LASER COMMUNITY.

Of people and photons

#27

NOVEMBER 2018

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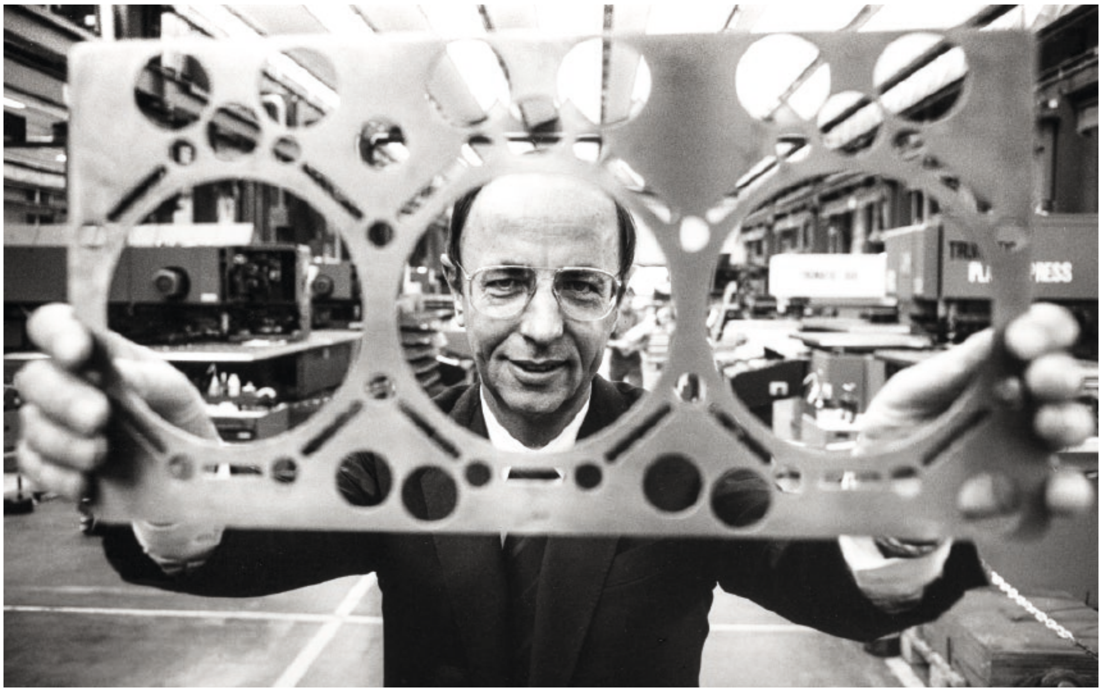
Berthold Leibinger died shortly before this issue went to press.

Issue 28 of Laser Community will include a more detailed look at his remarkable inventiveness and his life's work in the realm of laser technology.



His enthusiasm lives on

Berthold Leibinger was our laser pioneer. We will miss him greatly.

TRUMPF is the high technology company we know today because Berthold Leibinger was struck by something remarkable he saw in the U.S. in the late 1970s: a beam of light that could bore through steel. As an engineer and entrepreneur, he immediately recognized its potential as a tool—in fact, the ultimate tool! From that point on, Leibinger devoted himself to the task of understanding and controlling laser light and making it suitable for industrial use. We all know where that path led: in 1980, TRUMPF launched the world's first laser machine tool.

Berthold Leibinger retained his inquisitive spirit for the rest of his life. The researcher in him was determined to understand exactly what he was dealing with. Leibinger was fascinated by the new opportunities that light offered—and his enthusiasm for the topic went far beyond what might have been expected from a machine tool builder. Examples of this enthusiasm abound. Perhaps one of the most striking is the innovation prize he established in his name, which was awarded in 2018 for the tenth time.

I was there in the audience again this year, surrounded by a who's who of the global laser community, and I was thrilled to see the incredible things we are now doing with this miraculous tool in the fields of medicine, research and technology. Laser users are not only observing living neurons, but also building optical computers and developing life-saving tests designed to rapidly identify antibiotic-resistant bacteria. Obviously Leibinger didn't work on these topics personally, but he was one of the first people to understand the importance and potential of laser light. Over the course of his lifetime, he transmitted that fascination and enthusiasm to us and to countless others.

Berthold Leibinger passed away in October 2018. But enthusiasm for the laser lives on at TRUMPF and all around the world, for instance in the realm of 3D printing—which we present in this issue.

Dr.-Ing. Christian Schmitz
Chief Executive Officer Laser Technology
Managing Director of TRUMPF GmbH + Co. KG

TRUMPF

Flickering tube

Our Seattle-based photographer Stuart Isett is used to working in hostile environments, from the war on drugs in the Philippines to the Cambodian Civil War. Fortunately, our assignment at the LIGO Hanford Observatory in Washington only required him to battle the heat: 43 degrees Celsius, to be precise. You can see the shimmering results on **page 30.**

Lurking horrors

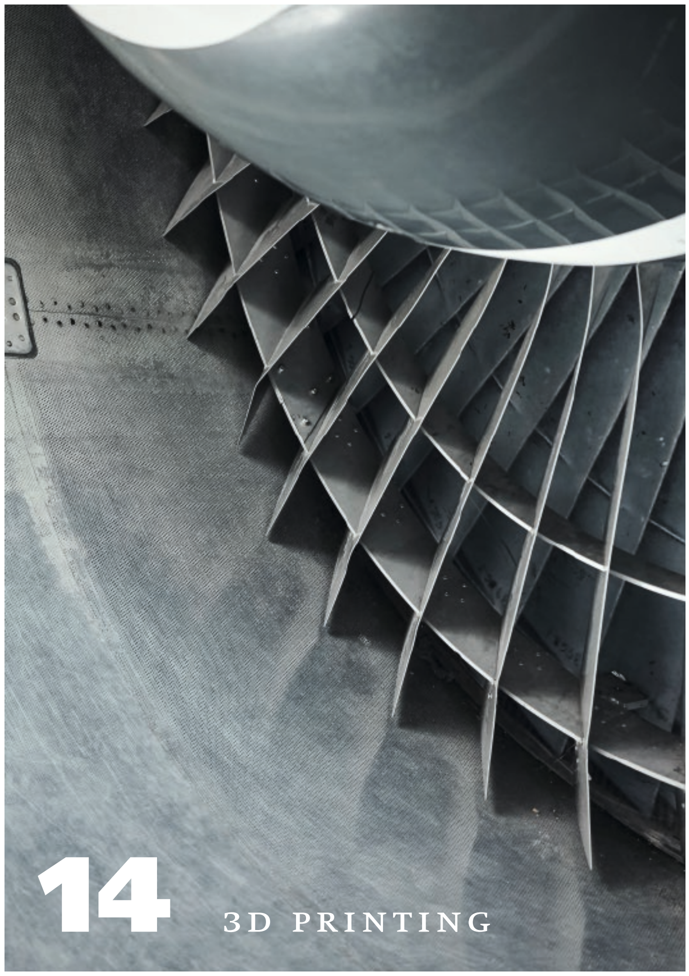
A sea monster dragging a boat full of desperate sailors to the bottom of the ocean certainly makes for a great picture. But the true terrors of the sea are the crustaceans and mollusks that cling to ships, hastening many of them to an unhappy end. Schwerin-based illustrator Jürgen Willbarth sets the scene for our article with some marvelous pencil drawings. Feeling brave? Then turn to **page 28.**

Oops!

It seems we were short of a few photons in **issue 26.** On **page 20**, we referred to a doctoral dissertation by Yinggang Huang on creating 3D micro-structures using femtosecond lasers—but we showed a picture of Rico Cayhadi, whose dissertation we are presenting for the first time in this issue! Our apologies to Yinggang Huang. Here is the photo we should have used!

Stuart Isett, public domain, private

LASER



edele-fotografie / Adobe Stock, Stuart Isett

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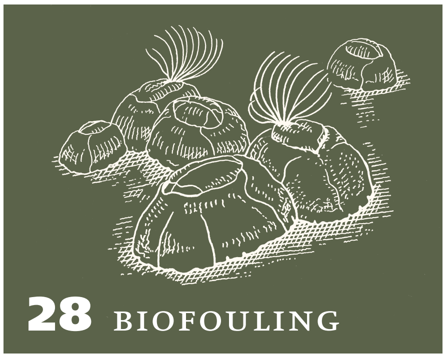
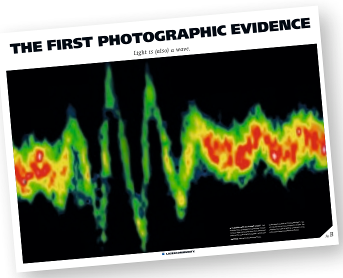




POSTER INSIDE:
The first photograph of a lightwave

Nuclear Advanced Manfacturing Research Centre, Cody Ellingham / Propaganda Studios, Jürgen Willbarth / Die Illustratoren

POWER

One in ten bombs dropped in the two world wars failed to explode on impact—and they are still being unearthed today.

THE PROBLEM OF UNEXPLODED BOMBS

Christian Hoff, Head of Additive Manufacturing – Metals at Laser Zentrum Hannover e.V., is in charge of the laser-based deflagration project. This method could offer a safe way to disarm unexploded ordnance in war zones.

Unexploded ordnance from World War II comes to light in Germany on a fairly regular basis. Defusing these devices is a hugely difficult—and sometimes deadly—task. Experts hope that an automatic laser system could make this job safer and easier in the future.

Clank! The excavator's shovel has struck metal—and what initially looked like a rusty boiler is, in fact, an unexploded bomb. One false move and it could bring entire apartment blocks tumbling to the ground. Shards of window glass could be thrown thousands of meters, creating lethal projectiles. The authorities move into action. The police evacuate everyone within a 12-kilometer radius—emptying hospitals, retirement homes, penitentiaries and rail stations—and the bomb disposal team arrives at the scene and attempts to eliminate the danger as best they can. All this happens several times a year in Germany as a result of some 1.6 million tons of explosives that were dropped on German cities in World War II by British and American bombers. Some 60,000 tons of unexploded ordnance remains buried beneath densely populated areas, and old bombs are unearthed on a regular basis.

Disarming these devices is becoming increasingly difficult. After 80 years in the ground, the old explosives and detonators have typically deteriorated to a degree that makes them highly unpredictable. But now a team of researchers led by project manager Christian Hoff at Laser Zentrum Hannover e.V. (LZH) is developing a new method of rendering unexploded bombs safe. Their approach relies on leaving the detonator alone and attempting instead to weaken the bomb casing. They then aim to interrupt the ignition chain by means of a targeted deflagration. Experts say that the thickness of the bomb casing is a major factor in determining the maximum possible explosion pressure. If the bomb casing immediately yields to the explosive charge then, instead of a gigantic boom, you get a comparatively harmless type of explosion.

There is no way of safely opening the casing of a live bomb using mechanical tools. Transporting the tools to the site is difficult or impossible, and they generate too much heat and vibration as they open up the casing. Using laser light, however, it is possible to ablate a grooved "notch" in the 10 to 25-millimeter thick casing without touching it. The amount of heat applied in this process can be controlled as long as the molten material is kept well away from the explosive charge. The bomb disposal team could then use this predetermined breaking point to carry out a deflagration at subsonic speed, converting only part of the explosive material in the process. Although the pressure wave would be lower, it would still be sufficient to "pop out" the detonator backwards, rendering the bomb safe.

The LZH engineers have already succeeded in significantly weakening bomb casings using their laser system in the lab. Their goal now is to complete the project by 2019 and unveil a mobile, automated system. This would make the hazardous job of bomb disposal substantially safer in the future. ■

Christan Hoff (LZH), Gernot Walter

GLORY

50!

Many happy returns! The Laser Institute of America (LIA) is turning 50. So what does the future hold?

We asked LIA President Professor Milan Brandt why the society still has the word America in its name: "I've been part of the LIA for nearly 30 years—and for 30 years we've been saying that the name is no longer suitable." Today, the LIA is a professional hub for 2,000 members that include laser end users, medical professionals, experts, researchers and entrepreneurs. Around half of them are not American, with many members stemming from Europe and East Asia–predominantly China in recent years. "I'm confident that the time has finally come: I think we will soon rename ourselves and change America into Global or International. That would better match the reality and our aspirations."

The LIA was founded in 1968 with the aim of unifying the laser community and fostering a productive exchange of ideas and views among its members. One of the key ways of achieving this is through international conferences, the most important of which is the annual ICALEO. The society's second major goal is to define and certify laser safety and raise global awareness of this key issue. "Despite our many successes in the past, laser safety continues to be an extremely important part of what we do. We are currently focusing on expanding the reach of our training programs to South America and China," says Brandt. "In the US, we are advocating for policies that would see laser technology embedded more firmly in schools."

The LIA can look back on a series of successes to mark its anniversary. These include the internationally renowned Arthur L. Schawlow Award, which the society has been presenting annually since 1982 to people who deserve particular merit for their work on or with lasers. So what does the future hold? Brandt thinks the LIA's primary goal should be to increase the number of members, corporate partners and conference participants: "We want to be a catalyst for international networking in the field of laser technology. One of our key goals is to recruit the young students who will help shape the LIA over the course of the next 50 years." ■

Laser safety continues to be one of the LIA's top priorities.

Gernot Walter

“Our superhydrophobic surface is set to become the first that is sufficiently durable for industrial use.”

Superhydrophobic surfaces are nothing new but their fragility has always been a limiting factor for their use in industrial applications. That’s about to change, though, according to Professor Minlin Zhong who believes the technology is on the cusp of a breakthrough.

Professor Zhong, superhydrophobic—or water-repellent—surfaces would, theoretically speaking, come in very handy in industry. But as things stand their use in industrial applications is very limited. Why is that?

We’re looking at two challenges here. Most of today’s surfaces lack sufficient durability because their nanostructures are so susceptible to wear and damage through contact with solid particles. Currently, there is not a single superhydrophobic surface on the market robust enough to meet the strict abrasion, impact and adhesive strength standards required for use in industrial applications.

And what’s the other issue?

The production process. Even if somebody developed a sufficiently robust surface, they would still need a scalable production process. It’s no secret that speed is the name of the game in industry, so a quick and cost-effective solution for producing large-scale surfaces is a must. That’s just not possible when processes such as chemical etching or plasma coating are involved.

You managed to tackle both problems in one go. How?

Throughout my career, I’ve gained a lot of experience with lasers used for surface processing. Needless to say, I know what these impressive tools can do. So, when it comes to producing nanostructures, I firmly believe the ultrashort pulse laser is the best tool for the job. Thanks to a technique known as cold processing, the laser can supply the high level of energy required without causing heat influence zones to form, which are counterproductive. This approach works with a range of different materials suitable for use in industry. So, after liaising with my team, we opted for a TruMicro 5000 femtosecond laser from TRUMPF. It delivers an average power of 40 watts, which was sufficiently high for our research purposes.

How does your technique of generating nanostructures with a laser differ from others?

The most important difference is that we don’t focus exclusively on the nano-level. To ensure we meet all the surface requirements, we produced a hierarchical

Superhydrophobic surfaces are not as smooth as you might first think. They are actually made of nanostructures that serve a very specific purpose: their job is to increase the contact angle at which droplets of liquid hit the surface to at least 120 degrees. This minimizes the contact the water makes with the surface and causes the droplets to “bead” and roll off.

AHEAD

Professor Minlin Zhong teaches at the School of Materials & Science Engineering at Tsinghua University in Beijing, where he is also director of the research center for laser material processing.

structure with two levels: micro and nano. At the micro level, we created tiny cones with the height and spacing we wanted on the surface. The nanostructures themselves sit on of the outside of these micro cones to form the second level. This approach doesn't impair the surface's superhydrophobic properties—in fact, it does the opposite. We work with a contact angle of 163 degrees. It's really quite amazing!

And that makes the surface more durable?

Yes, precisely, because the micro structure protects the nanostructure. The tips of the micro cones collectively intercept objects and particles that could come into contact with the superhydrophobic surface. This prevents any harmful matter from reaching the nanostructures in the first place. We pursued a rigorous test campaign covering all conceivable scenarios and always came out with the same result: our hierarchical structure is set to become the first superhydrophobic surface in real-world applications.

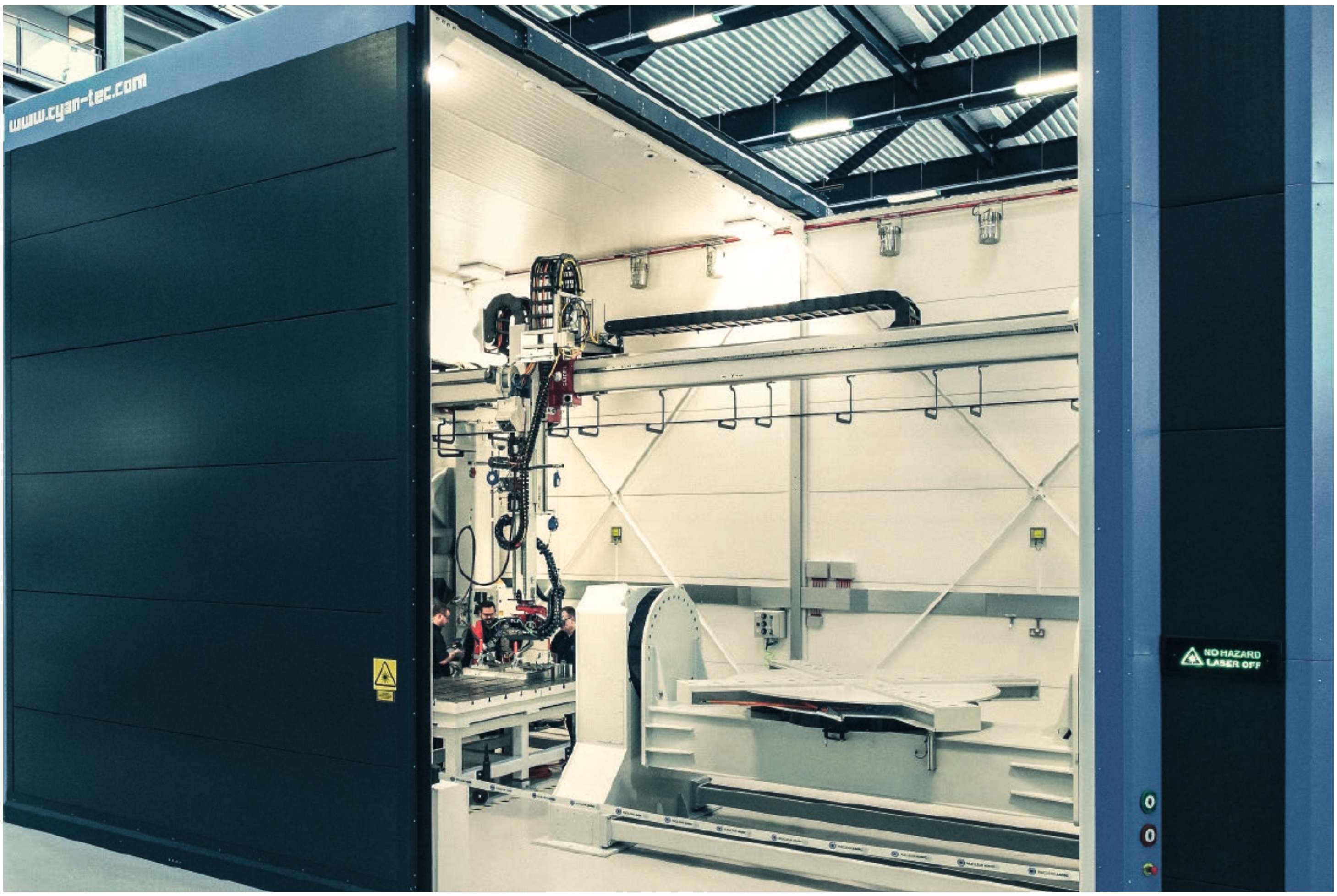
What are the next steps?

We're currently looking to identify industry partners—companies we could join forces with to scale up our method for real-world use cases. I don't expect we'll have any problems on that front. Existing tools and approaches, such as polygon scanners or multi-beam scanning, will enable us to bring our processing speed and surface up to the required level. Give it two years and I'm confident that our technique will be ready to go. ■

kolotuschenko / iStock, Dave Hanssen / Propaganda Studio

Sealing the fate of the UK's nuclear waste

The UK generates large quantities of nuclear waste. Temporary storage of this waste can lead to problems due to a lack of suitable metal containers. Fortunately, help is at hand: The Nuclear Advanced Manufacturing Research Centre has come up with an idea.



Nuclear Advanced Manfacturing Research Centre

Does the process work? Björn Krämer (left) and his team tried it out in a series of tests on small parts. That provided the proof they needed—but they will have to do a lot more welding to convince potential customers.

Everything we do here is big," says Björn Krämer. "From the thickness of materials to the size of parts and machines, it's all on a grand scale!" He works at the Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC), in Rotherham, on the outskirts of the English town of Sheffield and part of the University of Sheffield. In his role as Technical Lead—Laser Welding, Krämer is responsible for developing new laser methods. His job is to help British suppliers win contracts in the nuclear sector. One way to do that is by offering metal containers for the temporary storage of intermediate-level radioactive waste from nuclear power plants. The problem is that these containers are in short supply. Although they come in various designs, all of them are welded by hand, which is a time-consuming process. It can take as long as a week to complete just one container using traditional arc welding methods. The integrity and resilience of the weld seam is critical: radioactive waste must be packaged safely to ensure that absolutely no leakage occurs.

Demand for these products is high: "The UK market will need thousands of these containers over the next few years," says Krämer. As part of its efforts to reduce CO_2 emissions, the UK is keen to transition away from coal, and the government regards gas and nuclear power as suitable alternatives. The UK currently has 15 operational nuclear reactors, with one further reactor under construction. That means radioactive waste will continue to accrue over the years ahead—so providing appropriate temporary storage will be crucial.

Some countries—Germany for instance—already have suppliers that can produce suitable containers using lasers, but Krämer's customers are hesitant to follow their lead. "Companies working in this sector in the UK are still some way behind in the laser technology stakes," he says. "They are skeptical as to why they should invest in a laser if they are already successfully using other methods to weld the containers." He argues that an automated laser process is faster and more economical and that it creates higher-quality weld seams. Those are certainly persuasive arguments: even the most experienced welder needs several passes to build up an airtight weld seam in stainless steel or duplex steel that is between six and 15 millimeters thick—but a laser can do the same thing in just one pass at speeds of up to two meters a minute. Laser welding also generates less heat input in the metal than manual welding. That reduces thermal stress and results in less distortion.

THINKING BIG! There is a catch, however. Currently, it is not possible to get hold of a laser welding cell that can accommodate containers measuring 1.3 by 1.6 by 1.6 meters—and in the future the market will require even bigger containers measuring 2.5 by 2.5 by 2.5 meters. Those dimensions are simply out of the question for traditional systems. In fact, no commercially available system has enough space for parts of that size. So Krämer needed help—and he found it at Cyan Tee Systems. Together with the systems integrator, he began working on a design for a laser cell that could cope with these super-sized demands. It may sound like a mammoth undertaking, but Krämer says that it has so far been "astonishingly easy". By the beginning of this year, he had a system up and running in the Nuclear AMRC laboratory that exceeded all previous dimensions. The laser cell measures seven by ten meters, is eight meters high, and is equipped with a Class 1 laser. And things are just as impressive on the inside. A six-axis gantry drive moves the laser head across the two-axis table, which can support components weighing a total of up to 15 metric tons.

DISK LASER OFFERS SCOPE FOR CREATIVITY

Choosing the laser beam source was a fairly simple matter. A CO_2 laser was not an option due to the complex beam guidance requirements. That left the team with the choice between a disk or fiber laser. Krämer opted for the disk laser: "Our goal here is research, which involves trying out lots of different things. That means there is always a chance of something going wrong. One false step and we could get a back reflection that would damage the laser. But that can't happen with a disk laser." So the cell is now equipped with a 16-kilowatt TRUMPF TruDisk laser—the most powerful disk laser in the whole of the UK, Krämer notes. "Twelve kilowatts would have been enough to start with, but since we work with such thick materials, we wanted to be ready to tackle whatever the future might bring. Now we can be confident of being able to weld whatever we set our mind on."

Visit our website to see the laser cell in action: www.trumpf.com/s/tv3f5e

“Obviously users are not going to actually need a laser cell with a 560-cubic meter work area. But we need to think big.”

Björn Krämer, Technical Lead — Laser Welding, Nuclear AMRC

On the hunt for suitable welding methods for extremely thick seams, the researchers followed some leads in the shipbuilding industry. One method that particularly interested the welding experts was hybrid welding. That’s why the team decided to add a MIG welding head to their research cell at Nuclear AMRC to tackle material thicknesses in excess of 15 millimeters. Compared to MIG welding, the process causes less distortion and warping due to the lower heat input—and that makes the whole welding process a lot more flexible.

Stable laser power output was another prerequisite for achieving the high seam quality dictated by the nuclear industry. The TruDisk 16002 provides this stability with a plus/minus of just one percent. “That’s extremely good, and it sends an important message to end customers.” In fact, Nuclear AMRC believes in getting these end customers on board early on in all its research projects, Krämer says: “We can’t tell suppliers to use a laser that is perfectly suited to this process if their customers, the companies that operate the nuclear power stations, subsequently refuse to certify the manufacturing process.”

SO DOES IT WORK? The welding cell certainly checks a lot of the right boxes, but Krämer cautions that even the most experienced experts can find it challenging to handle the sheer power involved. “Because the system is a prototype, we have an enormous number of options available to us. Right now we are working out how to program it properly, seeing what it can actually do, and testing its limits.”

Tests carried out on smaller parts in different welding positions have already demonstrated that the process works. The idea now is to gradually increase the size of the parts and the thickness of the materials. But Krämer stresses that there is still a long way to go. The contract manufacturers that will subsequently use the method—and indeed their end customers in the nuclear industry—are still waiting for conclusive proof. Krämer knows that it will take a huge amount of welding experiments to convince them. “The only way to show that our method works is to build up the biggest possible database of process parameters.” Obtaining certification for a manufacturing process in the nuclear industry is a particularly time-consuming business. After all, nobody wants to take any chances with the safe storage of radioactive materials.

Double the power: As well as a disk laser for hybrid welding, the research cell also features an MIG welding head, enabling it to weld extra thick seams.

A QUESTION OF SIZE When it comes to helping companies in the supply chain to enter the realm of laser processing, the team of researchers need to know exactly how to make the most of the machine’s capabilities in order to pass that knowledge on. But isn’t a system with a 16-kilowatt laser and such enormous dimensions a little bit over the top for most companies? “Absolutely,” says Kramer. “In those cases it’s our job to say: You don’t need a 16 kilowatt laser and you don’t need a 5 x 7 gantry drive to move the process head. It’s possible that all you need is a robot and a different laser. We simply decided to think big so that we would still be able to use the cell for research in ten years’ time.”

Krämer is already mulling over another job his laser could do in the future: “At some point, it will be necessary to open the containers to transfer the radioactive waste to lower-security facilties. Since the containers are contaminated, special measures must be taken when they are cut apart. We call that ‘cutting for decommissioning’.” Equipped with a special cutting head, that’s another job the TruDisk would be capable of handling. Mobile applications that use robots to dismantle nuclear power stations might also be an option in the future. Krämer and his team are already working on the process. ■

Contact: Nuclear Advanced Manfacturing Research Centre, phone: +44 (0)114 222 9900, enquiries@namrc.co.uk

Nuclear Advanced Manfacturing Research Centre

PRINT

If 3D printing were a human being, it would be on the verge of adulthood. All the broad outlines are already there, but it might well still have some surprises up its sleeve. Here we take a look at the key trends.

PERFE

Gernot Walter

3D

printing is on everyone's lips, but the term has come to mean very different things to different people—or perhaps it always did. In the case of metal 3D printing, new methods seem to be taking root on an almost annual basis. The idea of constructing parts layer by layer in a powder bed has inspired numerous engineers and developers. Three methods that have already become well established are laser metal fusion (LMF), electron beam melting und binder jetting. They share the limelight with the nozzle-based method of laser metal deposition (LMD)—another additive manufacturing (AM) process—as well as wire-based methods that are also classified as LMD. Measured by market share, LMF and LMD are currently the top AM methods for producing metal parts. But ask "What's the best method for me?", and there is unlikely to be an easy answer, because each method has its ups and downs. For example, LMF may be the best option for producing parts with delicate structures at the highest level of quality, but binder jetting can do the job between ten and a hundred times faster.

If 3D printing were a human being, it would arguably be a gifted 17-year-old. The broad strokes of the teenager's personality and talents are already visible. The parents can hazard a guess at which direction their offspring is likely to take but, however much the teenager tries to act cool, there is still much they need to learn. Yet so much has already been achieved: the child has learned to walk and talk, read and do math. They have already done their first part-time job and been praised for their efforts, and now they are busy cramming for their high school diploma. There's something in the air, a sense of freedom and independence, a new dawn.

3D printing is at a similar stage. Engineers and universities are continuing to probe and develop new ways of using the technology. Yet 3D printers have also been in fully fledged industrial use for many years, especially in pioneering sectors such as the aerospace industry. The teething troubles that dogged it in the early stages—especially with regard to the reproducibility and robustness of the process—have been left behind, conquered by the machine-makers' skills. 3D printers are gaining ground on the shop floor and ready for industrial use. More and more business people see the technology making inroads into their industry and are seriously considering jumping on board before their competitors take the plunge. But what are the key trends they should take into account before making their decision?

More and more business people see the technology making inroads into their industry and are seriously considering jumping on board before their competitors take the plunge.

THE PROS AND CONS OF MULTIPLE LASERS The first thing to consider is the build chamber. In principle, it's true that the more lasers you have in a 3D printer, the faster you can build parts. This simple equation has fueled the commercialization of multi-laser machines with two, three or even more lasers. Unfortunately, however, it's not that simple, because there are all sorts of other factors that play a role, too. One of the keys to boosting the productivity of 3D printing is to find the optimum combination of scan field, scan speed, temperature adjustment, temperature field, build speed, and gas flow in the work area. The number of lasers and their power output is just one factor among many—though it is certainly one of the most expensive of all the factors involved. In some cases, a fourth laser can increase the cost of the system by 25 percent while only increasing productivity by a decidedly modest two percent. Often it can be more profitable to start with seemingly less trendy components of the machine such as the build chamber heating system. A smart heating concept is worth its weight in gold because it keeps the printing process stable and increases overall productivity.

Some multi-laser machines with large build chambers promise to speed up the job of producing bulky parts with the argument that two lasers can build the rear portion of the part while the others focus on the front. That also seems sensible at first glance. But the crucial question is what happens in borderline areas. If the lasers' scan areas are too far apart—in other words if there is not enough overlap between their work areas—, then the part ends up with non-homogenous sections and ugly seams. During use, these often mutate into unwanted, yet effectively predetermined, breaking points. What this comes down to is that you can't identify a highly productive 3D printer by the number of lasers it has, but only by its overall design.

Another aspect of the trend toward multiple elements is the idea of combining 3D printing with other machining methods in a single machine, for example with milling and drilling. Unfortunately, that typically ends up transforming the unquestionable marvels of 3D printing into an annoying drag on the other built-in processes. The reality is that the expensive, integrated milling cutter spends half the day waiting around idly for the 3D printer to reach a certain stage in the build process. Then it leaps into action for two minutes, before returning to its slumber for the remainder of the day. No production planner with any sense would install a high-end milling machine on the shop floor if it was hardly ever going to be used. Right now—and even in the longer term—the difference in processing speeds between 3D printing and traditional methods is simply too great to offer any good reason for combining them in the same machine. That is no longer the case for other additive manufacturing methods, however, such as laser metal deposition (see report on page 22).

A BROADER PERSPECTIVE However important it may be to ask "How many lasers does the part need?", it brings into focus a perspective that has traditionally, and understandably, been very narrow. For years, everyone was fixated on the build chamber. Just

You can't identify a highly productive 3D printer by the number of lasers it has.

like with any new method, engineers initially focused on how they could get the process under control and make it faster. And they succeeded: Over the past five years, they have managed to increase the productivity of the LMF process by a factor of three—a truly remarkable achievement in such a short space of time, and a trend that is likely to continue for some time to come.

But the time has now come to adopt a wider perspective by focusing on the upstream and downstream stages of the process. These include unpacking the powder, refilling the machine, sieving the powder and checking it is mixed correctly, as well as blowing or shaking off excess powder, removing parts from the build plate, removing any supports they may contain, and carrying out finishing work on the surface. That's where some of the greatest potential lies to accelerate and possibly automate indivdual steps, for example through powder management. An automatic, self-contained powder handling system is also an appropriate response to occupational health and safety issues, which play a bigger role in the broader industrial environment than they used to. The problem here lies in the metal powder itself, which poses a health risk and should not, under any circumstances, be inhaled. Currently, however, only the biggest companies are opting for the most complete automation solutions for production integration. In contrast, traditional job shops generally prefer to operate their 3D printer in isolation, rather than incorporating it directly in other production processes.

But however big or small their business, all 3D aficionados have a shared enthusiasm for good software. New concepts are opening the door to a self-contained software process chain without any frustrating interfaces—a chain that stretches from CAD data modelling right through to finishing work.

Apropos these post-processing stages: the supports required by the first generation of 3D parts once formed a magnificent bridge into the realm of this exciting new technology. They still have their uses today, but industrial-scale deployment has revealed their drawbacks by highlighting the increased cost and effort required during post-processing. This realization is a great example of what industry needs right now: new ideas that cater specifically to 3D.

3D THINKING The visionary power of 3D printing has always stemmed from the design freedom it offers. Parts can be formed exclusively on the basis of their functionality—and nothing else. Yet the greatest advantage of 3D printing is, at the same time, its greatest challenge. One of the toughest tasks design engineers face is how to rethink existing parts and leave old conventions behind. Most part developers have learned to base their designs on the intended machining process, and in doing so they have assimilated a number of what they considered to be 'golden rules,' for example "You can't drill around a corner", "You can't cast a cavity", and so on. Particularly in the early days of the 3D revolution, design engineers struggled to liberate themselves from this traditional mode of thinking. Many 3D printed parts greatly resembled their conventional counterparts. But now things have changed. More and more universities and apprenticeship schemes are teaching budding designers to think free form, with no inhibitions concerning the production process. Now the first of this new generation are graduating and looking for jobs. Equally, some suppliers of 3D printing technologies responded quickly to the huge demand they saw in this area and began supporting their customers with training courses in free-form design. Unlimited design freedom is increasingly becoming a core component of training courses, especially in Germany and Switzerland. China, too, has seen which way the wind is blowing and is teaching its design engineers accordingly. The new generation of designers are likely to make fundamental changes to the shapes and forms of future parts. At the same time, on the software front, design and simulation programs are improving all the time and automatically suggesting 3D-specific design options. All this will give industrial 3D printing even more of a boost—and that prompts the question of why the laser should only be melting metal.

BEYOND METAL Material diversity—a long underrated argument in the 3D printing debate—is now emerging as one of its most decisive strengths. Both LMF and binder jetting offer levels of flexibility in this respect that are quite simply beyond the scope of other methods. A huge array of metal powders are now commercially available. Users worldwide can acquire them quickly and easily, mixing them together to meet specific requirements. They include a class known as Inconel alloys, which can easily withstand temperatures in excess of 1,000 degrees Celsius in turbine blades. Equally impressive are the special alloys that allow parts to withstand extreme bending—alloys that can only be processed by 3D printers.

One of the key trends in 3D printing involves new functional materials that go beyond metals, because laser beams are also perfectly capable of melting other materials. Metallic glasses are one example: In the near future, we are likely to see high-grade optical components and mirrors coming out of 3D printers. Meanwhile, developers are currently working on ways to get ceramic powder into 3D printers—another material that is prompting a great deal of interest.

YOU CAN DO IT The more sectors we see taking the plunge into 3D printing with their industry-specific requirements, the greater the variety of machines and production concepts that are likely to emerge. Something that is good enough to meet the stringent quality standards of the aerospace industry is likely to be far too over-the-top for a moldmaker's needs. This kind of differentiation is also compounded by the increasing wealth of available materials. Much of the road ahead is already clearly signposted, but there are bound to be a few surprises, too.

So here we have our 17-year-old, a gifted teenager striding proudly and boldly into the world of industry. The parents of 3D printing can finally sit back and relax, safe in the knowledge that their teenage prodigy can take it from here. ■

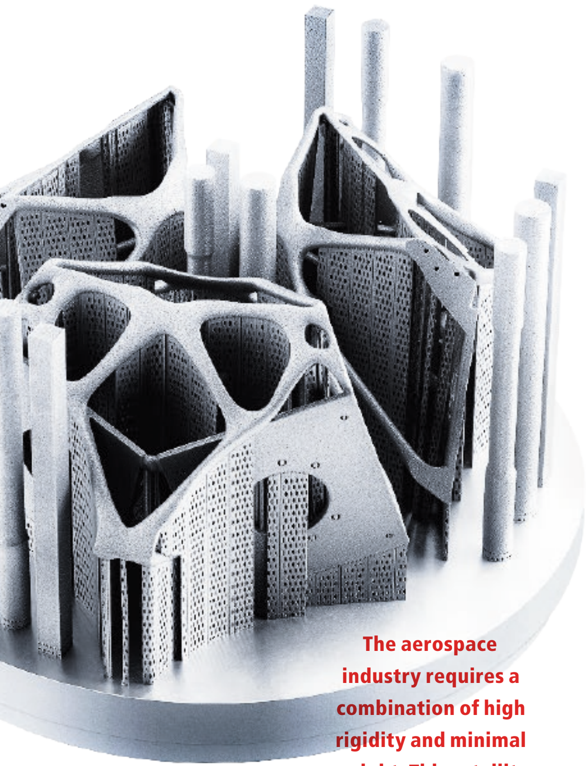
Contact: Dr. Thomas Fehn, General Manager Additive Manufacturing, phone: +49 (0) 7156 303-31823, thomas.fehn@trumpf.com

DLR/TRUMPF, Conmet

WHAT'S PRINTING?

Five industries are currently experiencing a 3D

1 AEROSPACE



The aerospace industry requires a combination of high rigidity and minimal weight. This satellite part is just one example.

The aerospace industry was the first to embrace 3D printing, and now regards it as a standard part of their toolkit. The reasons are clear: unlike cars, aircraft are in almost constant use and spend very little time parked. That means the price of each individual component plays much less of a role. The decisive factor is how well it fulfills its intended use—and in this case lightweight design is the name of the game. If you can make an aircraft component one kilo lighter by modifying its design, that can translate into direct savings of hundreds of thousands of euros in kerosene costs over the aircraft's service life. What the industry needs is the highest possible quality standards in batches that are typically very small—and that makes LMF the ideal choice. The most popular 3D printed parts in the industry are turbine components.

2 MEDICAL DEVICES AND DENTISTRY

These sectors are also playing a pioneering role, with 3D printing proving to be particularly popular for items such as dental prostheses, inlays and other implants. In practice, you need both off-the-shelf and custom-built parts, because every hip and dental prosthesis is different. Custom implants are easier to insert and can help patients recover faster. One likely development is that imaging methods will be used to measure a patient's knee or jaw and then send a CAD blueprint of the required implant directly to the 3D printer, which will then immediately start building it.

Skull implants such as this one will help many cancer patients in the future.

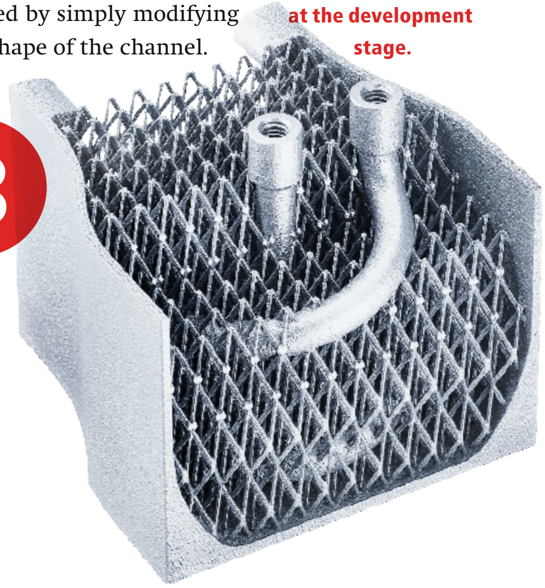
TRUMPF, TRUMPF, Philipp Reinhard

MECHANICAL ENGINEERING

It's a familiar yet unpleasant chore for machine makers: having to pacify a customer even though the machine they ordered is almost ready for delivery—all because a couple of small parts are unavailable and have brought the whole process to a halt. The industry is taking steps to rectify this situation by installing its own 3D printers to shake off the shackles of its suppliers' schedules. 3D printers can supply high quality versions of parts such as clamping fixtures. A first wave of companies is also starting to print its own consumables, such as milling tools and drill bits, asserting their independence in this area, too. More and more machine makers are discovering new functionalities through 3D printing—for instance nozzles that can be hugely improved by simply modifying the shape of the channel.

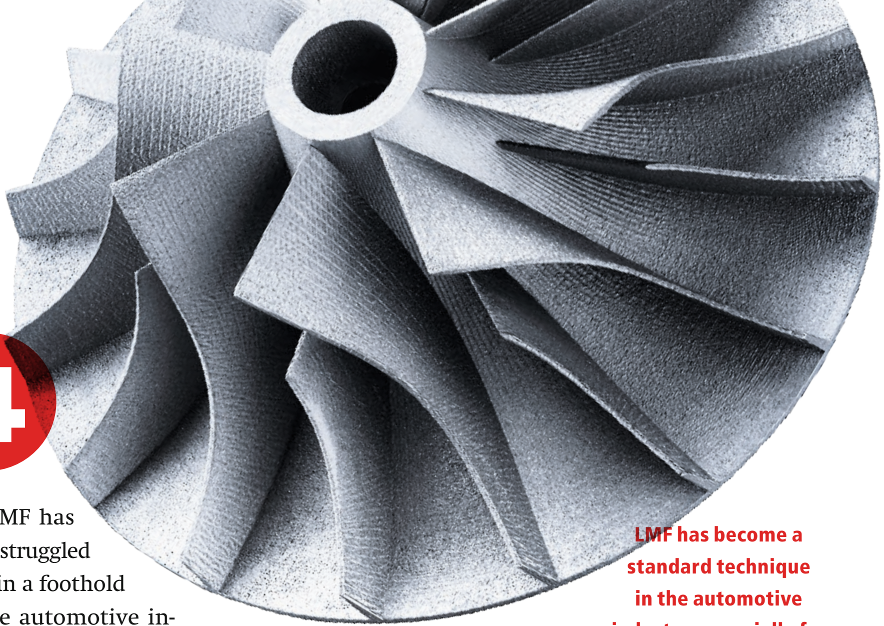
The ability to print your own heat exchangers saves time and money at the development stage.

3



AUTO-MOTIVE

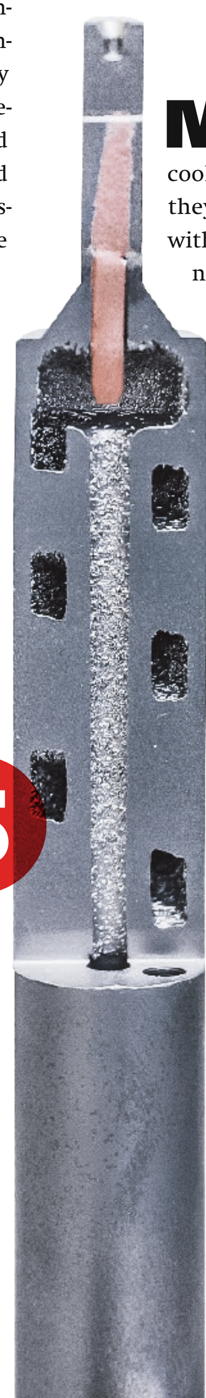
4



LMF has struggled to gain a foothold in the automotive industry due to the focus on minimizing prices and sticking to conservative design principles. All the components used in this industry are designed with well-established methods in mind such as casting and turning—and this situation is unlikely to change. LMF is only used for visible parts in premium vehicle segments and for filters and flow-optimized exhaust manifolds. The industry also has high hopes for the speedy binder jetting process. By eliminating the need for a mold, this method will help companies slash the cost of producing parts that were formerly cast and that are produced in quantities of less than 100,000 pieces.

LMF has become a standard technique in the automotive industry, especially for turbochargers and heat exchangers.

TOOL-MAKING



5

Manufacturers of injection molds have recently discovered the cooling effects of 3D printing—and they are now printing mold inserts with flow channel designs that have never been seen before. Conventional methods such as drilling or milling cannot always reach all the areas of a tool that need to be tempered, even though this is critical to ensuring that an injection-molded part cools in an optimum fashion. That has consequences, including manufacturing problems, diminishing quality over a part's service life, and high scrap rates. 3D printing opens the door to completely new cooling designs that can easily reduce scrap rates by 30 percent while increasing overall quality.

This mold core offers an example of how internal structures simply cool better.

printing revolution.

PERIODIC SURFACE MODIFICATION ON SEMICONDUCTORS

Ultrafast laser irradiation can be used to form periodic surface structures in the sub-micrometer range. In his doctoral dissertation at the University of Michigan, Rico Cahyadi (27) investigated the mechanisms and dynamics involved in forming these types of structures in semiconductors and metals. To do this, Cahyadi performed experiments under various irradiation conditions and with different material systems. He then carried out simulations of the systems using analytical models and finite element calculations and characterized the subsequent material transformations using a combination of microscopy and chemical analysis techniques. Find out more:

https://deepblue.lib.umich.edu/handle/2027.42/138571

CORRUGATED CORE STEEL SANDWICH PANELS FOR BRIDGES

Laser-welded corrugated core steel sandwich panels are significantly lighter than conventional orthotropic steel decks. Used as bridge decks, these panels can achieve major reductions in the weight of steel bridges. They are also more durable and cheaper to produce. In his licentiate thesis at Chalmers University of Technology in Gothenburg, Peter Nilsson (35) investigated the impact of production-dependent parameters on panel fatigue and developed simplified methods of structural analysis. The full paper is available online:

https://research.chalmers.se/publication/253342

LATEST RESEARCH ←

So what does the future hold for light as a tool? Work by four young researchers gives some idea of what possibilities lie ahead.

EFFECTS OF LASER RADIATION ON POWDERED MILK

In his master's thesis at Sudan University of Science and Technology, Sami Abdalla (33) investigated how laser beams affect the moisture content, pH value and ash content of powdered milk—three factors that determine its taste, shelf life and health properties. Red light from a helium-neon laser decreases the moisture content of milk powder. Ash and pH values both fall. Using a green diode laser, the moisture content stays constant, the pH value drops and the ash content increases. These findings will help companies to produce better and cheaper powdered milk. Read more about the results of his work:

http://repository.sustech.edu/handle/123456789/16091

LASER ABLATION IN LIQUIDS FOR FUEL CELLS

Hydrogen fuel cells convert the chemical energy of hydrogen and oxygen into electrical energy with the help of a catalyst. However, conventional catalysts contain precious metals such as platinum and are very expensive. In her doctoral dissertation at Duisburg-Essen University, Galina Marzun (32) investigated a method of preparing nanoparticles in liquids using laser ablation and then obtaining non-precious-metal catalysts in a subsequent processing step. This method could lead to huge reductions in the cost of manufacturing hydrogen fuel cells in the future. Find out more:

http://duepublico.uni-duisburg-essen.de/servlets/DerivateServlet/Derivate-44352/Diss_Marzun.pdf2

Private collection

Give me power!

Converting power to light and back again: The idea of transmitting electricity wirelessly via laser could provide the answer to some thorny problems.

≈≈≈ Example ≈≈≈

01

SPACE ELEVATOR

This idea basically involves an elevator traveling into space and back attached to a cable. But where would it get the power? Probably not via the cable. Stretching 36,000 kilometers into space, it would require hundreds of generating stations and substations to supply the pod with power over such a long distance. That's why experts prefer the idea of using defocused laser light. Lasers on the ground would fire at highly efficient photovoltaic cells on the underside of the space elevator, which would convert the light back into electricity.

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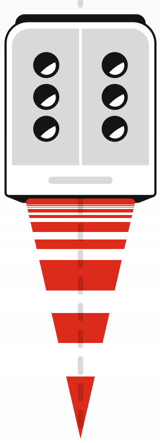
Despite regular proofs of concept delivered by various space elevator competitions, there is still a long way to go.



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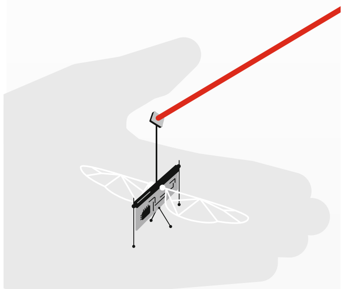
02



MICRODRONES

Microdrones require tiny components, which is no problem as far as mechanical parts, electronics, cameras and sensors are concerned. Batteries are a different matter, however. Bound by chemical laws that rule out miniaturization, they last just a few minutes. Experts have therefore come up with the promising idea of using a laser beam to supply airborne microdrones with power as and when they need it.

≈≈≈ Status ≈≈≈

It's already working in the lab. Challenges include the need for visual contact and, above all, how to supply power to a broadly dispersed swarm.

≈≈≈ Example ≈≈≈

03

PHONE CHARGING PAD

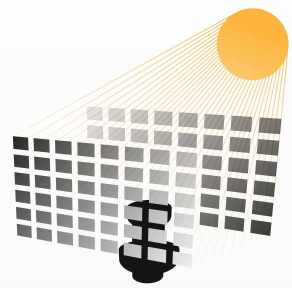
Ever since our phones became mobile, we have been faced with the question of where our smart devices will get their next charge. Wouldn't it be handy if we could charge our phone by simply placing it upside down on the conference table or bar counter in front of us? The control software of a laser battery would detect our smartphone and then focus laser light on the photovoltaic module built into the back of the screen until the device was fully charged.

≈≈≈ Status ≈≈≈

As far as the software and laser technology go, this idea is ready to roll. The same applies to the smartphone casing. The only thing that still needs a slight boost is the efficiency of the photovoltaic elements.

≈≈≈ Example ≈≈≈

04



SOLAR POWER FROM SPACE

The energy yield of a photovoltaic module nearly doubles outside the Earth's atmosphere. Solar cells in orbit could use the energy they capture to generate a laser beam and direct it at solar farms on Earth. Despite the conversion losses and the fact that the laser light would have to penetrate the atmosphere, this should still offer a substantial benefit over purely terrestrial photovoltaic farms with the same surface area.

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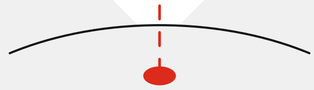
Despite various proofs of concept, there is still a long way to go. For one thing, the huge construction that would be required in space might well depend on our ability to implement the space elevator in our first example.



Gernot Walter

Seiei Yamamoto had no intention of re-inventing laser metal deposition, so he simply bought in the expertise he needed.

Cody Ellingham

What would it be like to have one tool that does it all? A machine that offers cutting, grinding, laser metal deposition and laser hardening, all rolled into one? Seiei Yamamoto from the Japanese company Okuma couldn't get that question out of his mind. *So he picked up the phone …*

The multitasking machines in the LASER EX series combine additive and subtractive manufacturing methods and can carry out hardening and coating of workpiece blanks.

Okuma

YAMAMOTO REMEMBERS:

"I explained that we had been following the development of additive techniques closely for a number of years. Just like all engineers, we were fascinated by the new technology here at Okuma. We were particularly interested in laser metal deposition (LMD), or laser cladding, because of its high process speeds and deposition rates."

Headquartered in the Japanese town of Ōguchi, Okuma is one of the world's leading CNC machine tool manufacturers. But what's different about this company is that it specializes in multitasking machines that combine several production methods in a single unit—turning, milling and grinding for instance. These are all subtractive production methods and, at the time of the phone call, the machines only offered this type of functionality. "But what if we incorporated an additive method, too?" Yamamoto continues. "That would give us the best multitasking machine anyone has ever seen."

Yamamoto had customers from the aerospace and automotive sectors and suppliers of castings and formed parts in mind. When it comes to low-volume parts, process reliability and superior production quality are key factors—and Okuma figured those parts would be ideal candidates for the laser. "Processes such as milling or turning always have to be followed up with a significant amount of post-processing. That costs time and money and requires a specialist. By integrating an additive process, you can produce many parts without the need for any rework at all," he says. He explains that the laser can perform a whole host of different tasks quickly and accurately, including 3D molding—applying protective coatings made of heat- and wear-resistant alloys—and material deposition for repairing turbines, blisks and die cast parts.

True to form, Okuma and its multitasking experts went one step further, arguing that if they were going to the effort of incorporating a laser, then it might as well be a multipurpose one. "That's how we came up with the idea of adding laser hardening to the machine, too, which would save yet another step in post-processing."

"We figured we might as well use the laser for hardening, too."

THE QUEST FOR THE PERFECT PARTNER Yamamoto emphasizes that Okuma wasn't looking to reinvent the wheel: "We wanted to work with a partner that had experience in additive technology and was prepared to pair their expertise with our tried-and-true machine components and the control system we have developed here in house." The quality expectations were high and Yamamoto was keen to get things moving quickly, without spending too much time on long test periods. "After my phone call with Antonio Candel-Ruiz at TRUMPF, I knew we'd found our perfect partner."

THE COMMON DENOMINATOR TRUMPF's coating expert Antonio Candel-Ruiz set to work. "It was an exciting but somewhat daunting prospect. Machining processes are really fast, so we weren't sure if adding LMD to the mix was even feasible. And how would we cater to Okuma's broad set of requirements? They wanted a full range of deposition coverage, from wafer-thin structures to larger surfaces—and the quality had to be second to none. Then, on top of all that, there was laser hardening to consider! That effectively narrowed down the options to just one type of laser: the disk laser," he says. In the end, Candel-Ruiz opted for a relatively powerful four-kilowatt disk laser with extremely high beam quality. Delivering twice the required performance, it more than exceeded Okuma's

“Eliminating the need for post-processing has enabled our customers to increase their output rates tenfold.”

expectations. They had cleared the first hurdle. “The next step was the optics,” Candel-Ruiz continues. “Flexibility was a key factor here, too, because Okuma understandably wanted to avoid having to change the optical system.” Fortunately Candel-Ruiz had the right answer up his sleeve. He chose an optical system with a variable laser spot diameter that can be adjusted between 0.4 and 8.5 millimeters.

A CRASH COURSE IN LMD Yamamoto recounts his side of the story: “LMD was unchartered territory for us, which is why we were delighted to find laser equipment so well matched to our requirements. The expertise in additive manufacturing that TRUMPF brought to the table was equally as important. Together, we managed to build up a huge knowledge base in a very short space of time.” The first step was for the experts from both companies to sit together, look at Okuma’s portfolio and determine which parts would lend themselves well to LMD processing. Candel-Ruiz recalls their collaboration from his perspective: “Okuma built several prototype machines for which we developed sample applications there on site. Our focus was on identifying suitable materials and the most favorable geometries. Know-how transfer was key. For example, we showed them how parameters such as laser power and gas quantity depend on which powder you’re using, and explained how to develop suitable exposure strategies.”

ONE TOOL THAT DOES IT ALL All the hard work has paid off and Okuma has now rolled out the enhanced multitasking concept to two new machines. They perform milling, turning, grinding and laser metal deposition and can also be used for heat treating workpieces of all different shapes and sizes. Yamamoto is over the moon with the results: “Using the machine for hardening is much faster and results in less deformation. And eliminating the need for post-processing has really paid off. Throughput times are reduced by 90 percent, enabling our customers to increase their output rates tenfold.”

Design engineers are increasingly aware of the advantages that hybrid manufacturing methods offer and are factoring the technology into their production plans from the outset. “We supply the right machines for the job,” he says. “I reckon we’ll soon be seeing parts that are specifically designed to be produced or processed on multitasking machines only.”

Contact: Okuma Corporation,
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Phone: +81 (0) 587 95 7801, se-yamamoto@okuma.co.jp

… and on the other end was Antonio Candel-Ruiz from TRUMPF.

Antonio Candel-Ruiz is an expert in laser metal deposition at TRUMPF.

i4.0

Kill the time killers

SOME PEOPLE THINK MACHINES JUST NEED TO WORK FASTER—BUT IT'S NOT THAT SIMPLE. THE PROBLEMS LIE ELSEWHERE. ANYONE WHO WANTS TO SPEED UP THEIR PRODUCTION LINE NEEDS TO DIGITALIZE THEIR ENTIRE PROCESS.

How can we produce things faster? That's a question many companies ask themselves. Their search for an answer typically leads them to their machines and the products themselves. How can we make our machines work even faster? And how can we design our products in a way that minimizes the number of production steps? But what many people fail to take into account is that the time spent producing a product on a machine only makes up some 20 percent of the overall manufacturing process. The remaining 80 percent of the time is spent on indirect processes such as ordering, storage and transportation. And the trend towards smaller batch sizes is steadily making these non-value-adding processes even more complicated.

The solution is to handle the whole business intelligently, in other words digitally. That starts from the moment you draw up an offer. It often takes several days for a customer to receive a quotation, yet this step can be automated with a web shop. The customer is given an account where they can upload their specifications and get a quotation within just a few seconds. When they click confirm, the job data is processed immediately. Another big issue is the time spent searching for things: knowing what stage a job has reached, for example, or where the parts are located that are next in line to be laser-welded. Trackers can be used to keep track of parts wherever they are and—with an additional code on the workpiece—staff can use scanners to immediately call up all the details of a specific job. Digital solutions can also minimize downtime or even eliminate it altogether. For example, a machine can call attention to itself by sending a message to a technician's smartphone if it stops working. This can be made even more efficient by getting machines to notify the technician before the problem even arises. Many machines from TRUMPF can already do this by using statistical data to announce when a component may fail, including an estimate of how likely it is to happen. That enables workers to order and replace the component in good time. We are working hard to extend this option to all our machines. The potential for connectivity also applies to intralogistics, in other words the flow of goods within a company. The right software can help automate stock levels and material orders and ensure that blanks always reach the right machine at the right time.

In 2017, TRUMPF opened a smart factory in Chicago to show customers the potential of connected manufacturing. Experience has shown that, in some cases, companies that connect up their entire process chain can achieve a 50 percent reduction in production times.

Tobias Reuther is the director of the TRUMPF Smart Factory in Chicago, US

Gernot Walter

Monsters from the deep

Barnacles, duck shells and shipworms are the true terrors of the sea. Swagatika Patra explains how ships might eventually be able to leave all those hangers-on in their wake.

Surfaces exposed to water are colonized by bacteria in next to no time. This bacterial layer provides the perfect gateway community for unicellular algae, fungi and other tiny organisms, which accumulate to form a biofilm. Next come the sessile crustaceans such as goose barnacles, which attach themselves firmly to the biofilm together with algae, sea anemones and soft coral species. This steady proliferation of organisms is known as biofouling, and it causes enough frictional drag to make ships burn significantly more fuel. What's more, the adhesion of microorganisms leads to a biocorrosion process that can decrease the strength of the ship's hull or even cause cracks that require costly repairs. Biofouling is a problem that affects not just ships, but also other structures that are permanently situated in water such as bridge piers, wharfs, buoys and offshore rigs. Experts put the cost of downtime and increased maintenance due to biofouling at some 200 billion US dollars a year in the shipping industry alone.

NON-TOXIC PATTERNING Our research aims to find an eco-friendly method of preventing biofouling from occurring in the first place. Currently, the shipping industry's go-to solution involves biocides such as cuprous oxide and zinc pyrithione—substances that exhibit poor biodegradability and pose a major threat to marine organisms. Non-toxic antifouling coatings gradually wear off, causing another form of pollution that affects aquatic habitats. They have now been banned by the US Environmental Protection Agency (EPA).

Our approach is different. Essentially it involves modifying surface structures on a micro and nano scale to prevent microorganisms from attaching themselves to the surface in the first place. It is based on two well-known examples from nature: shark skin and lotus leaves. Lotus leaves are known for their self-cleaning properties. They possess a superhydrophobic surface that causes droplets to "bead" and roll off the leaf, carrying any contaminants with them. This mechanism provides

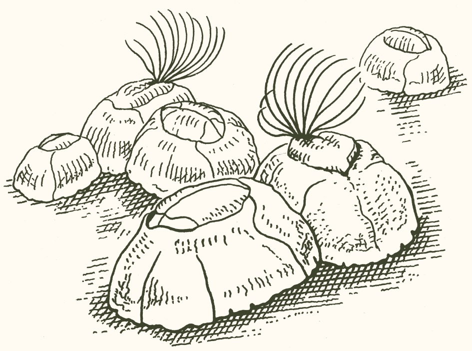


fig. **A**

BARNACLES (Balandiae) are arthropods that belong to the subphylum Crustacea. These sessile animals live primarily in coastal waters, though some species of barnacle live in deeper regions of the ocean. They use their feather-like appendages to fish for microorganisms and suspended particles.

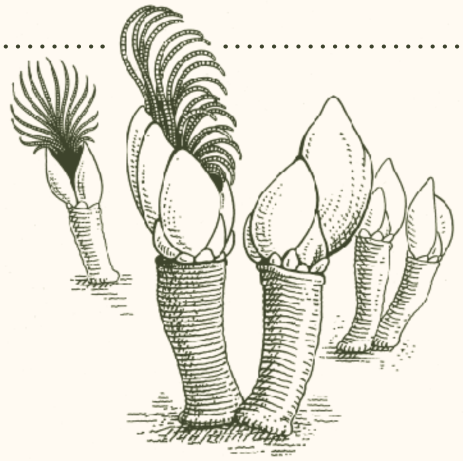


fig. **B**

GOOSE BARNACLES (Pedunculata) are sessile organisms. They are predominantly found on rocks and flotsam. Goose barnacles have a muscular stalk that supports a shell-shaped head. They feed on plankton, using their cirri to filter the tiny organisms out of the water.

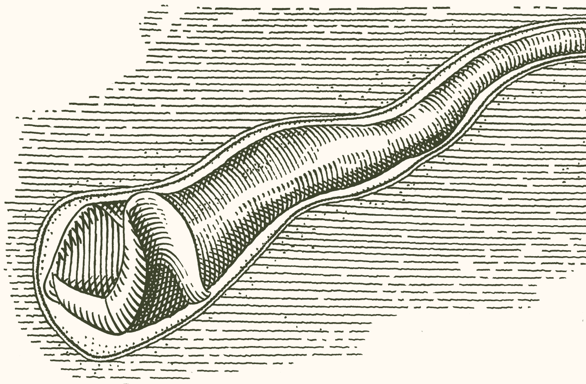


fig. **C**

SHIPWORMS (Teredo navalis) are a type of bivalve mollusk. This soft-bodied creature excavates a burrow lined with a calcareous tube, gradually working its way deeper into the wood. It prefers warmer waters and nourishes itself by converting wood cellulose into sugar.

a useful starting point for developing antifouling surfaces. Shark skin has typically attracted researchers' interest due to its useful hydrodynamic properties, but in this context, we are primarily interested in its surface topographies that prevent microorganism attachment.

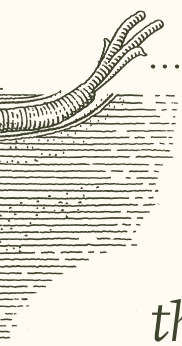
ANALYZING DROPLETS Armed with a clear objective and our two examples from nature, we set to work. We began by investigating how microscale topography affects a surface's hydrophobicity. To do this, we applied a microscale surface pattern using picosecond laser micro-machining. Our aim was to predict the antifouling efficacy of surface structures by comparing the results obtained with a range of different patterns. To classify the rate of microorganism adhesion, we applied two key concepts: engineered roughness index (ERI), and contact angle. The engineered roughness index is designed to illustrate the correlation between the settlement of microorganisms and the wettability of micro-patterned surface topographies. The ERI is a dimensionless value which is calculated as the ratio of the product of Wenzel's roughness factor (r) and the degree of freedom of the pattern (df) to the depressed surface area fraction (fD).

The other key concept is the contact angle. For our purposes, this is the angle that a water droplet on a surface forms to this surface. This angle characterizes the hydrophobic or hydrophilic nature of the surface. The higher the hydrophobicity, the lower the rate of microorganism adhesion. A surface is hydrophobic if the contact angle is between 90 and 180 degrees, in which case the water droplet does not sit relatively flat on the surface, but instead looks more like a balloon. If the contact angle exceeds 150 degrees, we refer to it as a superhydrophobic surface—one example of which is the lotus leaf.

ANTI-FOULING TOPOGRAPHY Using laser pulses, we fabricated patterns on a surface made of poly methyl methacrylate, also known as PMMA. We then studied the patterns under a scanning electron microscope to check the width of the cut and the spacing between adjacent surface features. The results showed that we could achieve the desired properties by creating a circular pattern with two 'hatch levels'—microscale square pillars and interconnecting depressions—with a feature size of 100-200 microns. This topological structure leads to a dramatic shift in hydrophobicity. It increases the contact angle of a five milliliter water droplet from 70 degrees for a smooth surface to 113 degrees for the topographically modified surface. At the same time, the ERI value of the surface increases from zero to 1.13. This implies that the rate of microorganism attachment would also drop significantly—and that makes our discovery an effective antifouling solution.

Our plans for the future include experimenting with new patterns and engineered features on different material surfaces to identify the most suitable patterns for real world applications. Making the best choice ultimately depends on finding an economical means of fabricating these micropatterns across the entire expanse of a ship's hull. ■

SWAGATIKA PATRA carries out research at Lamar University in Texas along with her research partner Raghabendra Rout under the supervision of Prof. Xinyu Liu. Their goal is to use ultrashort pulse lasers to create non-toxic methods of combating biofouling.



Biofouling costs more than 200 billion dollars a year in the shipping industry alone.

HOW IT STARTS

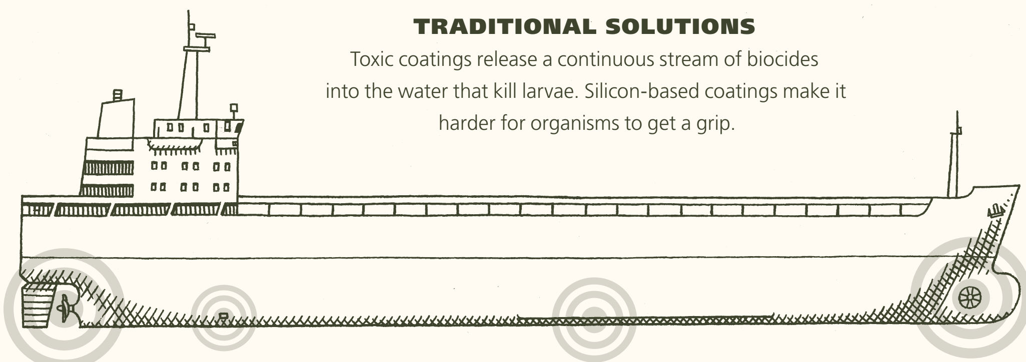
Biofouling starts with an initial film of sugar and proteins. Next come bacteria, then microorganisms such as algae and fungi, followed by small sea creatures such as barnacles and goose barnacles.

WHAT IT DOES

Biofouling increases the weight and frictional drag of vessels, leading to higher fuel consumption. To prevent further damage, the accumulation of organisms must be periodically removed in dry docks.

TRADITIONAL SOLUTIONS

Toxic coatings release a continuous stream of biocides into the water that kill larvae. Silicon-based coatings make it harder for organisms to get a grip.



THE FAVORITE SPOTS for organisms to cling onto—although typically they cover the entire hull—are the rudder, propeller, sea valve chest, bilge keel and bow thruster.

Jürgen Wilbarth / Die Illustratoren

"COULD WE BE ON THE VERGE OF FINDING SOMETHING

Aidan Brooks in front of one of the two four-kilometer-long concrete tubes at the LIGO observatory in Hanford, Washington. The tubes contain the world's most sensitive laser interferometer.

TOTALLY NEW —BEYOND ANYTHING WE'VE EVER IMAGINED?"

Aidan Brooks is in the business of measuring gravitational waves. He expects big surprises that challenge our understanding of the universe—if we trust our math.

Stuart Isett

Detecting gravitational waves has always required a huge effort and involved tremendous costs. Is it worth it?
I would say yes, without a doubt! The first detection of gravitational waves in 2015 was a beautiful signal in its own right. One of my friends even had the signal tattooed onto his arm. But the important thing is that we're experiencing the start of an entirely new field of astronomy—one unlike anything we've seen before. It's also worth remembering that relative to other Big Science projects, the cost of the Laser Interferometer Gravitational-Wave Observatory, or LIGO, is quite modest. The International Thermonuclear Experimental Reactor (ITER) and the Large Hadron Collider (LHC), for example, cost over ten billion dollars each. LIGO only cost 1.2 billion dollars, spread over almost 30 years.

So what do we get for those 1.2 billion dollars?
We can now start to use gravitational waves to probe high-energy physics regimes that we've never had access to before, such as mergers of black holes or neutron stars. And when you combine that with electro-magnetic observations of the universe to create multi-messenger astronomy, the science becomes even richer.

What do you hope to learn from this research?
There's a lot of science to be gained from examining the collisions of neutron stars. The pressures and densities of these events are far beyond what we can achieve on Earth. Gravitational waves give us a laboratory to explore physics beyond anything we could hope to achieve on our own planet. Of course, we still want to explore binary black hole systems and their population in the universe. And the question we're asking ourselves is whether there are dark matter candidates lurking in our gravitational wave signals. Could we be on the verge of discovering something completely unexpected? Something beyond anything we've imagined?

What do you mean by that?
It seems to be a universal law in science that brand-new technologies inevitably bring new surprises in terms of our understanding of the universe. And it's a relatively safe bet to say that gravitational waves are going to reveal plenty of surprises, both big and small. We've barely scratched the surface yet.

In 2017 you detected gravitational waves from a merger of neutron stars 130 million light years away. Can you describe how it feels to arrive at work one day and suddenly experience something like that?
"Sudden" is exactly the right way to describe it. There's no warning. You think you're having a normal day and then "bang!"—suddenly there's a signal alert. On that day, I had just arrived at the office. I made myself a coffee and planned, as usual, to check our event database which is normally just a long list of glitches. But suddenly my colleague rushed in and said there was something totally new in there. The signal was at least 20 seconds long—very different to anything we had seen before. At the same time, satellites had detected a large burst of gamma rays. We were all on a massive high for the next 24 hours, but then the news got even better: Our electro-magnetic telescope partners had used our rough localization and found the exact source in the sky—a bright new object that hadn't been there days beforehand. Seventy telescopes turned to look at that object— all because of our signal! It was an exhilarating feeling.

"SEVENTY TELESCOPES TURNED TO LOOK AT THAT OBJECT—ALL BECAUSE OF OUR SIGNAL! IT WAS AN EXHILARATING FEELING."

When you look at the curves on your monitor, how do you know what you're actually seeing? The observation of gravitational waves is such an indirect science. Doesn't that make you uneasy?
From a human and emotional perspective, sure. But as scientists we're trained to trust our mathematics. The fact that we can trust our math is key to everything we do—especially when operating far beyond human scales.

In addition to all the math, what are the essential requirements for detecting gravitational waves?
There's a long list of things you need, but the decisive factor is always stability. Let me give you an example. When the detector—a laser interferometer—is at full power, it has nearly one million watts circulating inside it. Even though we have mirrors with extremely low absorption—less than one photon in every million—, the power absorbed by the mirrors still comes to a few hundred milliwatts. The pressure from the photons and the thermal expansion

Aidan Brooks is Senior Staff Scientist at the LIGO Laboratory at Caltech—the California Institute of Technology.

of the glass create very weak lens effects in our optics. When I say weak, I mean a focal length of tens of kilometers, but it's still enough to create major problems for our detectors!

How do you counter that problem?
We project CO_2 laser beams onto the optics. The beams are precisely shaped to create a negative lens and remove this time-dependent distortion in the optics. It's extremely important that our CO_2 lasers are perfectly stable. Believe it or not, large enough fluctuations in the CO_2 laser power can show up as a dominant displacement noise source depsite being of the order of one billionth of a billionth of a meter!

What are the next steps in the LIGO project?
Our primary goal is to improve the sensitivity of our detector. If we double our sensitivity, we increase the volume of events we can observe by a factor of eight. Right now, we're working on squeezing quantum vacuum fluctuations. And we're always hunting noise. We are also proposing a project to come online around 2024 called A+ which will involve some even cooler new squeezing technology and state-of-the-art coatings on the mirrors. With all that in place, we could be detecting one or more gravitational wave signals per day!

You've been working for LIGO for over ten years. Up until 2015, you knew that the likelihood of detecting a gravitational wave was extremely low. How did it feel to spend years working on a goal with so little chance of success?
I certainly wouldn't characterize the likelihood of success as low, especially after the major sensitivity upgrade of LIGO into Advanced LIGO in 2015. I admit that the project was hugely daring and ambitious, but it wasn't a pure gamble—it was based on solid science. With Advanced LIGO, we knew that there was a strong chance of detecting gravitational waves—so much so that we would have to review our understanding of General Relativity if we hadn't seen anything. Again, we had to trust our mathematics. Our sponsor, the U.S. National Science Foundation, could see that if the project was successful, it had the potential to revolutionize physics and astronomy. And, following our first major upgrade, we were fortunate enough to detect something after only a few days. Things happened so fast that we didn't have time to worry about not seeing any signals.

Do you ever look at the stars at night?
I live in Los Angeles, so the stars are never really visible. That said, when I'm at either of the detectors I occasionally take advantage of the opportunity to gaze at the stars. I have to admit, though, that I'd probably need an astronomy app to point to the location where our gravitational waves came from. ■

GRAVITATIONAL WAVES

Gravitational waves are not vibrations travelling through space, but rather vibrations of space itself. They stress and compress it, causing ripples in the fabric of space-time. The waves are generated by accelerated masses moving through the universe. Albert Einstein first predicted the existence of gravitational waves in 1916. One hundred years later, scientists detected them directly for the first time.

THE LIGO PROJECT

The Laser Interferometer Gravitational-Wave Observatory (LIGO) consists of two gravitational wave detection facilities in the United States. Hundreds of researchers all around the world are involved in the project. In 2015, LIGO detected gravitational waves generated by the collision of two black holes for the first time using extremely sensitive, multi-kilometer laser interferometers. Following this breakthrough, three LIGO researchers received the 2017 Nobel Prize in Physics.

ACCESS LASER

TRUMPF's Seattle-based subsidiary produces high-tech CO_2 laser-beam sources for industrial and scientific applications. The company developed exceptionally stable CO_2 lasers for use in the LIGO project.

"AT FULL POWER, THE LASER INTERFEROMETER HAS NEARLY ONE MILLION WATTS CIRCULATING INSIDE IT."

Each day, researchers filter out thousands of interfering signals for the highly sensitive laser interferometer—including their own footsteps.

Stuart Isett

Prints like Teen Spirit

WHEN 3D PRINTING GROWS UP

F minor power chords ring out from his electric guitar, initially without distortion. But now the drummer joins in, and he repeats the same chords, heavily distorting each one. As he reaches the chorus he seems to be carried away by an infectious sense of excitement, the sense of a new beginning. The magic of youth infuses the performance, and anything seems possible.

In January 1992, grunge band Nirvana and their lead singer Kurt Cobain knocked Michael Jackson's Dangerous off the top spot in the US charts with their album Nevermind. This shift in power was almost emblematic of the transformation that hit the music industry in the 1990s.

3D printing is undergoing a similar process today. The transformation is well underway, and there is a palpable mood of optimism. The technology may still be young, but it has already prompted a revolution on the shop floor. And you could argue that 3D printing has given today's engineers a similar sense of excitement! Everything seems possible: metal parts with cavities and bionic structures, one-of-a-kind pieces of jewelry, implants, and lightweight construction—the sky's the limit.

This is a happy development for people like me who are notorious for buying gifts at the last minute. Soon I will be able to pop a 3D printer in my basement and take life a lot easier. Whether I want a toy car for a child's birthday or earrings for someone special, my 3D printer will sort it out. Simply add the material, press start and the printer will build my gift layer by layer, reducing my stress levels at approximately the same rate.

In science fiction, of course, things have moved even faster. They are already printing entire living beings, for example in the box office hit "The Fifth Element"—another throwback to the 1990s, albeit slightly later than Nirvana. In the movie, a 3D printer reconstructs the protagonist Leeloo from a trace of her DNA, creating such a perfect copy that the hero—played by Bruce Willis—falls in love with her.

Leeloo's revival is certainly science with a capital S, but it is no longer purely the realm of fiction. Fraunhofer ILT in Aachen, for example, is busy working on the development of an organ printer. One day this could print meat to eat, new skin for burns victims, and even entire limbs to replace those lost in accidents, though I admit some of these applications may still be some way off!

But people are already tentatively trying out the first riffs on the shop floor. If the 3D printers leading the wave could make music, they would also start playing power chords and bellowing the refrain from Nirvana's hit tune "Smells like teen spirit": "Here we are now—entertain us!" ■

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

→ *Could 3D-printed guitars soon sound better than ones made by traditional methods? What do you think? Let me know by email: athanassios.kaliudis@trumpf.com*

Gernot Walter

WHERE'S THE LASER?

In the ticket slot: Action films have long taught us the best method of escaping if you are being chased. You simply run into a crowded subway station and jump onto a train just before it leaves. But before the hero makes his escape, he always has to sprint through the station and leap over the ticket barrier. Most ticket barriers are made by the French company Ricupero, which solidly welds together the sheet metal housings with a TruLaser robot. So at least you have the reassurance that the barrier won't collapse when you push off for your leap to freedom. Now you just have to make your getaway! ■

Gernot Walter

50 METERS OF SAFETY IN ZERO VISIBILITY: Thick fog even thwarts on-board computers in self-driving vehicles, preventing them from using laser pulses to take direct readings of where obstacles are located. Unlike its human counterparts, however, the computer has an alternative method up its sleeve. Using a process developed at MIT, the computer registers incoming photons every few picoseconds and uses a statistical evaluation of these readings to calculate the shape and distance of objects up to 50 meters away. That means the car can keep moving even when passengers can't see past the end of their nose.

Thomas K. / photocase.de