed."

Peter Brown (on left page) is upbeat about the prospects for his growing company and for additive manufacturing in the UK. With their new 3D printer and a decidedly hands-on mentality, Brown and his team are working hard to build this future.

WHO USES 3D CONTRACT MANUFACTURING?
Not content with these additions to the company portfolio, he then acquired a machine for additive manufacturing using the power bed process. Brown is bullish about the prospects for this technology. "I can't imagine a world where additive manufacturing won't play a big role," he says. Brown sees the biggest potential in the areas of aerospace, medical technology and power generation: "These industries all have one thing in common: they use components with complex inner structures made of specialized alloys. Many of these components can only be made with additive manufacturing—or can be made much more cheaply that way. And the specifications with respect to engineering, safety, quality and documentation are all high."

The key question now is whether, given their own stringent specs, these industries are prepared to use subcontractors providing additive manufacturing services. Here, too, Brown is quietly confident: "The chances of this happening in aerospace are high. Companies there are used to working with partners. That's already very much the case for aero and will definitively be so for space as well." The prospects for medical technology, on the other hand, are not so clear: "We don't have any experience in this sector; we're therefore going to have to persuade the customer." So, are there risks involved in committing to additive manufacturing in the UK? Brown has both feet planted firmly on the ground: "Of course, there are risks. It's still early days for a UK market in additive manufacturing. But, if we invest now, we'll be ready when the first wave of orders arrives." ■

Contact: Laser Additive Solutions Ltd, Peter Brown,
phone: +44 1302 868 988,
peter.brown@laseradditivesolutions.co.uk

Maximilian Schlosser

Professor Anne L'Huillier —joint winner of the 2023 Nobel Prize in Physics— tells us where research with attosecond laser pulses is heading and what industry stands to gain from this.

"The easiest way to picture an attosecond?— You can't."

Professor Anne L'Huillier helped found the field of attosecond laser physics. This work may soon shine a light on the world of electrons.

Professor L'Huillier, you're at a barbecue, and someone asks what you do for a living. What's your answer?
For situations like this, I've got a stock response that I'm pretty happy with. I say that I work at the interface of laser physics and atomic physics. Our team uses short—very, very short—laser pulses to illuminate and thereby film—as with the flash of a normal camera—extremely fast-moving processes; for example, those involving electrons.

When you say, "very, very short," you mean ...?
I mean laser pulses that are only a couple of attoseconds long.

What's the easiest way to picture an attosecond?
You can't. Of all the various ways of trying to picture this incredibly short span of time, there's a comparison I sometimes use. It goes like this: one attosecond is to a single

second what one second is to the total age of the universe—i.e., 14 billion years. But does that really help? I'm not so sure. Did it help you?

Well, maybe a little.
We're just going to have to get used to the idea that it can't be grasped with our human sense of time. Fortunately, however, we don't need to do that. That's because we can call on the abstract methods of mathematics and scientific theory as well as practical experimentation. An attosecond is simply 10^{-18} seconds long. Besides, what's much more interesting than thinking about the length of an attosecond is the question as to why we would ever want to get down to such a small timescale.

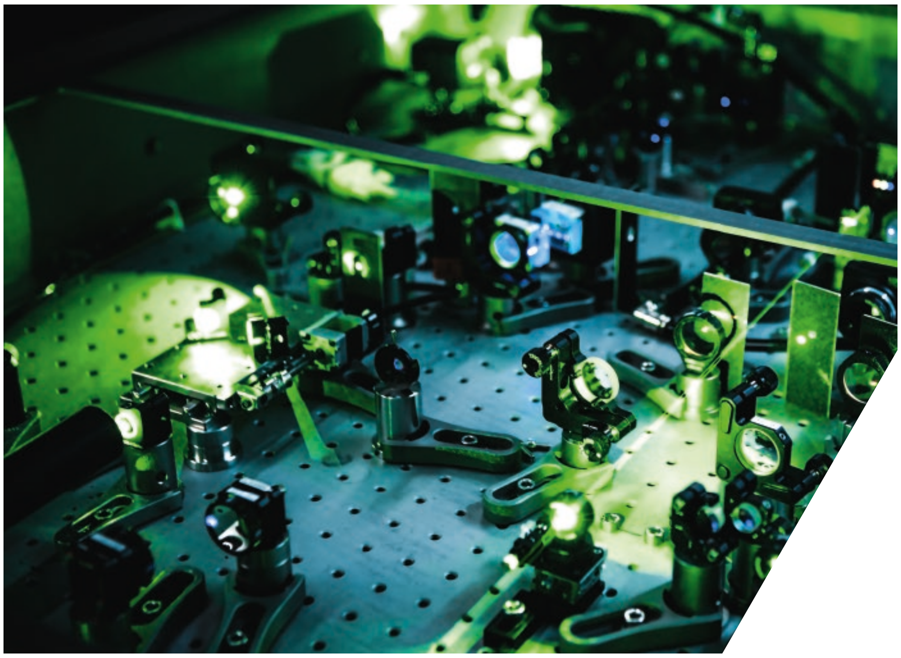
“So, in the long term, the big goal is to be able to control chemical reactions at the electron level.”

Okay. So, why do we need attosecond-length pulses?
There are certain processes in nature that are so fast that we can only measure them with the help of attosecond pulses of light. The most important of these are the movements of electrons. The quicker the flash—i.e., the shorter the pulse of light—the more closely we can observe this process. Right now, my research group is still mainly filming processes in and around simple atoms, because that's easier. But, if we can make further advances here, we'll then be able to observe electron movements in more-complex systems—in molecules, for example. Chemical reactions take place because electrons move. One day, we'll be able to measure these initial movements.

And then?
Being able to measure something is the first step towards being able to control it. So, in the long term, the big goal is to be able to control chemical reactions at the electron level.

And this will enable …?
It's hard to give a well-defined vision. But that's how it is with basic research.

Anne L'Huillier is Professor of Atomic Physics at Lund University in Sweden. She was one of the key figures involved in establishing the research field of attosecond physics. L'Huillier has won numerous prizes. Earlier this year, she received the Berthold Leibinger Zukunftspreis in recognition of her research achievements. Only a few days later, she was awarded the 2023 Nobel Prize in Physics, together with Pierre Agostini and Ferenc Krausz.



L'Huillier's research team in Lund, Sweden, uses femtosecond lasers to produce high-harmonic pulses of light. These are then used to generate attosecond laser pulses, which can render atomic processes visible.

"Our work has repeatedly inspired laser manufacturers to develop new and better ultrashort pulse lasers."

In an experiment of 1987, you discovered something called high-order harmonic generation, a precondition of being able to produce attosecond pulses.
Yes, that was a happy coincidence. But it's the best thing ever when you discover something you weren't expecting! That means there's something to puzzle over. What we were really trying to do was to bombard noble gases with intensive laser light and investigate fluorescence effects. It turned out that the strongest light observed in the process was not in fact fluorescent but rather the high harmonics of the laser frequency. This discovery changed my career. With high-harmonic generation, it then became possible to produce attosecond pulses. And that's what I'm still doing now.

Is it possible at least to form a mental picture of high-harmonic generation?
It is! I've got a comparison that works much better than the one for an attosecond and the age of the universe. If you run a bow across the string of a violin, you get not only the pure tone—the pure tone frequency—but also other frequencies as well. In music, these are known as overtones. They're what give the sound its timbre. Overtones are also known as harmonics. Something similar happens when, under specific conditions, you expose a gas to femtosecond laser pulses. It creates new laser frequencies of a much shorter wavelength. If you will, high harmonics are the overtones of laser physics.

What can you do with high-harmonic pulses of light?
You can use them to generate attosecond pulses. But they're also useful in their own right. We're currently collaborating with a manufacturer of lithography and metrology equipment for the semiconductor industry. The idea is to use high harmonics to inspect semiconductor microstructures. For someone like me, who works in basic research, this a very concrete project. I'm amazed and delighted that our work has proved useful to society.

Does laser technology also benefit from your research?
Absolutely. Over the past decades, our work in attosecond physics has repeatedly inspired laser manufacturers to develop new and better ultrashort pulse lasers. We too benefit, of course, from better beam sources. And the better the initial laser source, the better the high harmonics and, ultimately, the attosecond pulses. For us, this then results in further technical advances, such as new diagnostic and measuring methods in the field of USP laser technology. In other words, we're constantly spurring each other on. But aside from these pleasant side effects, there's also something else that is really important to me about my work.

What else is really important to you?
I'm a researcher. But I'm also a teacher. That means I get to teach a bunch of bright, young people and watch how their knowledge grows. I think that's my biggest contribution. ■

Maximilian Schlosser

Ireland

VIEW ON THE ECONOMY

The **"Celtic Tiger's"** economy began to boom in the 1990s and now rates as a major success story.

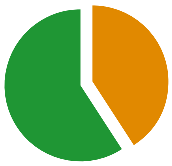
Ireland consistently exports more goods than it imports. In 2022, its **trade surplus** was 68 billion U.S. dollars, one of the largest of any country in the world.

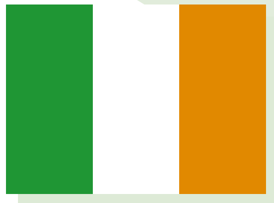
Ireland's major exports are **medical and pharmaceutical products** as well as organic chemical products.

WELCOME TO LASER LAND IRELAND!

Industry as a proportion of GDP

41 %





Nominal GDP per capita

103.176

U.S. dollars

5 m

inhabitants

LAND OF LASER

Ireland is a **latecomer** to the field of laser technology. Following a slow start, the country has since made up for lost time, becoming a significant user of laser tech.

Photonics-based applications are used in the processing industry as well as in **analytics, biotech and lab technology**.

Industry and higher education collaborate closely in Ireland, with research spawning a steady stream of high-tech **startups** in the sectors of optoelectronics and laser processing.

WHERE IS THE LASER?

In the leap of a mountain bike.

It might not sound like much, but 100 grams can make all the difference. Especially if you can cut it down by a third or even half. For a freerider looking to fly across rough terrain, every little gram helps. Take the brake levers: such a lot of metal, such a lot of extra weight. Aircraft-grade aluminum is practically standard, but why not use titanium? Besides, wouldn't it make the brake lever even lighter were metal only used where this is actually required? No sooner said than done! These high-end brake levers are made with a 3D printer: a filigree design of titanium and light, formed by a laser in line with the distribution of forces. A total of 112 brake levers from a single batch run with a TruPrint 2000—that's fabrication on a mass scale. Here's mud in your eye! ■

unsplash | marc sendra martorell

0.8 MICRONEWTONS

OF OPTICAL PULLING FORCE

It's a classic scene from umpteen alien films: a so-called tractor beam draws a terrestrial object up into the belly of a UFO. Although still impossible in real terms, there are encouraging signs that it may one day become feasible. Chinese researchers from Quingdao have now used a laser beam to attract an object visible to the naked eye. With a specially prepared flake of the pure carbon material graphene, the beam was able to exert an optical pulling force of 0.8 micronewtons. Not much, admittedly, but a small and perhaps decisive step toward generating a genuine tractor beam!

TRUMPF

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