Laser Community

THE LASER MAGAZINE FROM TRUMPF

#22

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CLEAR SKIES AHEAD

CHANGING THE WEATHER AND FIGHTING MALARIA: WHAT THE FUTURE OF LASERS HAS IN STORE FOR US

#22

May 2016

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This issue features a range of laser applications that are at the more unusual end of the spectrum. These examples are meant to inspire and provide food for thought, not to mention entertain! As you'll discover, these unusual applications are often found in niche segments—and sometimes they're surprisingly off the wall! Although laser cutting has evolved into a standard process that has inevitably lost a little of its fascinating appeal, it's also a major money-maker. And this business demands both aspects: standard applications in widespread use and captivating, exotic niche applications.

The fact is that novelties emerge from niche environments, so some form of cross-subsidization from mass-market applications to niche products makes sense. Exotic niche applications can also help broaden people's horizons by enabling them to see and experience what will be possible in five or ten years' time. And these attention-grabbing applications offer a level of fascination that motivates and inspires.

Fascinate, motivate

It's tough to find the right balance between niche and mass market. We need to try out new things without overstretching our own capabilities. And that means it's equally important to put a halt to development work if it becomes clear that it will never lead to lucrative products. I personally feel this is one of the most difficult issues of all. Project-based research with multiple partners in institutional settings plays a key role in this context. In the past, our industry has always managed to pursue this approach profitably—and we intend to continue in the same vein in the future. That is why we'll be meeting with old and new partners at the CODE_n innovation festival from September 20 to 22, 2016. We'll be sharing experiences, developing ideas and hopefully giving new impetus to the future development of photonics.

Lasers and their applications are science through and through, but they also create an emotional connection. I very much hope that we can stir up some emotion among our readers, too—and, as always, we're grateful for any feedback on whether we've hit the mark!

?

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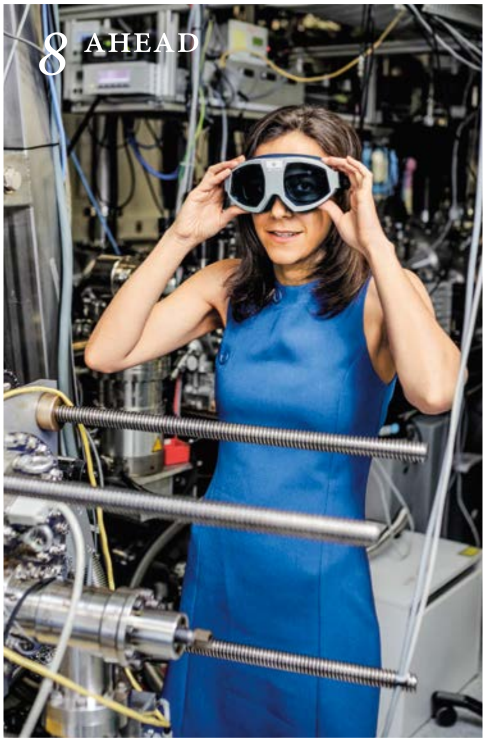

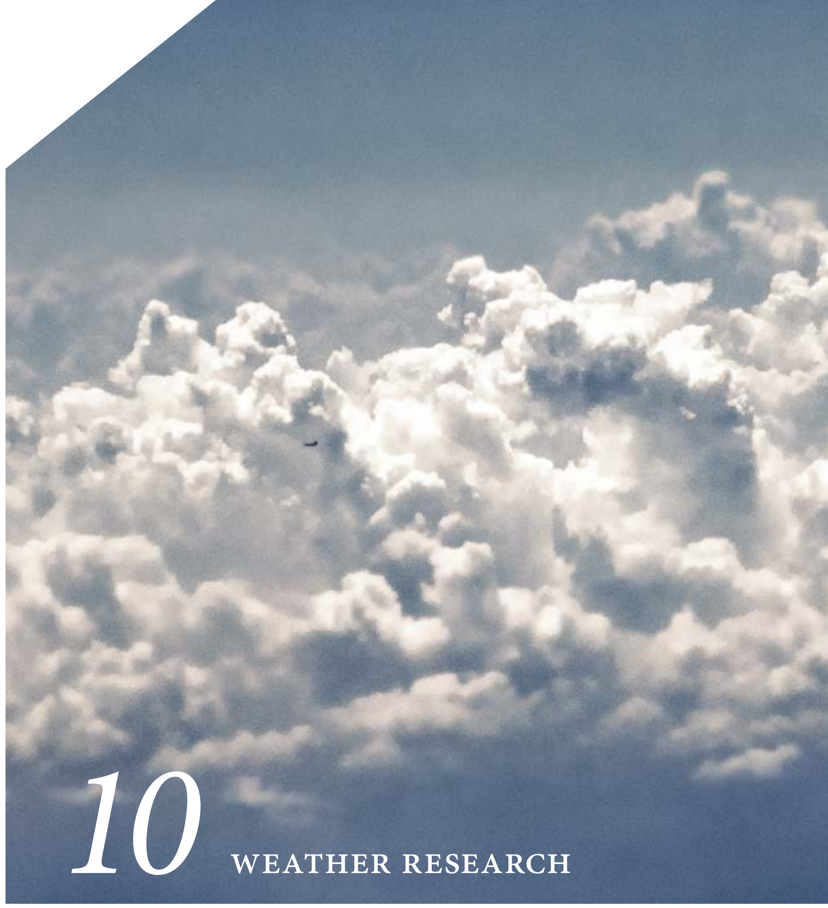

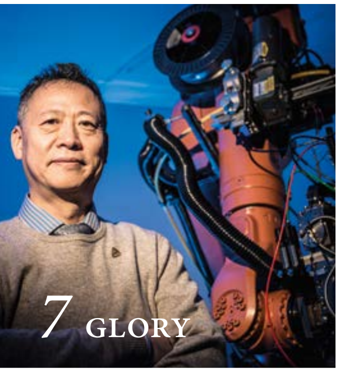

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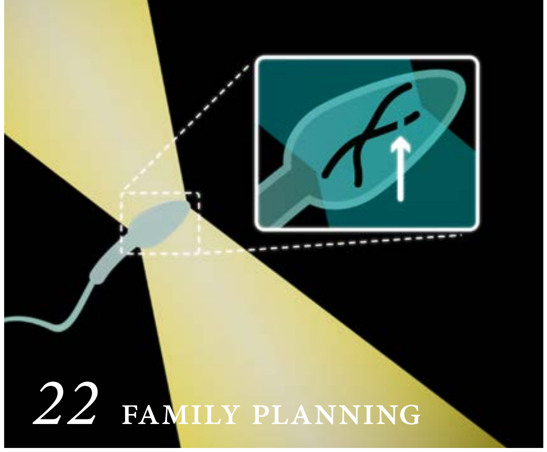

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Erik Jacobs, Laservorm GmbH, Gernot Walter, Angelika Grossmann

POWER

PEOPLE VS. MOSQUITOES

Mankind's greatest enemy is tiny, brown, and very hard to catch. But now researchers have developed a new weapon which they hope will finally give them the edge they need to defeat the aggressors.

It's a battle which has been raging for centuries—an army of blood-sucking creatures just six millimeters long on the attack against enormous opponents. The aggressors are fast and agile, and their opponents' blows often fail to connect. A single bite from this insect can be lethal, and some 600,000 people die every year as a result. The enemy is the malaria-carrying Anopheles mosquito, and the tropical disease it transmits is often fatal, especially in the developing countries of sub-Saharan Africa. Without treatment, malaria can kill in a matter of days.

The only way to stay safe is to avoid being bitten. But the only means of achieving this are mosquito nets and insecticides. Both of these defenses can only be used indoors, and the aggressors quickly build up resistance to the chemicals. But hopes have recently been buoyed by a new development from the US funded by the Bill & Melinda Gates Foundation: a "photonic fence" which kills mosquitoes by zapping them with a laser.

When a mosquito flies into an area protected by a photonic fence—for example a school, hospital or village—cameras on both fence posts detect the intruder's shadow in the light between the posts. The system immediately fires a non-lethal laser beam at the insect and uses the reflected light to determine its size and the frequency at which its wings are beating. This information tells the system whether the intruder is an Anopheles mosquito and also identifies the insect's gender. This is an important distinction to make because only females bite. Once the mosquito is confirmed as a female Anopheles, the system fires a second, lethal laser beam, shredding the insect in mid-flight.

All the components used in the fence come from inexpensive consumer electronics, a fact which will hopefully make the fence affordable in malaria-stricken regions. Who would have thought that the decisive weapon in the battle against malaria would turn out to be a laser diode for a Blu-ray player? ■

Bzzzz … zap! This female mosquito didn't make it through the laser fence.

Fotolia/yongkiet, Fotolia/kolazig

Professor Lin Li from Manchester is the President of the Laser Institute of America for the year 2016.

DanD photography+Video

"WE HAVE A STRATEGY!"

Professor Lin Li, the elected President of the Laser Institute of America for the year 2016, wants to whip the Institute into shape, increase its profile in Asia and attract more members.

After 20 years of high-power laser research, 340 articles in respected scientific journals and 47 patent applications for laser material processing and photonic science, Professor Lin Li has found a new challenge. The chair of laser engineering at The University of Manchester is also the President of the Laser Institute of America for the year 2016. Li wants to pursue reform: "We are developing a long-term vision and strategy for the LIA," he says. "We will also review the institute's finances and come up with a sound financial plan that will facilitate healthy growth in the community. This will enable us to better serve our members, the laser community and society in the future." During his term of office, Li aims to expand the LIA's membership list. "To attract more people, LIA plans to improve its services for members," says Li. "We also want to increase the institute's international profile." To achieve these goals, he plans to target the U.S. job shop sector and also Asia. "The Asian laser community is expanding incredibly fast," he says. "I'm eager to know more and to learn about what they are looking for."

Born in Shenyang, China in 1959, Li completed his Bachelor's degree in control engineering at Dalian University of Technology in 1982, which laid the foundations for his scientific career. He came to the UK to study laser technology in 1985 and earned his PhD from Imperial College London in 1989. Li spent six years as a research associate at the University of Liverpool before moving to his adopted home of Manchester. As Li says, "Manchester is where Ernest Rutherford and Niels Bohr first discovered the structure of the atom, where Alan Turing invented the first programmable computer and where the Industrial Revolution started, which changed the world." He keeps in touch with his Chinese roots through his hobbies: playing flute and erhu in a band that performs Chinese music, and practicing Tai Chi. Li was elected fellow of the Royal Academy of Engineering and received the prestigious Sir Frank Whittle Medal in 2013.

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AHEAD

"STRONGER, FASTER, AND SHORTER"

Physicists, doctors, chemists—all are waiting for shorter and higher-energy laser pulses. And all want to conduct research on the tiniest processes in the universe. Dr. Hanieh Fattahi shows how it's done.

You talk about the "third generation of femtosecond technology". What does this mean?
The first generation of femtosecond pulses came from dye lasers, which could produce different frequencies. But, although they yielded ultra-short pulses, it wasn't possible to increase either the pulse energy or the average power—in other words, the repetition rate. Next came titanium-sapphire-based laser technology. Here you had to choose whether you wanted to crank up the pulse energy or the repetition rate. Doing both at the same time doesn't work because it causes the crystal to overheat. With the third generation, it is possible to create many very short pulses with high pulse energy and also a high repetition rate.

How does it work?
The third generation is based on OPCPA—short for optical parametric chirped-pulse amplification. To really get the most out of OPCPA, however, you need one heck of a pump source. It needs to be scalable and stable. Luckily, one exists in the form of the TRUMPF turn-key Ytterbium:YAG thin disk laser. This laser reliably generates pulses with durations of 900 femtoseconds and is freely scalable in terms of repetition rate and energy. We amplify the pulses from this high-power disk laser and make them 1,000 times shorter with coherent synthesis. In my dissertation, I show how it is possible to attain the following parameters: ultra-short pulses with durations of one field cycle, peak pulse power in the terawatt range, average power in the hundred Watt range and a repetition rate between 500 and 1,000 Hertz. This wasn't possible before.

Could you explain how you do this?
To do it, you need a very broad color spectrum. The more frequency components you combine in a pulse, the shorter it becomes. However, there are physical limits with OPCPA: you can only amplify a few frequencies simultaneously. So, I designed an amplifier setup to get around this limitation: I split the laser pulse into various frequency components and send each one through a separate amplifier. It's a kind of multi-channel OPCPA system, if you like. In this way, I obtain various high-energy ultra-short pulses of different frequencies. Then I resynchronize them using a waveform synthesizer.

And what is the result?
A sub-cycle pulse with a spectral bandwidth of several octaves. In this way, we can compress the duration of laser pulses down to as much as 500 attoseconds. So we actually can obtain attosecond pulses directly from the OPCPA and the Ytterbium: YAG disk laser!

What is the goal of your research?
We want to use these compressed and amplified laser pulses to generate attosecond pulses that are even shorter. To do this, we focus the pulses into an inert gas beam and accelerate the electrons of the gas atoms. As the electrons fall back to their ground state, they emit an attosecond pulse. So far, the maximum photon energy that we've gotten out of the inert gas atoms is 200 electron volts. However, with the third generation of femtosecond technology, we will hopefully increase the photon energy to over a thousand electron volts. Kiloelectron volts in the lab—the dream of every high-energy physicist!

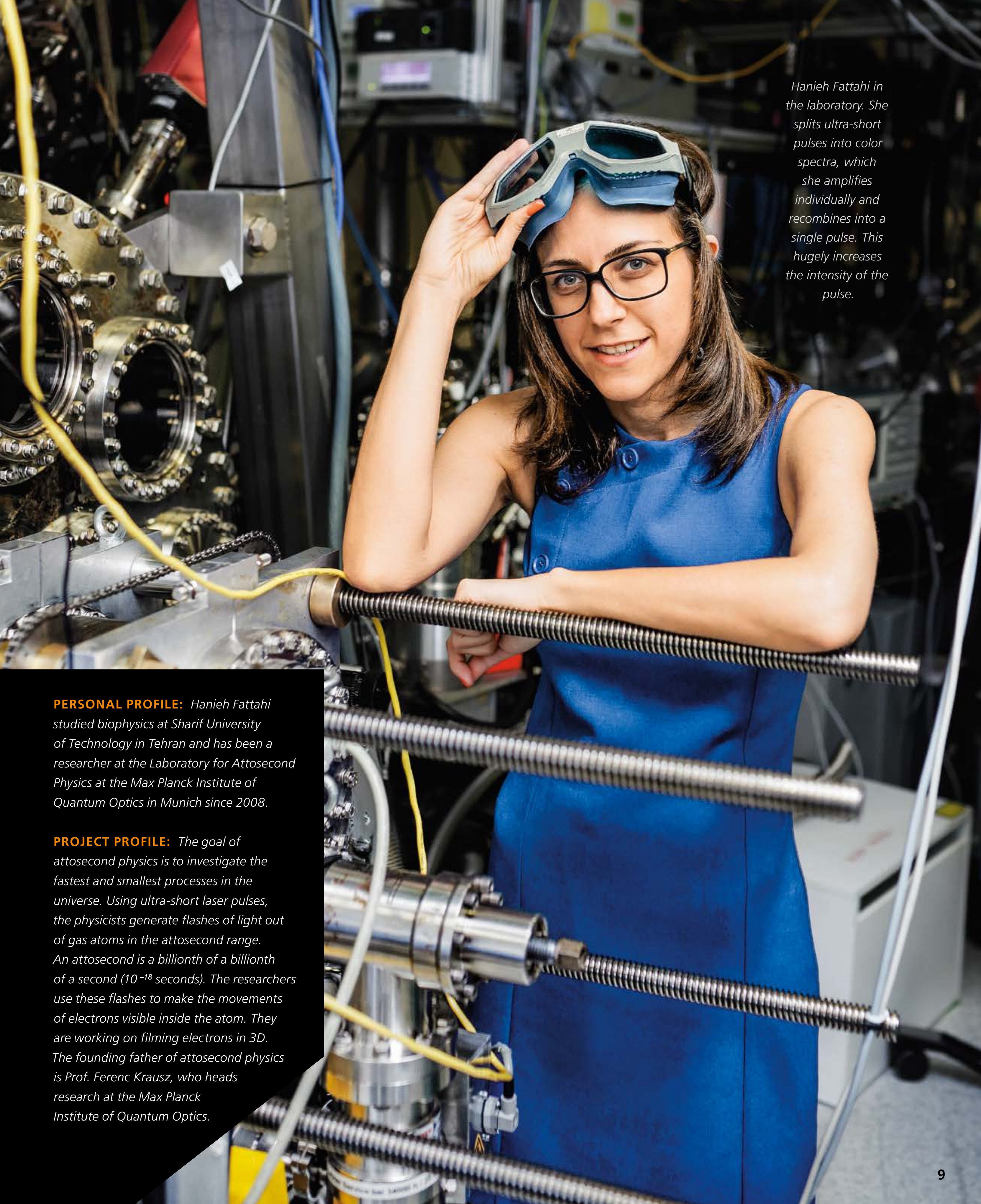
What can you do with shorter attosecond pulses?
They will allow us to make the movements of electrons in the atoms of solids visible and to actually film them! The attosecond pulses function as a sort of camera shutter here. And if this helps us to better understand the interplay of light and matter, then one day it will be possible to build optical transistors that open and close at unbelievable speeds, enabling super-fast computing operations.

What motivates you personally?
I want to have the opportunity to look inside an atom one day. I love the idea of peering down that deeply! You know, around 95 percent of the day-to-day life of a researcher is pretty unglamorous stuff: setting up lasers, fixing defective components. But the other five percent, when everything works and you make progress—those times are so wonderful that they make it all worthwhile. ■

Contact: hanieh.fattahi@mpq.mpg.de

The laser pulse amplifier compresses the pulses by a thousand-fold.

Simon Koy



Hanieh Fattahi in the laboratory. She splits ultra-short pulses into color spectra, which she amplifies individually and recombines into a single pulse. This hugely increases the intensity of the pulse.

PERSONAL PROFILE: *Hanieh Fattahi studied biophysics at Sharif University of Technology in Tehran and has been a researcher at the Laboratory for Attosecond Physics at the Max Planck Institute of Quantum Optics in Munich since 2008.*

PROJECT PROFILE: *The goal of attosecond physics is to investigate the fastest and smallest processes in the universe. Using ultra-short laser pulses, the physicists generate flashes of light out of gas atoms in the attosecond range. An attosecond is a billionth of a billionth of a second (10^{-18} seconds). The researchers use these flashes to make the movements of electrons visible inside the atom. They are working on filming electrons in 3D. The founding father of attosecond physics is Prof. Ferenc Krausz, who heads research at the Max Planck Institute of Quantum Optics.*

Could a laser save the sunny weather?

Rohan Kelly / action press

And now it's time for the weather

Turbulence researcher **Eberhard Bodenschatz** fires lasers at clouds to help him solve the mystery of why it rains. Meanwhile **Jean-Pierre Wolf,** an expert in nonlinear optics, is hoping to use his lasers to make his own weather.

Germany's highest-altitude building is packed to the rafters with high-tech equipment. The Schneefernerhaus was originally set up as a hotel for tourists on the Zugspitze at 2,656 meters above sea level. But in the 1990s, the last hotel guests left and the scientists arrived, transforming the building into an environmental research center. Now an ultrashort pulse laser from TRUMPF has made its way up the Zugspitze, too. Eberhard Bodenschatz, professor of experimental physics at the Max Planck Institute for Dynamics and Self-Organization in Göttingen, purchased the device for his lab in the Alps: "We're hoping to use the laser to reveal the dynamics of water droplets and ice particles in clouds so we can see exactly what's going on."

Capturing patches of turbulence on video The laser light cable runs from the laser through the laboratory ceiling to a flat roof where a climatized, waterproof container the size of a beer crate is positioned on a seven-meter-long rail. The crate contains four high-speed cameras. The researchers in the lab, and the measuring device on the roof, wait patiently for the weather to deteriorate—and they start collecting data the moment a cloud moves across the roof. The optics system expands the laser light to a diameter of five centimeters and the light pulses are projected at a vertical angle toward the camera box onto the cloud particles. The forward scattering causes the particles to light up with every pulse of light, and the cameras record this in the form of stereoscopic images taken at a distance of around 60 centimeters from the lens. In order to create a three-dimensional video of the cloud particles, the high-tech crate keeps pace with the cloud's average speed as it travels along the rails *(#1)*. This enables the cameras to track individual cloud particles, snapping about 15,000 images a second. These images are then instantly converted into 3D pictures by the computer. It takes just one second to complete the measurements. Then the sled returns to its starting position and the entire process starts over. This is the method the researchers use to film small patches of turbulence—each a few cubic centimeters in size—in order to discover what happens to tiny cloud particles in that single second of time. "Each measurement tracks somewhere between 300 and 1,000 individual cloud particles, each of which is no bigger than a few micrometers. We've been doing that in our wind tunnel for a while, but this summer we'll be using our new laser to perform the first measurements on real clouds on the Zugspitze," says Bodenschatz.

Max-Planck-Institut für Dynamik und Selbstorganisation

"I want us to finally get to the bottom of turbulent mixtures, and clouds are the perfect test environment."

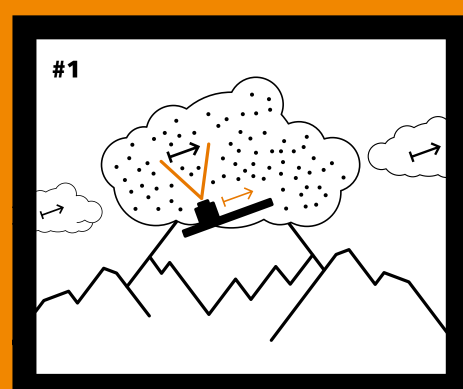
Prof. Eberhard Bodenschatz, Max Planck Institute for Dynamics and Self-Organization

Laser flashes To make the motion of the swirling droplets visible, Bodenschatz and his team need plenty of light. "That's why we need the ultrashort pulse laser. It delivers up to 50,000 flashes a second with 40 millijoules per pulse. Those parameters give us enough photons in the measurement zone to make the swirling droplets visible," Bodenschatz explains. He notes that the laser pulses have very little effect on the droplets themselves: "At most they get a little warmer, but that doesn't affect how they move."

Bodenschatz is currently developing another experiment designed to investigate droplet distribution in clouds on a larger scale. His idea is to hang a high-speed camera from a long rope and fly it directly into a cloud using a balloon-kite hybrid known as a Helikite. "We fan out laser light from below, firing high-intensity, green pulses around 100 meters into the cloud. That makes the turbulence visible—and with the TRUMPF laser we finally have a beam source that is up to the task." *(#2)*

Three unsolved puzzles However fascinating he finds the weather, Eberhard Bodenschatz really has his sights set on a broader context. He has devoted virtually his entire career to investigating turbulent fluxes. "We already have a few equations for this field of physics, but the process is so complex that the parts we understand are just the tip of the iceberg. And when it comes to inertial (i.e. heavy) particles in turbulence, we don't have any equations at all! So, the only solution is to collect data on particles in the turbulence and subject it to statistical analysis. Clouds are perfectly suited to studying these complex processes because they occur in nature and consist of just four ingredients: water vapor, ice, airborne particles known as aerosols, and, of course, air. "My goal is to understand how collisions and evaporation occur in turbulent mixtures." Bodenschatz hopes this will allow him to draw conclu-

All these experiments are already up and running in the lab. But in recent years researchers have made the leap to real weather.



Gernot Walter

MEASURING TURBULENCE IN CLOUDS

sions on other mixing processes such as those that take place in ocean currents, technical sprays, and even combustion engines. The combustion process in a diesel engine, for example, mixes together thousands of individual components. "Understanding clouds eventually improves one's understanding of combustion, too."

And clouds harbor yet another secret. Rain only falls when numerous tiny droplets suspended in the air combine to form one large raindrop. This raises the fundamental question of how large droplets are formed from smaller ones. "And that's something physics can't answer at the moment. The droplets are heavier than air and spin off at an angle as they whirl around. We understand the process pretty well on an individual level, but unfortunately we don't understand the 'avenues' of turbulence, and those are changing all the time," says Bodenschatz. "The droplets live in the wildest rollercoaster imaginable. What we're interested in now is how many collisions take place and how this causes larger droplets to form which then fall toward the ground, swallowing up numerous tiny droplets on their way."

This question of how small particles combine to form larger ones in turbulence is also relevant to the formation of planets. "Look at our current models and you would be forced to conclude that space shouldn't contain any clumps of matter with a diameter larger than about one meter, since they burst apart when they collide. To have the kind of gravitational pull required to cluster matter together you would need clumps measuring at least 100 meters across. "Obviously we know that planets exist. But how is that even possible? We're hoping that our experiments on particles in turbulence will give us some clue as to how our world was formed in the first place."

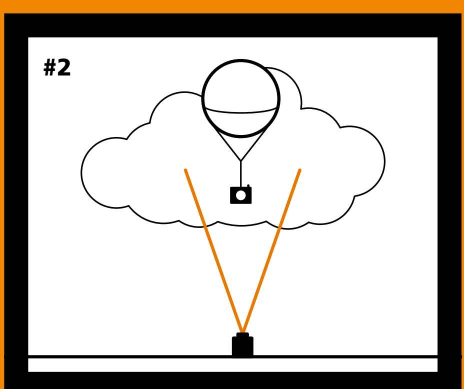
An improved understanding of clouds will also have some more immediate, practical benefits, such as improving the accuracy of predicting when and where it will rain or snow. "Wet clouds produce rain up to ten times sooner than current models predict. And I believe that has something to do with turbulence."

For climate researchers, cloud formation is one of the most important issues of all. A huge community of scientists is currently striving to create better climate models—and Bodenschatz's work forms part of these efforts, too. "But soon things will develop even further: it won't be long before climate change becomes so serious that we'll be actively intervening in weather processes."

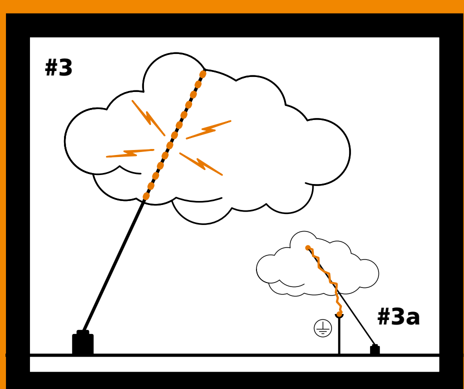
Stretching things out Jean-Pierre Wolf has already reached precisely this stage at the University of Geneva. He wants to use laser beams to influence cloud formation and control lightning. The Swiss expert in nonlinear optics came up with the idea while investigating how air reacts when you expose it to a high-power laser beam. His results showed that the air ionizes. This is due to a phenomenon known as Kerr-induced self-focusing: the field strength of a high-intensity laser beam affects the refractive index of the air in such a way that the air itself acts as a kind of focusing lens for the laser beam. This creates high intensities that ionize the air. Electrons are released, defocusing the laser beam and causing the entire process to start over. The beam remains stable, continuously focusing itself. "With the right beam source, we can stretch the focus out to a length of one hundred meters," says Wolf. "Ionization produces plasma channels known as filaments—and that's what we can use to affect the weather."

Using lasers to trigger lightning from clouds Wolf is currently working on three applications for his filaments, the first of which is to trigger lightning in clouds. "The filaments trigger discharges and the lightning follows the channel. So, in addition to triggering lightning, we can also cause it to discharge in a certain direction," says Wolf. This gives Wolf two possible ways of eliminating the risks posed by thunderclouds. He can either trigger lightning within a cloud that never actually reaches the ground—discharging the cloud until it becomes calmer *(#3)*—or he can use the filament to guide the lightning to a standard lightning conductor on the ground *(#3a)*. "There is huge demand for improved protection. The costs associated with thunderstorms and lightning strikes run to five billion dollars a year in the US alone, primarily due to disrupted air traffic and damage to aircraft and

USING LASERS FOR CLOUD MEASUREMENTS AND WEATHER MANIPULATION



MAKING DROPLET DISTRIBUTION VISIBLE



DISCHARGING STORM CLOUDS

power lines." Wolf would like to see stationary laser systems installed around airports and power plants, which could discharge approaching storm clouds before they pose any danger. "I think we'll be ready to do that in five years' time. It works perfectly under laboratory conditions and we've already run successful tests outdoors, too." The key to success is choosing the right beam source. "You need a femtosecond laser with a peak pulse power of one terawatt and a high, stable repetition rate of more than one kilohertz. TRUMPF Scientific Lasers is currently developing a laser for me with those specifications." The collaboration stems from some trial measurements for lightning conduction carried out at the TRUMPF laboratory in Munich.

"If we use lasers in the right way, we could eliminate the damage caused by lightning strikes in the future."

Prof. Jean-Pierre Wolf, University of Geneva

Delaying rainfall The laser-generated filaments can also be used to affect the weather in other ways. Wolf converts vapor into small water droplets that hover in the air—in other words, he creates clouds. For water vapor to condense in the air, you need surfaces on which the phase transition can take place, in this case aerosols such as dust or sand. "Ionization with the high-power laser enables us to make the existing aerosols more hydrophilic. They attract more moisture, forming droplets where there were none before," says Wolf *(#4)*. "What we can't do is make the cloud rain. Once we've created it, it simply lives out its natural lifespan." Where Wolf has succeeded, however, is in preventing wet clouds from raining for a certain period of time under laboratory conditions. To do this, he draws on the principle investigated by Eberhard Bodenschatz, which states that small droplets do not fall. By turning the aerosols contained in the cloud into genuine moisture magnets, Wolf ensures that the water spreads itself over multiple surfaces. "The droplets split up and are not big enough to fall to the ground. In the future, this could enable us to prevent wet clouds from raining until they are over dry areas. This could help us combat both droughts and flooding," Wolf explains, setting out his vision of how the technology could be used. *(#5)*

Drilling holes in clouds Wolf also hopes to use his filaments to improve communication between satellites and ground stations, which is often obstructed by clouds and fog. In the course of his experiments, Wolf hit upon a further phenomenon of ionization. The jump in temperature of the air molecules triggers a shock that produces a sudden sound wave. "We can use this acoustic explosion to push aside droplets in mist and clouds, basically using the long laser focus to drill a channel through the clouds." This requires the individual shocks to take place at very short intervals. "And that's why this application is all about having a very high repetition rate". The hole in the clouds could be used to transfer information between the Earth and space without anything getting in the way—and the data transfer could also take place via laser!

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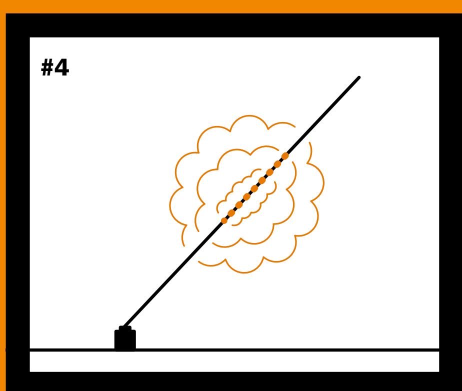
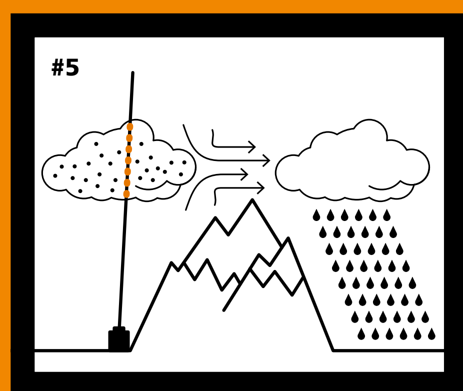


MAKING CLOUDS



DELAYING RAINFALL

Prof. Jean-Pierre Wolf, Gernot Walter

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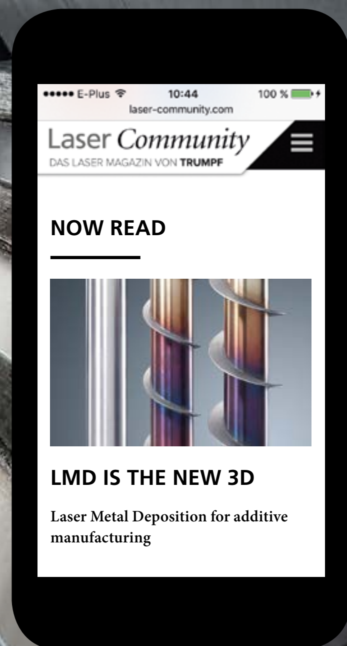

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RED E-VOLUTION

More and more cities around the globe are opting for electric buses made by BYD. One of the strengths of this Chinese company is its in-house expertise in high-performance batteries. Laser technology is used to weld their highly sensitive components.

It looks like any of the other thousands of red double-decker buses plowing through the loud traffic on London's streets, but if you listen closely you'll soon realize that this number-16 bus is different. Instead of the usual engine rumbling, all you can hear is a high-pitched hum. Indeed, it is the world's first double-decker bus designed to run on electricity. It is part of a plan to improve air quality in the English capital. More and more cities around the globe share London's dream of zero-emissions local transportation and are switching to environment-friendly electric buses.

THE FUTURE PROMISE OF ELECTROMOBILITY The Chinese company BYD has taken advantage of this trend and is driving it forward. The three letters making up the company's name are indicative of its great ambitions—they stand for "Build your dreams." In 2015, BYD sold 7,500 electric buses to cities around the globe—more than any other manufacturer. No less than 160 municipalities in 40 countries have run trials of the different variants of BYD's electric bus, including New York, Tel Aviv, Montevideo, Kuala Lumpur and now London. Electromobility is the way forward to a greener future. Electric motors do not produce harmful CO_2 emissions and are much more efficient than internal combustion engines: a gasoline-powered vehicle converts only 19 percent of the energy it consumes into motion, whereas electric vehicles have a conversion efficiency of 64 percent.

MADE IN ASIA Thousands of kilometers away, in the southeast Chinese city of Huizhou, Liu Huaping, BYD's process department manager shows visitors around the plant where BYD manufactures the batteries for its electric buses—one of three such sites. "The batteries are the core components of our vehicles; they determine how far the buses can travel. They have to be able to store as much energy as possible without being too bulky or heavy," says Huaping.

When designing electric vehicles, the biggest challenge is the storage battery, not the engine. One of the reasons for BYD's unparalleled success as a manufacturer

In October 2015 the world's first electric doubledecker bus entered service in the streets of London.

of electric buses is that the company was able to build on its reputation in the battery industry. BYD began producing rechargeable batteries in 1995, but didn't turn its full attention to the automotive industry until 2003. Almost every single component is manufactured by BYD in house: from the electric motor to the steering wheel and the fenders. The company grew rapidly and soon joined the ranks of China's largest carmakers. Buses were finally added to its portfolio in 2009. BYD developed its own iron phosphate battery for these vehicles. Iron phosphate batteries are safer than the more common lithium-ion batteries because they are not susceptible to the thermal runaway phenomenon, which can cause the latter to catch fire or explode. The batteries developed by BYD are also kinder to the environment because they are recyclable and don't contain any heavy metals. Efficient and reliable production processes are the key to meeting the growing demand for these energy-storage devices, while ensuring quick delivery and affordable prices. "Welding plays a significant role in the battery manufacturing process. Among other things, it is used to attach the connectors and to seal the battery enclosure," explains Huaoping.

BYD developed its own iron phosphate battery for electric buses. They are safer than the more common lithium-ion batteries.

BYD uses different techniques depending on their suitability for a particular type of welding job. They include resistance welding, ultrasonic welding and electron-beam welding. "But laser welding is our method of choice for applications requiring a high degree of precision," says Huaping.

A glance at the factory's fleet of machines shows how important lasers are in the company's manufacturing processes. BYD has installed a total of 120 TRUMPF laser machines in its battery plant: 70 from the TruDisk series and 50 from the TruPulse series. Huaping illustrates this point by fanning out three thin strips of metal: "The majority of our welding operations involve part thicknesses of no more than two millimeters or even less. These parts are made of copper, aluminum or an aluminum alloy." So as not to damage the sensitive battery components, the welding process must have the least possible impact on the surrounding material. "Fine weld seams, low heat diffusion, low intrinsic stress and minimal distortion are our key requirements for such processes," says Huaping as he walks toward a TruDisk laser machine.

Disk lasers are ideally suited for welding highly reflective materials such as copper or aluminum. The connections between each battery cell and the next are welded this way. "By adjusting the focus of the laser beam, we can rapidly move from one weld point to the next. We can also adapt the working angle to avoid damage to the optics," explains Huaping, who is meanwhile walking toward a TruPulse system. "We use pulsed lasers to seal our battery enclosures because the weld seams have to be absolutely gastight. This process must not generate too much heat because this could damage the internal components of the battery." The chosen method fits the bill because it allows time for the material to cool down between successive laser pulses.

250 KILOMETERS Meanwhile back in London, it's time for our number-16 double-decker bus to return to the depot and recharge its batteries after 250 kilometers on the road. A fully charged battery can easily cover this distance, and the bus will be ready to go again after it has been plugged in for four hours. It won't be the last electric bus operating in the city: London Transport plans to integrate 300 electric buses into its fleet by 2020. ■

BYD, Gernot Walter

"I said, listen, we really have to look into semiconductors now!"

Harvard physics professor
Eric Mazur reflects on the discovery of
black silicon and the art of serendipity.

Erik Jacobs

Y

You originally wanted to be an artist, but now you're a professor of physics. What went wrong?

I don't think those two things are as far apart as they might seem! Scientists need to be creative, they need the ability to recognize and articulate patterns, just like artists. The act of interpreting a series of measurements has certain similarities to a painter steadily building up a scene. Take Leonardo da Vinci, for example: he was a great artist and a great scientist. Personally, I was inspired to pursue both of these areas by my family. My father was a professor of theoretical physics and my grandfather was an engineer. When I was little, they were always giving me science books and engineering kits. My mother was an art historian who taught me a lot about visual arts and graphic design. As a teenager, I really wanted to become a photographer or filmmaker. But in the end I chose science because it had always been my strongest subject at school. To be honest, the main reason was that I thought it would be easier to make a career in science than in the arts. But I still have my artistic side. I love photography and I invest great effort into crafting the perfect designs for the slides I use in my talks.

What are you working on at the moment?

So many different things. To give you one example, our group is currently investigating how light behaves when you send it through a material with a refractive index of zero. We've built what we call a metamaterial, a gold-clad transparent photoresist in which tiny crystalline silicon pillars are embedded. It turns out that light behaves very differently in this material than it does in ordinary materials. In our new material, photons essentially behave like electrons, giving us a far simpler and more efficient way of manipulating, bending and squeezing light at the nanoscale. That's one of the projects we are working with at the moment. The overarching idea is to fabricate an optical chip that could process optical signals. Before we manufactured this zero-index material, we demonstrated that light, including ultrashort laser pulses, can be guided by "nanowires," paving the way for nanophotonics in a broad frequency range. We are also expanding our research in the realm of biophotonics. For example, we developed an efficient way of using light to punch small holes in cell membranes that we can use to insert genetic material into the cell. And with an ultra-short pulsed laser, it only takes a second for us to perforate tens of thousands of living cells, potentially revolutionizing medicine and medical research.

You've already worked in so many different areas of optical research. How do you keep making all these discoveries?

I'll tell you something: the most interesting discoveries in my laboratory were all serendipitous. None of these discoveries resulted from careful planning. Although…, at a Chinese restaurant I recently got one of those fortune cookies when the check came, and it said: "Good luck is the result of good planning," and that actually got me thinking. Perhaps what really matters is giving luck a chance to run its course. People generally see research as something focused and linear, but trying things out and playing around are perhaps just as crucial. I've always encouraged trying out new things and pushing boundaries in my research group.

> *"The most interesting discoveries in my laboratory were all serendipitous."*

Could you give an example?

In 1997 my research group and I discovered black silicon, a form of silicon that is extremely good at absorbing light and is now finding applications in sensors and solar cells. At the time we were using femtosecond lasers to investigate how carbon monoxide reacts on platinum surfaces to form carbon dioxide, a reation that occurs in the catalytic converter of a car. This research was funded by the U.S. government for two successive three-year periods, and when I submitted my third application for a new round of funding, I felt that I had better offer something else too — otherwise they might stop playing ball. So in my application I wrote, "We will also investigate other materials such as semiconductors." This got a program manager excited enough to give me a call and ask for more details. As I had no specific ideas, I quickly made something up. The funding was extended for another three years and, as you might imagine, we continued our work on platinum. As the end of that third funding period approached, however, I suddenly got nervous because I had promised research on semiconductors. I called one of my students in the lab and said, "Listen, we *really* have to look into semiconductors now!" We unearthed some silicon wafers in the corner of the lab and my student found a cylinder of sulfur hexafluoride from our gas store as a reaction medium. He then fired femtosecond laser pulses at the surface of the silicon and it turned completely black, darker than black velvet.

LIFE Eric Mazur was born in Amsterdam in 1954. He studied at Leiden University and moved to Harvard University in 1981 where he was tutored by the Nobel laureate in Physics Nicolaas Bloembergen.

LASERS Mazur pioneered the use of ultra-short pulse lasers as a research tool. In 1989 he built a femtosecond laser at Harvard and became the first person to systematically investigate the effects of femtosecond laser pulses on materials. His research has led to numerous applications in both medicine and industry.

CAREER Eric Mazur heads up the Mazur Group at Harvard which employs around 40 people. The team conducts research into areas including femtosecond laser microfabrication and nanosurgery, nonlinear nanophotonics, and pedagogical techniques in the realm of science.

Erik Jacobs

Black silicon was born. He called me, I came over and we examined the surface. That haphazard discovery ultimately led to a whole new field of research, a new company, and novel products.

You've followed quite a linear career path …

Not at all. I've zigzagged all over the place. When I was five years old, my grandfather gave me a book about the universe. I immediately knew that I would become an astronomer. So when I was 17 I began a degree in astronomy at Leiden University in the Netherlands. But after just six weeks I was totally disillusioned. Instead of investigating the big questions, all we were doing was working on formulae for calculating star positions. I wanted to see the forest, but all they kept showing me were the individual trees. I switched to physics, but as I quickly discovered, physics wasn't any better than astronomy. Classes were really dull and mostly focused on endless problem-solving. I stuck with it because I was too embarrassed to switch fields again.

But eventually something must have sparked your interest?

In my third year, when I was just about ready to quit, I joined a research group and started to work in the laboratory. My project involved laser spectroscopy of cold gases, and I was really excited to be in the laboratory and have a chance to observe phenomena that nobody had ever seen before — uncovering new knowledge. Suddenly I was hooked.

And that made you want to be a professor?

No! I was determined to follow a career path that was different from that of my parents, I didn't want to become an academic. So when I finished my doctoral thesis, I applied to Philips and was offered a job in their research laboratories. That was in 1981 when Philips was working on the development of the CD in a joint venture with Sony. I was assigned to a group that had to reduce the diameter of the discs from 30 centimeters to the 12-centimeter size we're familiar with today. When I told my father about the job offer he said, "How about first spending a year in the US as a postdoc and learn more about optics?" I thought it was a great idea and Philips agreed to keep my job open for me. I wrote to Harvard and they accepted me as a postdoc. And what can I say? It's been a long year, because I'm still at Harvard.

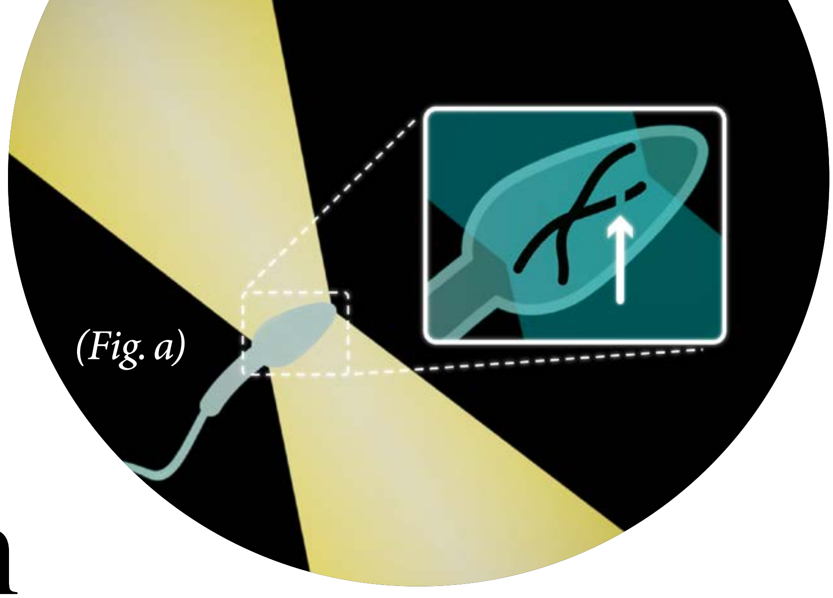
What made you change your mind?

I suddenly found myself in a place where 17-year-old string theory enthusiasts were chatting to 70-year-old Sanskrit experts. Politicians, writers and artists were visiting the campus giving talks. And when I thought about Philips all I saw was that long, long corridor with an endless row of PhD nameplates stretching along the walls. All the offices were occupied by male physicists aged between 27 and 40 who spent all day long solving predefined problems. Suddenly it seemed so claustrophobic. So I became an academic after all. As you can tell, I make a habit of changing my mind.

You teach introductory courses for non-physicists. Isn't that a bit unusual for a top researcher?

I love it! I think it's so important to get people interested in science, and I think one way to do that is by changing the way we teach. I've already told you how boring I found most lectures when I was a student. When I started teaching, I realized I was doing exactly the same thing as my teachers had done to me. I may have been a good lecturer, but I was a terrible teacher. My students memorized facts and regurgitated them on the exam—much like I had done. This process bears no relation to knowledge discovery. So I developed a new active learning approach, now called the "flipped classroom": students prepare before coming to class and the class period is more like a debate. I teach by asking questions. My students are constantly involved, and they learn more. My goal is to create "aha!" moments in the classroom. When I see that look of sudden understanding on a student's face, I feel a great sense of satisfaction. ■

Contact: Eric Mazur, mazur@seas.harvard.edu

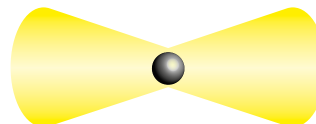

(Fig. a)

On a mission *to conceive*

For some couples, artificial insemination is the only way to have children of their own. Researchers are constantly improving the methods used in reproductive technology—and lasers are providing assistance in key areas.

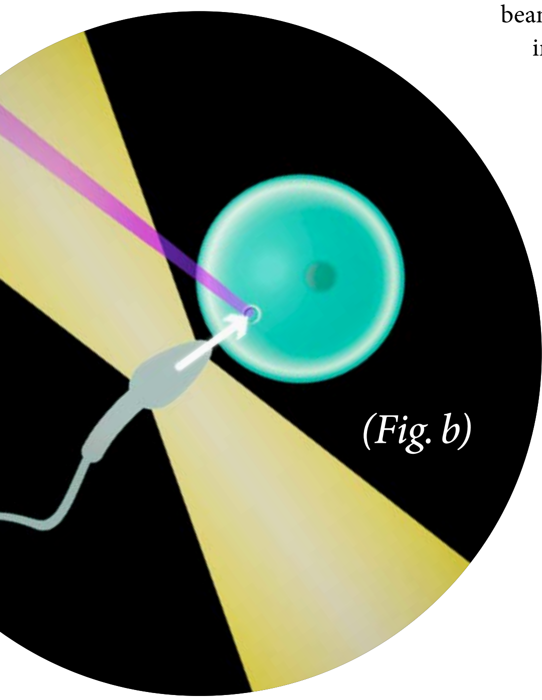
Sperm must display a certain amount of agility for artificial insemination to work. DNA-strand breaks in sperm cells have a negative effect on factors such as sperm motility, representing a possible cause of miscarriages. For many years, doctors assessed quality by examining sperm through a microscope—a relatively imprecise method. Lasers give greater certainty to the process. Two highly focused beams act as "optical tweezers" that are used to hold the spermatozoa firmly in place. The way in which the laser light is reflected provides important information on the sperms' motility (Fig. a), enabling doctors to identify the best candidates. The optical tweezers also provide support in the actual process of insemination, transporting the spermatozoa to the egg. Further assistance is provided by a UV laser beam, which drills a tiny hole in the egg to help the spermatozoa get inside (Fig. b). The ability to influence the process with such precision makes this a highly reliable method of insemination—and the non-contact nature of the technology eliminates any possibility of contamination.

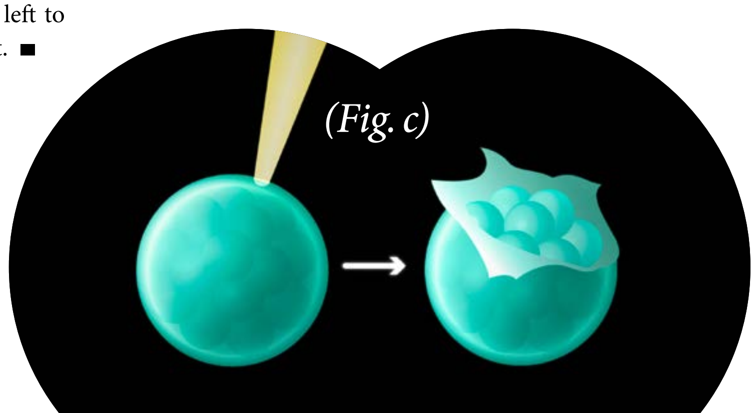
Pregnancy begins once the egg has been implanted in the uterus. For this to take place, the embryo must "hatch" from the egg, something that sometimes fails to occur because the egg membrane (zona pellucida) is too tough. A method known as "assisted hatching" can help the embryo penetrate the zona pellucida. This is performed using an infrared laser, which perforates the membrane (Fig. c). Mother Nature is left to take care of the rest. ■



HOW DO OPTICAL TWEEZERS WORK?

When a photon collides with a particle, the force of the impact causes two things to happen: the photon changes course, and the object struck is set in motion. If the light is powerful enough, it can push the object away with significant force. This effect can be harnessed by using two beams to hold or move the object in the same way you would use a pair of tweezers.


(Fig. b)


(Fig. c)

Gernot Walter

LASER WELDING OF CARBON STEEL TO STAINLESS STEEL 316L

The petrochemical and oil industries primarily use welding to join different metals and alloys due to the advantages this method offers. In his doctoral thesis for Loughborough University (UK), Mohammadreza Nekouie Esfahani (31) set himself the goal of investigating the fundamental phenomena that occur inside the dissimilar weld zone between carbon steel and stainless steel 316L and their effect on weld quality.

The results of his work are available at: bit.ly/1MVtyoK

SIMULATION OF LASER ADDITIVE MANUFACTURING AND ITS APPLICATIONS

For his dissertation at The Ohio State University, Yousub Lee (36) investigated heat transfer, molten metal flow and free surface evolution in both powder injection and powder bed forms of metal additive manufacturing processes. The results provide an in-depth understanding of the underlying mechanisms of solidification morphology, solidification scale and surface finish quality.

The full dissertation is available at : bit.ly/1NWnc92

FURTHER READING

So what are the next steps for light as a tool? The work of five young researchers gives some idea of what possibilities are feasible.

LASER WELDING OF BORON STEELS FOR LIGHTWEIGHT APPLICATIONS

Boron steel is strong and light, making it a good choice for lightweight design. For his thesis at University West in Trollhättan, Sweden, Karl Fahlström (29) investigated the suitability of this material for laser welding. His work focused on the occurrence of cracks, porosity and strength-reducing microstructures that can occur during laser welding, as well as distortion studies. The results provide insights into boron steel laser welding and give some ideas on how to avoid problems with this application in production environments.

To request a copy of the full thesis, please send an email to: Karl.fahlstrom@swerea.se

P-DOPED (AL)GAN LAYERS BY MOLECULAR BEAM EPITAXY

For his thesis at the Swiss Federal Institute of Technology in Lausanne, Marco Malinverni (27) grew p-doped aluminum gallium nitride layers using molecular beam epitaxy—a process that enables scientists to grow thin crystalline layers by means of physical vapor deposition. Malinverni succeeded in using this method to realize electrically injected indium gallium nitride-based laser diodes with a lasing wavelength greater than 500 nanometers. These green laser diodes are an important tool for producing extremely compact and energy-efficient RGB projection systems. *You can read the full thesis here: bit.ly/1RM2psL*

LASER-DRIVEN PROTON ACCELERATION WITH TWO ULTRASHORT LASER PULSES

Laser particle acceleration could reduce the cost of cancer therapy—if the proton energies are high enough. This is why Jürgen Böker (34) decided to search for unknown acceleration mechanisms as part of his thesis at the Heinrich Heine University in Düsseldorf. He focused two laser pulses with peak powers of a few hundred terawatts on a thin foil in a vacuum. The ions were accelerated to mega-electron-volt energies through the interaction between the plasma and the laser pulse, showing signs of a new acceleration mechanism.

The full thesis is available at: bit.ly/1MDti2k

Private

The beam of a CO_2 laser is divided, allowing it to cut four eggshells at the same time.

A *cracking job!*

The pharmaceutical industry wants to know: How do you remove the shell from a chicken egg without damaging the egg inside? Laservorm has the answer: with a laser!

"An egg is perfect," says Thomas Kimme, managing director of the laser systems manufacturer Laservorm GmbH. "From the moment it emerges, it's a sealed space that keeps nutrients inside and keeps bacteria out." Kimme grabs a pencil and draws two rings on a piece of paper, one just barely inside the other. "This perfect space has a double layer of protection." The outer calcareous shell, which is approximately 0.3 millimeters thick, protects the egg against knocks and bumps. Directly behind this is the extremely thin egg membrane, which is impermeable to bacteria, fungi and similar culprits. Kimme looks up from his drawing: "Our task was to cut the shell while leaving the membrane completely intact."

No more mess The job was commissioned by the Dessau Vaccine Plant, now known as IDT Biologika. The pharmaceutical industry has long been aware that eggs are the perfect choice for certain applications. They have spent decades using chicken eggs as sterile nutrient containers as part of their efforts to grow viruses for attenuated vaccines, such as those used against rabies, tetanus and malaria. But first you need to get the viruses inside the egg: "Obviously the outer calcareous shell makes this extremely tricky," says Kimme. The standard approach has been to crack the shells manually using mechanical pneumatic methods: "But no matter how careful you are handling the tool, the result tends to be pretty messy, with lots of breakages and rejects," says Kimme. "It really wasn't very efficient—and it obviously goes totally against the ethical treatment of living organisms, because there are chicken embryos growing in the eggs."

A laser dance around the egg So Horst Kassner from the Dessau Vaccine Plant decided to find a better way to open the shell. Hoping to hit upon a sterile method, he asked LIM Laserinstitut Mittelsachsen GmbH

An IDT Biologika employee watches the shell separation process in the cleanroom.

whether there was any way of doing it with lasers. LIM brought Kimme on board as a mechanical engineer, and together they began experimenting. "Calcium carbonate is an insulator like glass or plastic. So we quickly realized that a CO_2 laser would be the best choice," Kimme explains. "The laser delivers light at a wavelength of between 9.4 and 10.6 micrometers, which is absorbed very nicely by the calcareous eggshell." The laser specialists carried out several rounds of tests to optimize the parameters, ultimately creating a stable industrial process that perfectly opens the eggshell in 99.9 percent of cases. "The laser only cuts the shell. And the very low amount of heat that is applied can be contained in the minimal coagulation at the beam entry point." Once the tests were completed, Kimme and his colleagues set about building the special machine.

Opening on the fly

The result was the Laser Egg Opener, or LEO. So how does the process work in practice? First the fertilized eggs are placed in a container that passes through an airlock. This prevents any surrounding air from entering the processing chamber. At the interface between the two zones, sensors detect whether the container is full, i.e. whether all spaces contain an egg. This tells the laser if there are any unoccupied spaces that it can safely ignore. The laser cutting process itself is carried out on the fly, but without a scanner. "A scanner isn't capable of scanning an entire rack of eggs, so we came up with a faster method." The egg container moves through the laser system and the laser optics track its forward motion. The laser beam is divided into four beams which are guided with millimeter precision by mirrors. This establishes the optimum opening geometry for the downstream process and means that the system always opens four eggs at once. "It's an extremely challenging process in terms of the control technology involved," says Kimme. "But it allows us to process 3,000 eggs an hour, which is ten times faster than using scanning optics." The number of eggs wasted is close to zero.

Once the eggs have been opened, a filter system sucks up any shell particles, and the eggs continue their journey through a second airlock. This minimizes the risk of any bacteria hitching a ride. "Our customers work with living organisms, and they are extremely sensitive to even the slightest nonconformity in the production process," Kimme explains. "This is why it's crucial to have such tremendously high standards of hygiene—and this was a huge challenge for us when it came to building the machine." For example, you can only use a limited number of very high alloy stainless steels and certain plastics that are capable of withstanding the aggressive detergents used in the industry. "We had to cut almost every screw thread ourselves." Other pharmaceutical companies are now also showing an interest in the high-tech egg opener. "The market for this kind of application is tiny. But thanks to laser technology, we can offer something truly unique." ■

Contact: Thomas Kimme, Phone: +49 3727 9974 – 0, info@laservorm.com

Laservorm GmbH

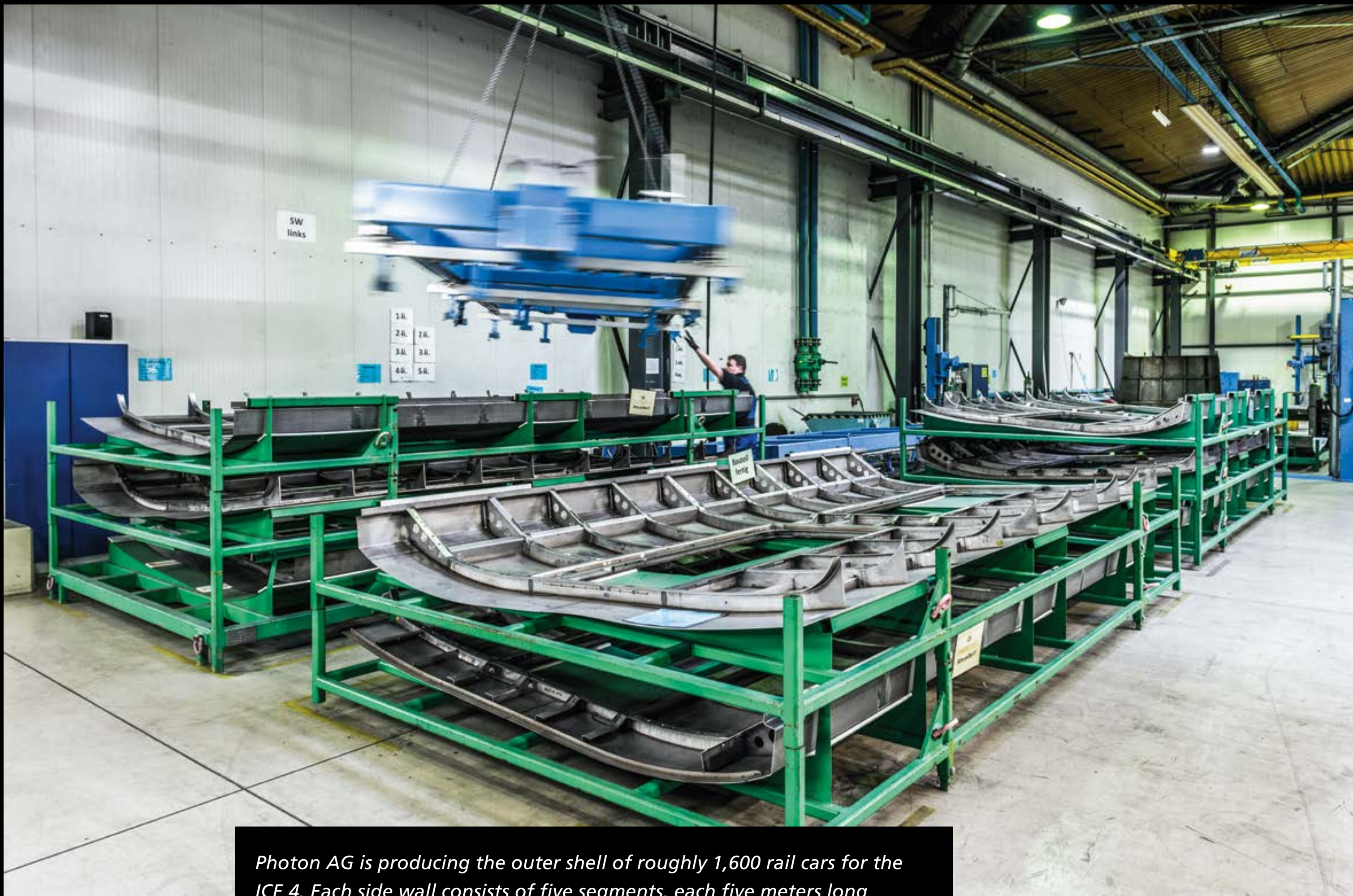
Everything on a larger scale: the side wall of a regional train at Photon AG.

RAIL

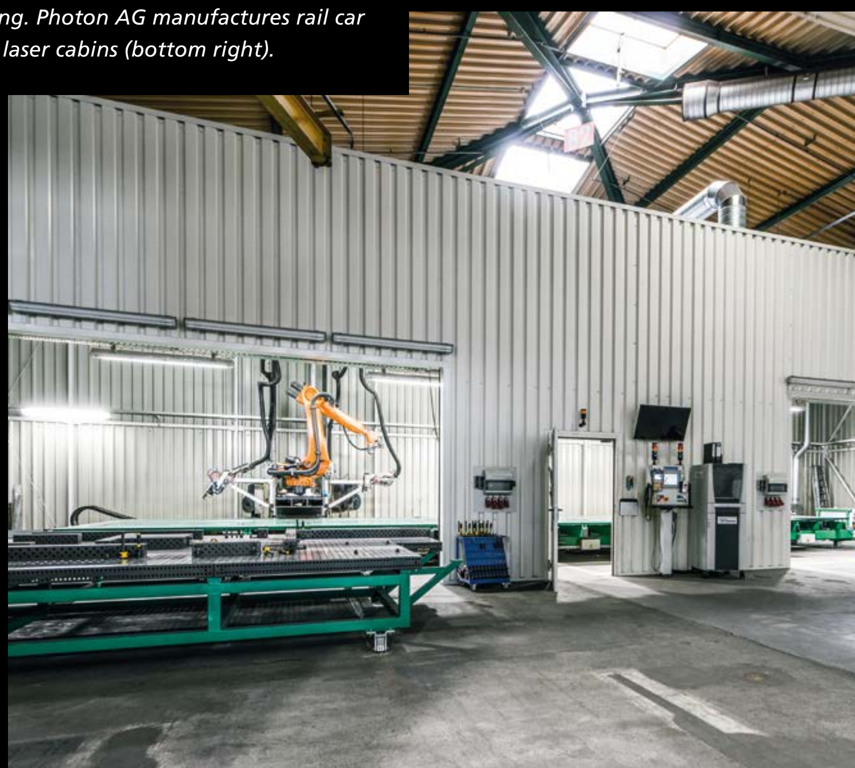
Angelika Grossmann

The automotive industry has long enjoyed the benefits of lasers—and rail vehicle manufacturers are increasingly following suit. Photon AG and its subsidiaries have been using lasers successfully for years. Now they're putting them to the test in a prestigious large-scale project.

WAY



Photon AG is producing the outer shell of roughly 1,600 rail cars for the ICE 4. Each side wall consists of five segments, each five meters long (top). For Holger Alder (bottom left), this major order represents another milestone in rail vehicle manufacturing. Photon AG manufactures rail car side walls up to 25 meters long in its laser cabins (bottom right).



Ten or fifteen years ago, the steel age seemed to be coming to an end in the automotive industry as experts heralded a new era of aluminum. But then along came laser welding, tailored blanks, 3D laser cutting, high-strength steels, huge boosts in productivity, and the widespread emergence of lightweight steel construction. Applying these new developments to rail vehicle manufacturing is the recipe for success chosen by Berlin-based Photon AG—and something of a personal mission for its technical director, Holger Alder.

"In the auto industry, lasers have a proven track record of faster, cheaper and more efficient performance. They've even created entirely new methods of construction," says Alder, who was employed by an automobile manufacturer before joining Photon AG. "In the past few years, we've repeatedly shown that the technologies used to build cars can also be applied to rail vehicle manufacturing. But obviously this isn't a one-to-one transfer—you need to get people on board and make them rethink what works best."

A prestigious large-scale project The know-how gained by Photon AG in its early days suggests that this may be something of an understatement. In fact, the differences between manufacturing automobiles and rail vehicles are substantial. While batch sizes in the auto industry often run into the hundreds of thousands, a decent order in the rail industry could be much smaller, perhaps in the region of several hundred parts. What's more, the safety standards in rail vehicle manufacturing are sometimes higher than those in the auto industry—especially when it comes to high-speed trains—and that makes the processes involved more complex. Once a company has finally obtained all the necessary stamps and certificates for a product, it can be tempting to stick to the same track rather than reworking designs from scratch. "Copy and paste is the lowest-risk method," says Alder with a smile.

Yet at the same time the rail industry is facing similar problems to those besetting carmakers. For example, manufacturers are starting to pay more attention to the weight of their rolling stock. Since many rail cars and locomotives have a service life of up to 30 years, every unnecessary kilogram will ultimately travel millions of kilometers, dragging down the train's overall energy efficiency year after year. Efficiency is also becoming a bigger issue on the production side as companies strive to make their rail vehicle manufacturing processes faster and more cost-effective. The challenges that make lasers an appealing option for rail vehicle manufacturers are practically the same as those facing the automotive industry. Photon AG has overcome these challenges hundreds of times in recent years thanks to the advantages of laser machining. "Lasers enable us to save time, costs and materials in component welding while simultaneously boosting quality," says Alder. The industry is increasingly embracing this approach. In 2014, Photon AG was awarded a prestigious large-scale project involving the production of side walls, roof panels and undercarriage components of around 1,600 rail cars for the new ICE 4, which Siemens/Bombardier is building for Deutsche Bahn. Before assembling the prototype, Photon AG worked with the customer to define the manufacturing strategy for the side walls. These are composed of five modules—each five meters long—which are almost completely prefabricated by Photon AG before being assembled by Bombardier in its own facility. In terms of materials, the ICE 4 marks a return to steel. The rail car bodies of previous incarnations of the ICE were made of aluminum to keep them as light as possible. "That's a material that many people associate with lightweight design, and rightly so," says Alder. "But aluminum generally has a lower tensile strength than steel. So to meet the load-bearing requirements you have to compensate by using thicker materials and large-volume profiles." Since the width of trains is limited by the track gauge, this increased volume could only be extended into the freight and passenger compartments. The ICE 4 is aiming to regain this lost space for passengers by switching to an outer skin made of lightweight steel—obviously without upping the weight or making any compromises in regard to rigidity or safety. Photon AG is familiar with these requirements from the automotive industry and can fulfill them using laser technology. "To stay within the weight limits, most of the outer steel shell can't be any thicker than two millimeters. Yet, if we were to weld metal that thin by conventional means, the amount of heat applied would make the outer skin look like a rollercoaster track," Alder explains. "But thanks to the very high quality of laser weld seams, we can weld even thin steels like this with virtually no distortion and virtually no need for any postweld work." Additional weight reductions are achieved by using tailored blanks that ensure that all the sections of the outer skin are only ever as thick as they need to be.

The side wall segments from Photon have already been fitted to seven ICE 4 trains—some of which are already in on-track testing—and a further four trains are currently in production. Once series production gets underway in late 2016, the company will be producing ten segments a day, equivalent to the outer skin of one complete rail car. The logistics of dealing with this quantity of components in such large dimensions is another challenge that Photon AG has mastered over the years. In fact, the company has manufactured almost 3,000 side walls for regional trains over the past three years, some of which were as long as 16 meters. Five-meter sections seem fairly easy to manage in comparison. "The big challenge of this project was to find a time-optimized automation method for producing the outer skin segments," says Alder. Photon came up with the idea of producing the segments in two laser cabins that can be loaded from two sides. Each cabin contains a robot that welds the sheet metal parts together and attaches them to the longitudinal and transverse struts to keep them stable. While one automated fixture is leaving the cabin with its welded assembly on board and the next is taking up position, a TruDisk disk laser is busy feeding the welding robot in the other cabin. This ensures optimum use of the laser at all times.

Aviation beckons Having already tackled both the automotive and rail industries, Photon AG knows a thing or two about tapping into new markets—and the company already has the next in its sights: "Our experience in designing and producing safety-relevant components and focusing on small and medium production runs makes us the perfect choice for jobs in the aviation industry. We're hoping to secure more orders in that industry over the next few years." The company is always careful to ensure that customers get the competitive prices they expect. "Nobody buys things any more just because they have a 'made by laser' sticker on them! What customers are ultimately looking for is high quality at a price that is comparable to that of conventional welding, or even lower." ■

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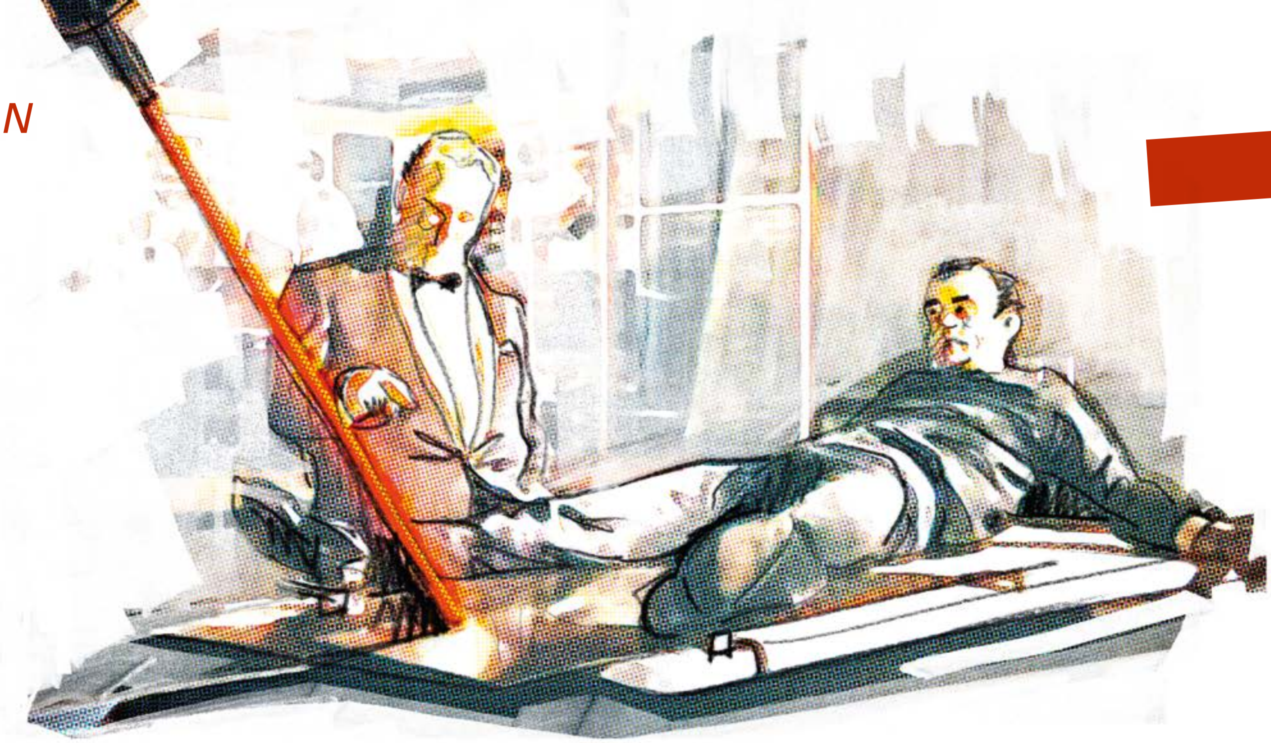
Angelika Grossmann



Gernot Walter

James Bond …

AND LASER MATERIAL PROCESSING

Laser Community's editor-in-chief Athanassios Kaliudis writes a regular column on the laser as an object of popular culture.

When Theodore Maiman demonstrated the world's first laser in his laboratory in 1960, researchers were euphoric. Daring visions of the future began to take shape in their heads. And while engineers were still puzzling over the ins-and-outs and looking for a problem for the laser to solve, Hollywood charged ahead with an innovative idea: material processing. In the 1965 movie Goldfinger—probably one of the most successful and defining examples of the 007 franchise—it wasn't just James Bond who burned himself into the collective consciousness of a generation, but the laser, too.

Sean Connery — alias 007 — lies helpless, tied to a gold-topped table while master villain Goldfinger explains that he no longer has any use for him. He therefore intends to kill him. How? Using a futuristic tool called a laser. To help both 007 and moviegoers come to grips with the concept, the villain introduces the machine with the following words: "You are looking at an industrial laser, which emits an extraordinary light not to be found in nature. It can project a spot on the moon or, at closer range, cut through solid metal. I will show you." At this point a red laser beam begins slicing its way through the table, threatening to cut Sean Connery in half. Goldfinger leaves Bond squirming, the face of the usually cool special agent transformed with fear. A tense dialog ensues in which 007 finally succeeds in escaping certain death by luring the villain with his apparent insider knowledge.

The method used for the special effects suggest that Sean Connery's fear of the laser beam may have been more than just good acting. The laser system was just a mock-up, with optical trickery used to add the beam to the scene during editing. But the cut in the table getting closer and closer to Connery's torso was decidedly real. A member of the film crew was hidden under the table using a welding torch to cut the table, which had been prepared in advance, in half. A single slip-up could have had dire consequences! The laser scene took on cult status because lasers were completely new at the time, heralding a high-tech future. What's more, director Guy Hamilton was able to show what cutting metal with a laser would actually look like—at least approximately.

What was visionary back then has become standard for us today. What kinds of developments might the next 50 years hold? What sorts of laser-based visions of the future will have become a part of our everyday lives by then? Perhaps when I'm 82 years old, I'll be able to simply blink to project the answer into my field of vision using a miniature laser integrated in my bathrobe. ■

What visions do you have for the future of laser applications? Will they be part of our everyday lives in 50 years' time? Send an email with your ideas to athanassios.kaliudis@de.trumpf.com

Where's the laser?

Reaching into eternity: The only data storage media that have proven their ability to endure for thousands of years are stone and clay tablets. Parchment and paper last a few hundred years under normal conditions, CDs are expected to become unreadable after 50 years, and hard drives have a lifespan of just ten years. Now researchers at Southampton University are using femtosecond laser pulses to inscribe micrometer-scale binary data on nano-structured quartz crystals the size of a two-euro coin. The combination of the size, orientation and position of the nanostructures allows information to be encoded in five dimensions, yielding a storage capacity of 380 terabytes. The researchers say that the data in the crystal can remain intact for five billion years. Who said nothing lasts forever?

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