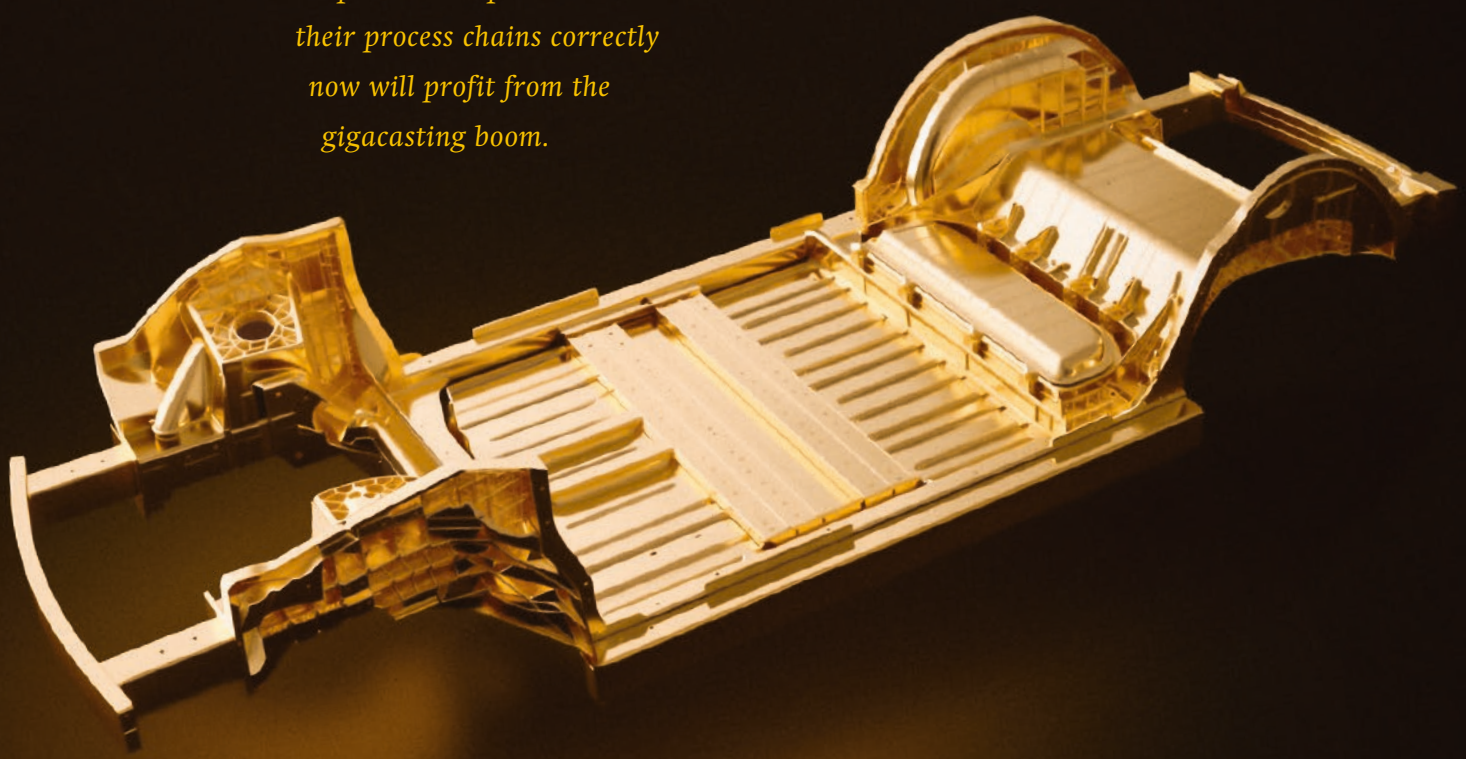
LASER COMMUNITY.

Of people and photons

Aluminum die casting is set to dominate automotive body manufacturing. Companies that position their process chains correctly now will profit from the gigacasting boom.



Making money with giga

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LASER COMMUNITY. *#42*

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Dear Readers,

The laser is more than a tool. Together with optics, sensors, beam guidance systems and now artificial intelligence, it is a key technology with the power to reshape entire industries.

One example is the transformation taking place in automotive body manufacturing. For around 40 years, laser technology has enabled innovation and increased efficiency in the automotive industry. In the 1990s, lasers replaced punching tools. In the 2000s, only lasers could process high-tensile steels. In the 2010s, laser remote welding reduced cycle times.

Now automakers are using large-scale aluminum die casting—also known as gigacasting—to radically reduce manufacturing complexity. But it is the laser that makes it possible to process these new large-format aluminum structures with the precision and stability required for series production. You can read about how gigacasting works and why lasers are ideally suited for high-volume post-processing *in our cover story beginning on page 14.*

Our AI solutions are also helping manufacturers become more efficient. In laser processing, they already enable users to monitor processes and quality, as you can see in the example of our customer Audi *on page 32.* To learn what else AI may make possible in the future and how far the industry still is from moving from automated to fully autonomous manufacturing, read our interview with Prof. *Carlo Holly from Fraunhofer ILT beginning on page 28.*

Wherever precision and productivity are critical, new light-based solutions are emerging. This applies not only to automotive manufacturing but also to aerospace and semiconductor manufacturing. For example, 4Jet uses our lasers to give aircraft a kind of shark skin. *You can read how this works and why it helps airlines save fuel on page 6. A very different industry is the focus of pages 26 to 27:* for the semiconductor industry, LidroTec has developed a process that uses our lasers to separate wafers into chips many times faster than conventional methods.

These examples show that despite the constant evolution of laser technology, one fundamental principle remains unchanged: using a laser is never an end in itself. It must solve real problems and create tangible value in order to expand its range of applications.

I hope you enjoy reading this issue!

DR. RER. NAT. HAGEN ZIMER

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

Julian Rentzsch



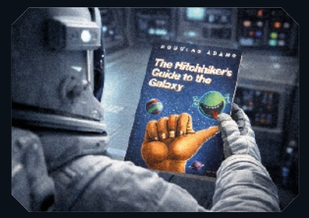
Nineteen years

Back in 2007, *Laser Community* celebrated its first birthday with a major interview: Swiss physicist and laser researcher Ursula Keller looked back on what was already a long and storied career. Nineteen years later, we called up to congratulate her on a well-earned retirement. **Page 13**.



Three Colors

We usually always praise our photographers. Today, the praise goes to the man behind the scenes: photographer's assistant Lennart Neuhaus. Standing on a ladder behind Prof. Holly, he patiently held up cloths—red, yellow, blue—so we could get beautiful, colorful pictures. **Images from page 28**.



Forty-two issues

42 percent of our readers love the cult novel *The Hitchhiker's Guide to the Galaxy,* they all know the answer to everything is "42." To mark the 42nd issue of *Laser Community,* we are celebrating with 42 questions, each with a special answer (no, not "42"!), and a bunch of laser stickers. On page 42, uh—**24**.

LASER COMMUNITY.



AI-generated picture — Gernot Walter & Comy UI, Firefly



Florian Burkhardt, Petra Nolis, Gernot Walter & Comy UI, Firefly

Dominik Asbach

Florian Müller, Heidi Hostettler / ETH Zürich, Audi

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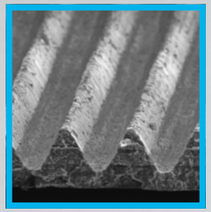






SHARK SKIN SAVES FUEL

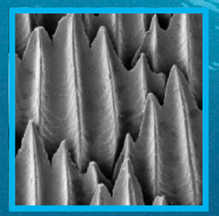
4Jet transfers the shark skin principle to aircraft wings, embedding microscopic structures in the paint—reducing CO_2 emissions and kerosene consumption.



Laser-induced V-shaped grooves directly in the wing paint reduce friction drag by up to ten percent.

4Jet, unsplash/Aakash Dhage

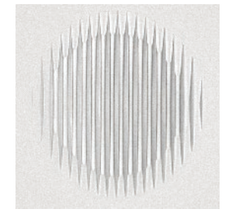
unsplash/Aakash Dhage



With this surface structure, sharks glide through the oceans with minimal drag.

michaelgeyer / Adobe Stock

Two beams for shark skin



Two laser beams interfere, distributing their intensities so that small V-shaped grooves form on the surface.

4Jet

Ever stroked a shark? From a tactile perspective, it's a rough experience. The reason lies in its scale armor made up of microscopically grooved shark scales. It may not look glamorous, but from a fluid dynamics standpoint it offers clear advantages. The grooves create a microstructure that significantly reduces energy-draining water vortices along the body. This allows the predator to cut through the water at speeds of more than 70 kilometers per hour—less drag, less energy consumption, higher speed.

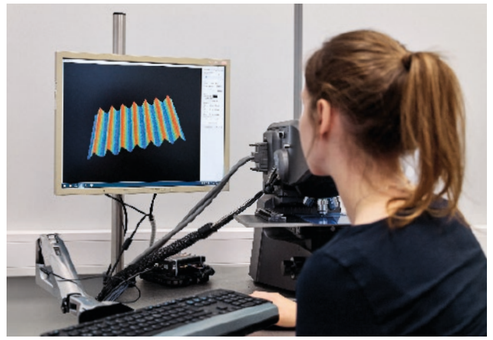
DIRECTLY IN THE PAINT Michiel Top has never touched shark skin himself. But he plans to process aircraft components with a similar structure soon. Together with nine colleagues, he works as a product developer at laser system manufacturer 4Jet on the LEAF project. The goal is to turn the aircraft's surface itself into shark skin. What works in water also works in air. Here, too, microstructures can reduce energy consumption—in other words kerosene. Some airlines already use adhesive films with such structures. 4Jet is also developing these films but sees a better long-term solution.

Michiel Top explains: "We introduce small V-shaped grooves, known as riblets, directly into the paint. This allows us to reduce friction drag by up to ten percent. That accounts for about 50 percent of total drag in an aircraft. In other words, if we structure the entire aircraft, we can achieve fuel savings of three to four percent on every single flight." On average, an aircraft is in service for around 20 years and typically requires repainting every seven years. Over its service life, the savings in fuel and CO_2 emissions are therefore substantial.

SMALL RIBLETS IN LANES So why use films that add weight and ultimately become waste? Because until now there has been no way to equip many hundreds of square meters of aircraft paint with a functionally optimized microstructure in a manageable time frame. It can't be done. Or so it seemed.

The LEAF team at 4Jet sees it differently: Can't be done? Think again. LEAF stands for Laser Enhanced Air Flow. The project has been running for ten years and pursues an ambitious idea. The process uses the physical phenomenon of laser interference to structure surfaces. Using a special optical setup, 4Jet splits the laser beam and then recombines it so that the beams overlap and interact. This interaction creates a characteristic pattern of varying intensities, allowing surfaces to be modified on a microscopic scale.

At 4Jet, Lukas May is responsible for the LEAF system. He explains: "We generate a texture of riblets that are 100 micrometers wide and 50 micrometers deep. We apply this extremely fine microstructure evenly across an aircraft wing with an area of around 400 square meters." The paint is therefore not processed point by



4Jet chooses a relatively large depth of focus to ensure reliable processing even on slightly uneven aircraft surfaces.

point but in larger paths: With the laser, the system structures strips about 15 to 20 centimeters wide. Within these so-called lanes, a fully homogeneous riblet structure is created. At the transitions, there are offsets in the millimeter range, but across the full surface these are functionally negligible, says May: "Otherwise we would have to structure a riblet twice, and that carries the risk of penetrating too deeply into the material. So we play it safe. We can still effectively place nearly 2,000 riblets side by side, then there is a seam that is not quite perfect." Compared to conventional laser structuring, the relatively large depth of focus of around 20 millimeters ensures reliable processing even on slightly uneven aircraft surfaces—at speeds of up to one square meter per minute.

CO_2 LASER VS CO_2 CONSUMPTION To make this approach work on large aircraft in a hangar, a flexible system is needed to guide the laser over the aircraft body. 4Jet has developed a portal system for this purpose. Its dimensions are enormous: The demonstrator in the company's Alsdorf facility is ten meters high and 20 meters wide—designed to process the wings of an Airbus A330 or a Boeing 777. The system consists of a motion system, laser, mirrors, interference optics as well as sensors and software. The beam source is the CO_2 laser TruFlow 5000. It best meets the physical requirements of the process.

Michiel Top explains: "The wavelength is crucial. The CO_2 laser is very well absorbed by aircraft paint, enabling precise and material-friendly structuring." At the same time, the laser must have high coherence so that the required interference pattern formed by overlapping beams remains stable. For this purpose, TRUMPF adapted the TruFlow for use at 4Jet, including spectral narrowing of the beam using a special grating. "With a CO_2 laser, however, we cannot use an optical fiber," May adds.

Due to the size of the portal, the beam path to the aircraft surface is long. A specially developed mirror system directs it to its destination. "The system itself twists, which is why we use active tracking. These are movable mirrors that are continuously adjusted." Despite its size, the system is mobile. A safety laser scanner detects the exact position of both the aircraft and the system.

In principle, the riblet structure could be applied to the entire aircraft. In practice, however, 4Jet focuses on aerodynamically critical areas. Calculations show that the effect is greatest on the wings—where air friction plays the biggest role. Potential customers such as airlines are enthusiastic about the process, Top says. But it may take some time before the LEAF team coats their aircraft with shark skin. "We are currently looking for partners in the aviation industry who want to offer this service together with us," May explains. Certification by the relevant aviation authorities is also required. And that takes time. May and Top remain confident: "We know it will take another three to four years before this is commercially airborne. But we have shown that our process works. Now we are ready for the next step." ■

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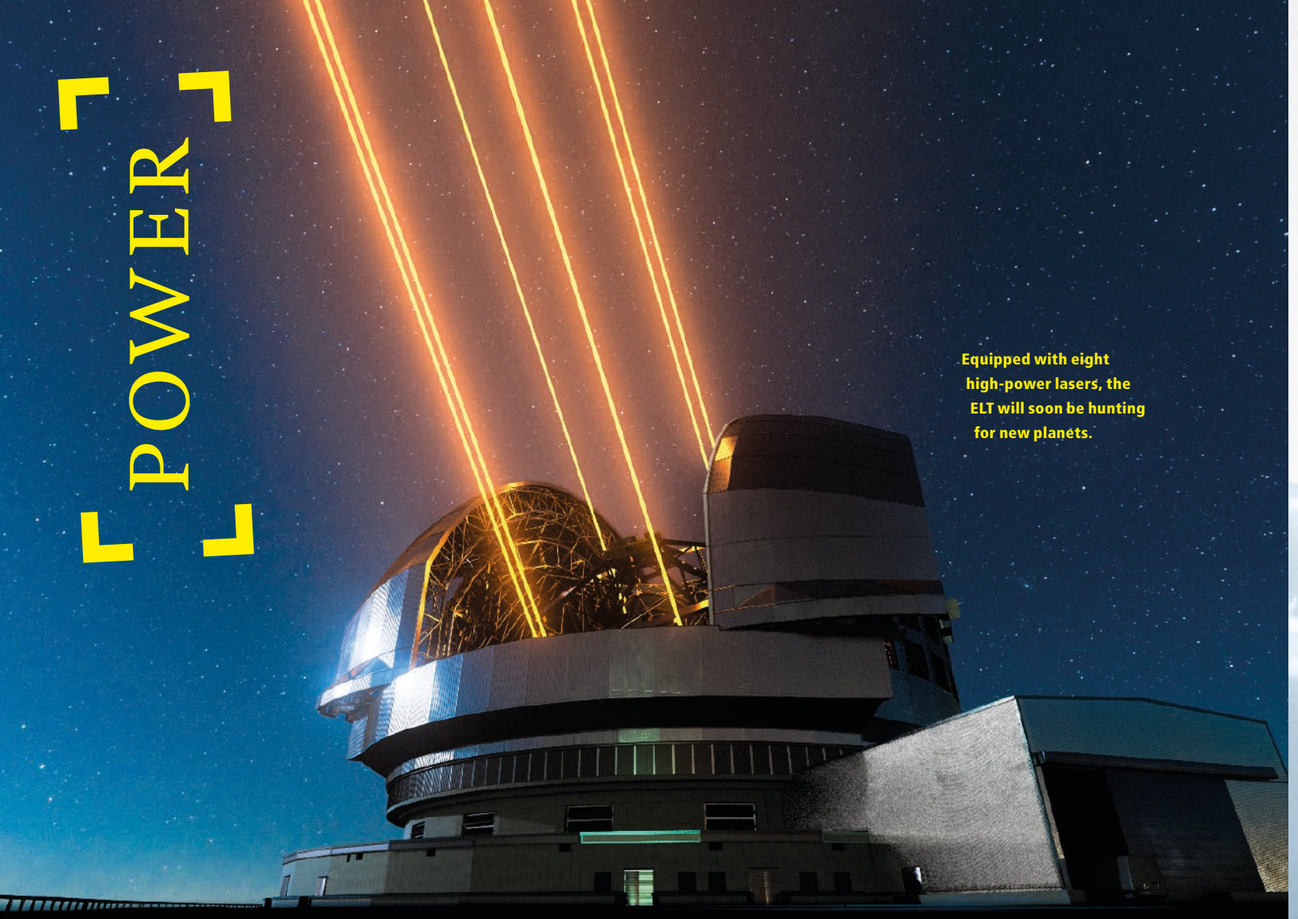
"We know it will take another three to four years before this is commercially airborne. But we have shown that our process works. Now we are ready for the next step."

Lukas May and
Michiel Top of 4Jet.



Lukas May and Michiel Top at their laser portal as a wing is being processed.

© Florian Müller



Equipped with eight high-power lasers, the ELT will soon be hunting for new planets.

GUIDE STARS ON DEMAND

How lasers help sharpen our view of the universe.



Construction is still underway in Chile. The ELT is scheduled to enter operation in 2029.

Might there be a second Earth out there? We just don't know. Distant planets are notoriously difficult to detect—yet the odds of finding them have never been better. In Chile's Atacama Desert, construction is underway on what will become the world's most powerful window onto the cosmos: the Extremely Large Telescope (ELT).

Measuring 39 meters across, its primary mirror will capture vast amounts of light that will show the universe in unprecedented detail. But before any starlight can reach a ground-based telescope, it must first pass through Earth's atmosphere—which is in constant motion, like heat shimmering above an asphalt road. As a result, incoming light is minimally refracted, reducing image sharpness and blurring fine details. To compensate, astronomers use guide stars as a reference point. This tells them how strongly Earth's atmosphere distorts the light from these stars. If there are not enough natural guide stars available, the ELT will create its own. Eight high-power lasers will each fire a beam some 90 kilometers into the atmosphere, exciting sodium atoms there and making them emit light. This creates artificial guide stars precisely where astronomers need them for their measurements. Using this data, the system computes the necessary adjustments to an adaptive mirror within the telescope. On the rear surface of this second mirror are thousands of tiny servomotors that modify its shape on a micrometer scale. In this way, the system is able to subtly counteract any turbulence in Earth's atmosphere.

The ELT is scheduled to begin operation in 2029. A key mission will be to detect exoplanets. Laser systems and adaptive mirrors offer the precision required to make this possible. It remains an open question whether a second Earth exists. But the tools to find it are now in place. ■

ESO

THE QUEEN OF USP

Ursula Keller's lifelong work with ultrafast lasers.

Ursula Keller likes to make things short, especially when it comes to lasers. The first ever woman to be a tenured professor of physics at ETH Zurich, she made a pioneering invention in 1992: the semiconductor saturable absorber mirror (SESAM). This made it possible to produce ultrashort pulses in the femtosecond range and helped turn the solid-state laser into a standard tool for research and industry.

Yet Keller wanted more—even shorter pulses. By controlling the electric field within each pulse, she and her team achieved a further breakthrough: the development of the frequency comb, which brought about a revolution in precision measurement and paved the way for attosecond laser pulses, which would then make it possible to track electron motion in real time. It was work by Anne L'Huillier, Pierre Agostini and Ferenc Krausz that enabled the generation of these ultrashort flashes of light, a development for which they were awarded the 2023 Nobel Prize in Physics. In her last research project before retirement, Keller showed that electrons and atoms can fall out of sync—and that charge carriers and energy propagate differently in novel two-dimensional transition-metal materials.

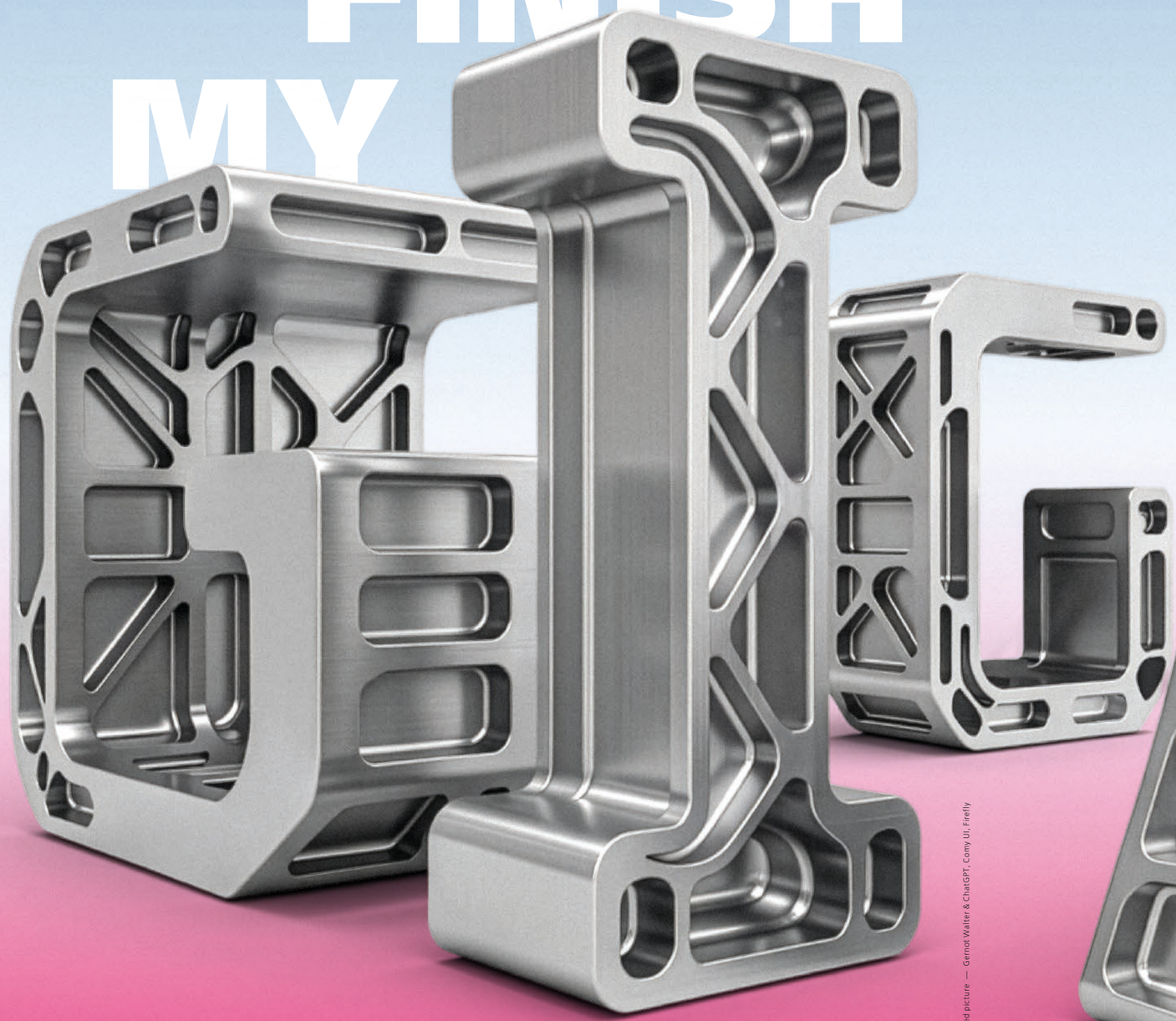
After 500 peer-reviewed publications, 21 patents, two ERC Advanced Grants from the European Research Council, and numerous awards, Ursula Keller retired at the end of 2025. In her farewell lecture, the first lady of laser science offered advice to young researchers: "Go out and explore the world, learn from the best, and leave each place better than you found it!" ■

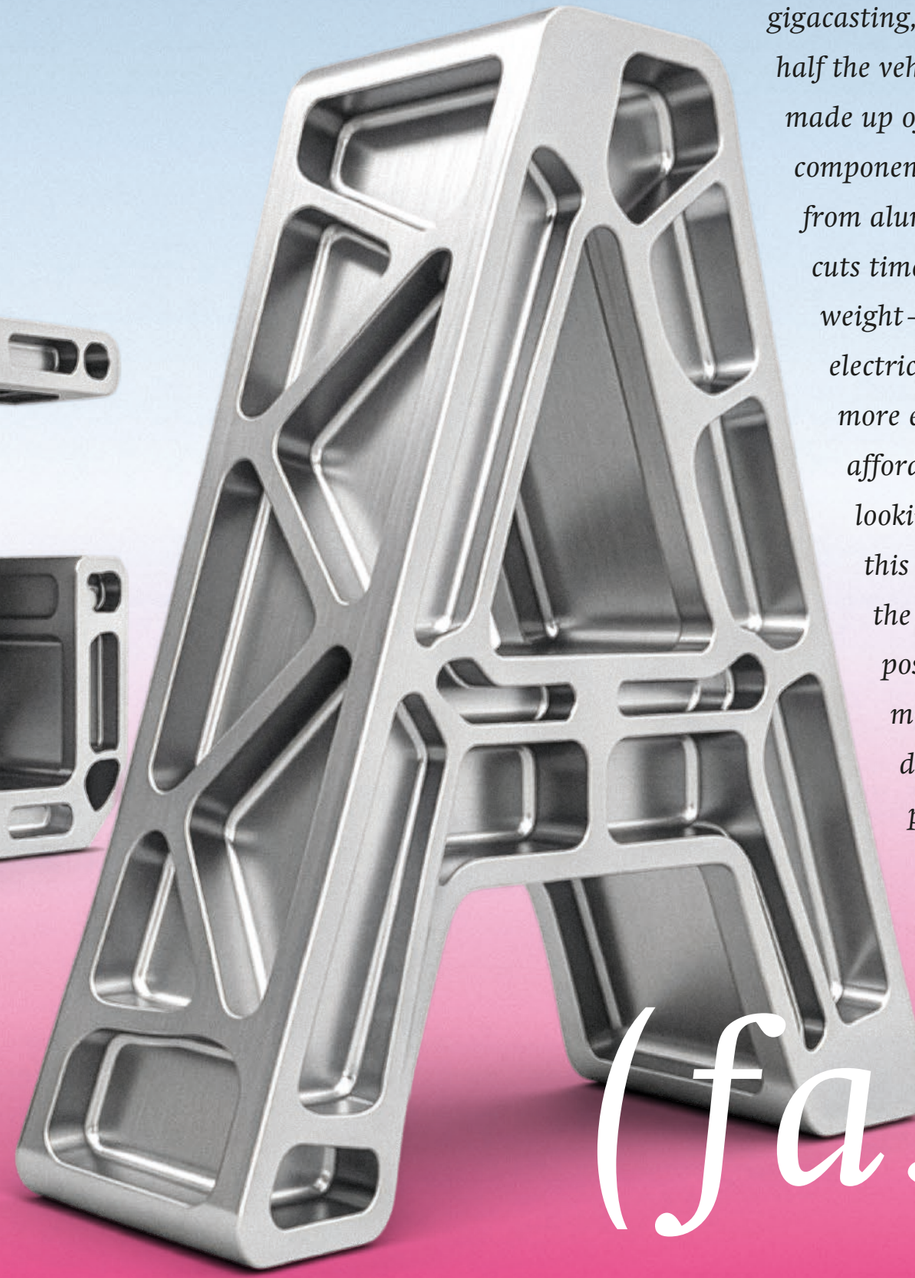
Ursula Keller's advice to young scientists: "Go explore!"

Meidi Hoogerdijk / ETH Zurich

HOW TO FINISH MY (fast)

Huge parts, and zero chaos! With gigacasting, virtually half the vehicle is made up of large components poured from aluminum. This cuts time, cost and weight—making electric vehicles more efficient and affordable. Yet anyone looking to upscale this process faces the question: Which post-processing methods meet the demands of mass production?





AI-generated picture — Gernot Walter & ChatGPT, Comy UI, Firefly



A now legendary move by Tesla in 2020 marked the beginning of it all. The US automaker famously abandoned the industry-standard "shell construction" method—a tried-and-true technique of assembling car bodies from numerous steel panels. Instead, engineers pivoted to a radical approach: casting huge structural components from aluminum. They dubbed this new manufacturing process "gigacasting."

The first major cast body component to enter series production was the rear underbody of the Model Y. Chinese EV manufacturers such as XPeng, Geely, Xiaomi, Aito and NIO have followed suit, casting large structural parts for luxury models in place of complex multipart assemblies. Volvo and Ford, along with industry giants Hyundai, Volkswagen and Toyota, have now joined this trend too. Since few OEMs produce these aluminum castings in-house, specialized suppliers will likely handle manufacture and delivery. As such gigacasting is on its way to becoming the new standard in EV body production.

WHY GIGACASTING? "Large-format die casting" is the technical designation for this new process; "megacasting" is also common; and in China "large-scale integrated die casting" is the preferred term. "Gigacasting" is actually a marketing term coined by Tesla, but it enjoys the widest industry recognition, which is why we use it here.

Call it what you will, the rapid adoption of gigacasting is a no-brainer. *(For details on the process, see opposite.)*

Gigacasting is simply the next logical step in the mission of many OEMs to strip complexity from car manufacturing. The significant benefits of this method are clearly illustrated in a key body component: the lower rear underbody.

In traditional shell construction, this rear component is made from around 80 individual parts. Each one must be cut, bent, pressed and welded—then packaged, shipped and transported to the OEM, where it is warehoused until being delivered to the assembly line. Once there, it takes around 30 steps to assemble the rear underbody. Even state-of-the-art production lines require 45 minutes for this process.

Gigacasting is a game-changer: the entire rear underbody is created in just one step—literally cast in one piece. The casting process itself takes 90 to 120 seconds. After factoring in post-processing (*see pages 20–21*), which takes approximately a few minutes, body manufacturers save tremendous amount of time on assembly while also substantially reducing logistics.

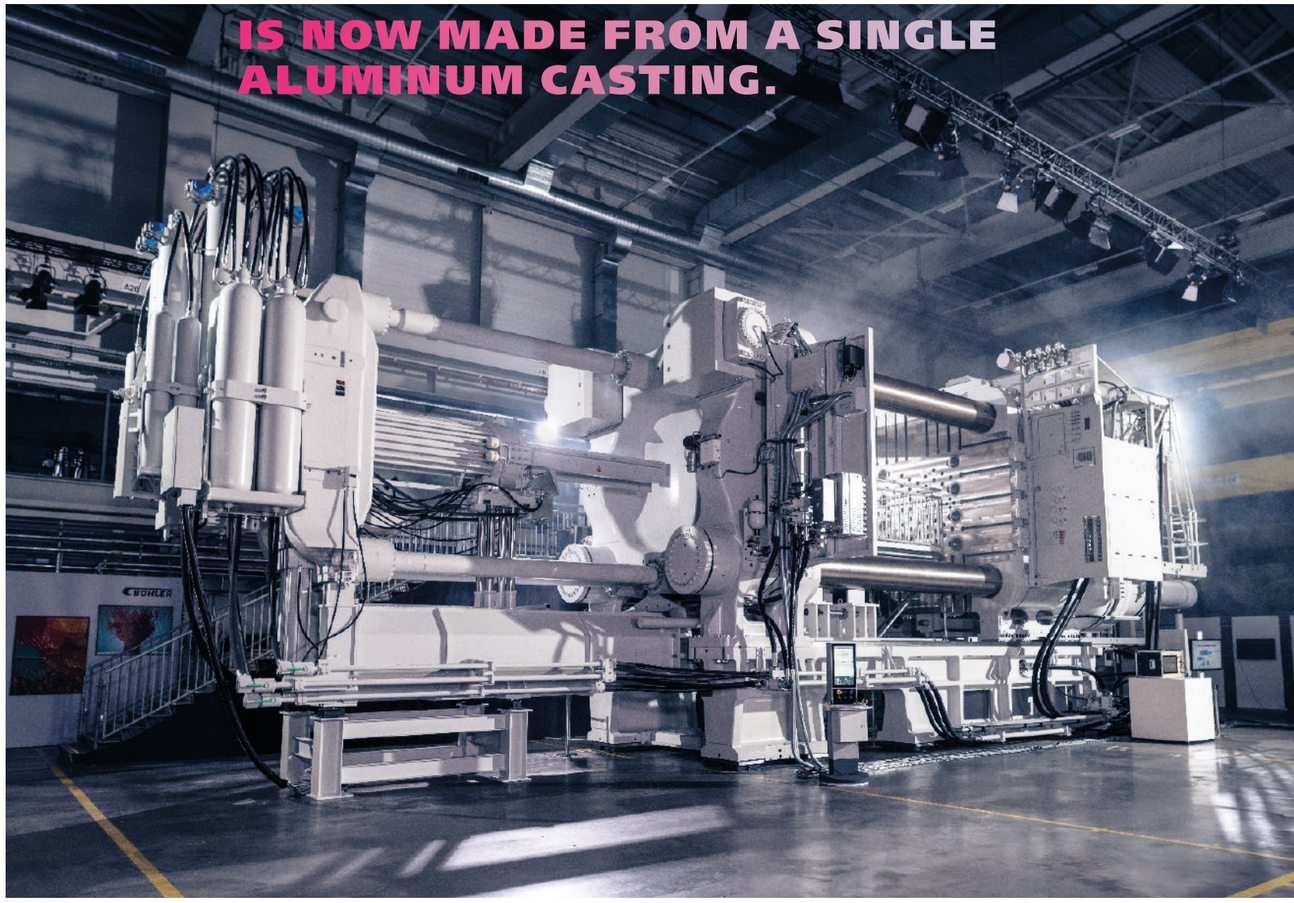
WHY GIGACASTING NOW? It is no coincidence that this revolution in body manufacturing has coincided with the rise of the electric vehicle. EV manufacturers have a serious problem: electric cars are relatively expensive for customers, and automakers have very little influence over the single largest cost factor—the battery.

Naturally, manufacturers continually optimize battery production and explore new concepts. Yet by far the most expensive part of a battery remains the raw materials themselves: nickel, lithium, cobalt, manganese and the rest. Since all these commodities are traded on the global market, there is little that automakers can do to actively drive down the cost of battery production.

What's more, most EV customers have high expectations when it comes to handling, range, design and interior fittings. Cutting costs in these areas would drive them straight into the arms of the competition.

If the battery can't get any cheaper and customer comfort is off limits, then everything else has to come down in cost. With that mindset, EV makers are willing to question every conventional production step and rethink it from the ground up. That's why the shift from proven shell

THE IDEA BEHIND GIGACASTING IS CLEAR: KEEP THINGS SIMPLE. INSTEAD OF MANUFACTURING 80 INDIVIDUAL PARTS FOR ASSEMBLY ON A PRODUCTION LINE, THE ENTIRE REAR SECTION OF A VEHICLE IS NOW MADE FROM A SINGLE ALUMINUM CASTING.



AI-generated picture — Gernot Walter & ChatGPT, Comy UI, Firefly

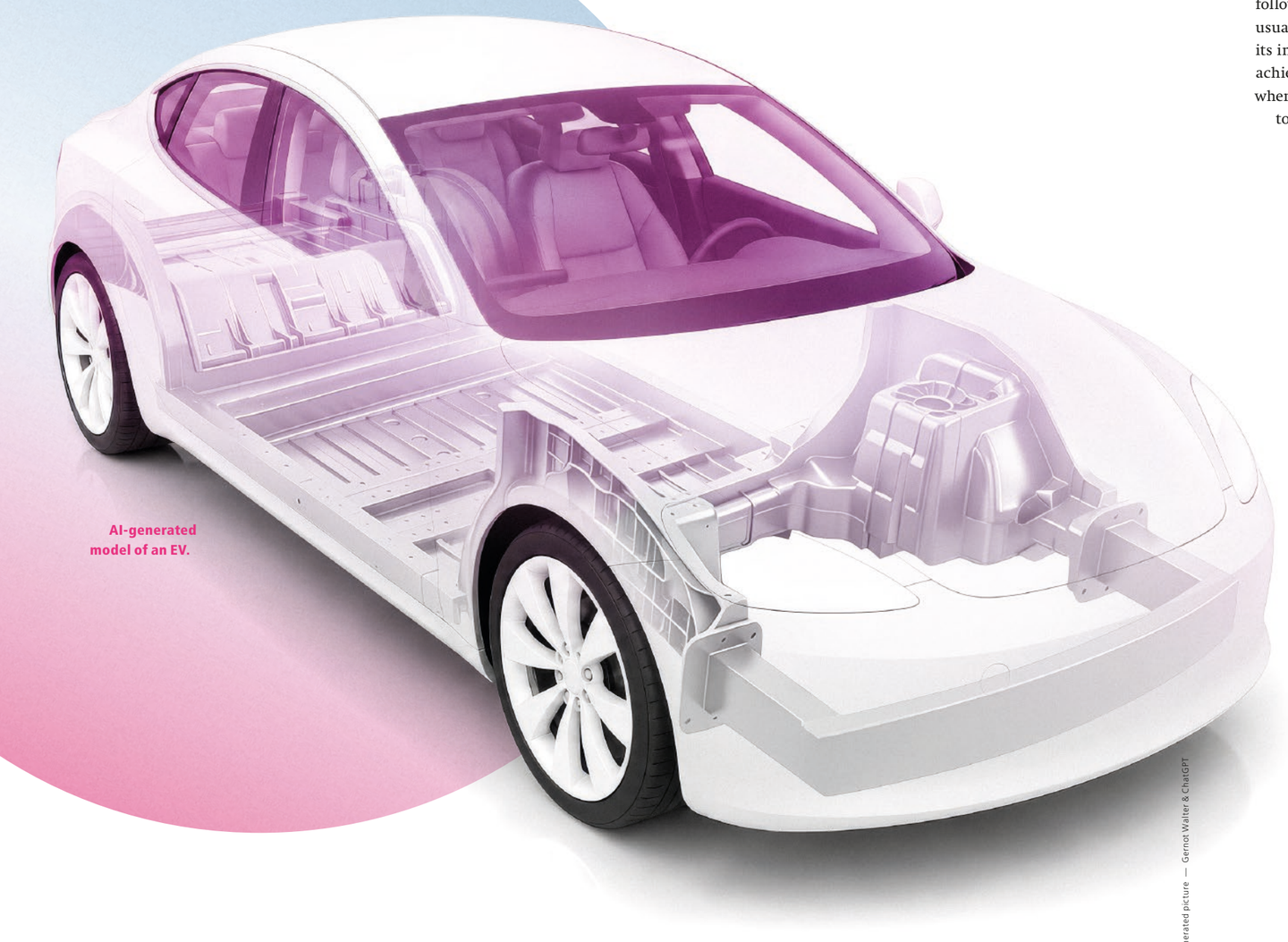
Bühler Group

Die casting taken to the extreme. A machine like the Carat 840 from Swiss manufacturer Bühler forces two massive mold halves together under enormous pressure while creating a vacuum inside. It then injects 700-degree molten aluminum through multiple channels into every corner of the mold. That all takes around a tenth of a second. The machine then maintains counterpressure on the mold for a few more seconds until the aluminum solidifies, before opening it.

It has only become possible to produce aluminum castings of this size thanks to four major technical breakthroughs of the past ten years or so: 1. High-flow aluminum alloys designed to fill complex molds. 2. Advanced simulation models that accurately predict metal flow. 3. Sophisticated vacuum systems that stabilize the extreme conditions inside large casting molds. 4. Clamping forces of 9,000 metric tons (around 90,000 kilonewtons) or more, applied without deforming the mold or the machine itself.

The number of cast structural components is steadily increasing, At present, these are mainly floor sections and underbodies, along with housings for electric motors and power electronics. Once the casting cycle ends and the mold opens, the solidified component is still over 200 degrees Celsius. Typically, such parts weigh between 60 and 80 kilograms, though significantly larger and heavier castings are already possible. A robot then grips the component and removes it from the mold. This is followed by quenching in a water bath or spray quench station, where the aluminum cools rapidly and its microstructure stabilizes uniformly. Only then does the post-processing begin (*see pages 18–19*).

One more point: when a car body eventually ends up on the scrap heap, the large cast aluminum components are essentially single, homogeneous blocks of pure aluminum alloy. They are therefore relatively easy to remelt and reuse.



AI-generated model of an EV.

AI-generated picture — Gernot Walter & ChatGPT

construction to relatively new gigacasting looks less like a gamble and more like a bet with real upside.

On top of that, gigacasting is simply lucrative now that all the major technical challenges in the casting process have been resolved. Once it's running, there's usually no problem. What is not yet quite clear, however, is what happens once the casting leaves the mold.

GIGACASTING COMES OF AGE In many ways, gigacasting is following the usual path of automotive innovation—just faster than usual. Initial pilot projects focused on the casting process itself and its integration within existing production lines. Once that had been achieved, gigacasting was implemented first of all for luxury models, where higher margins and lower volumes give automakers more scope to handle a few hiccups in production. But now, barely six years after its debut, the industry's big three are adopting the technology—which means mass production. This environment is far less forgiving: every second is critical for cycle times, and every cent when it comes to assembly costs. Gigacasting lines must now rapidly mature to meet the demands of high-volume manufacturing.

To achieve this, the industry will need laser technology *(see pages 20–21)*. Mass production can no longer accommodate the downtime required to replace worn tools on press brakes or milling machines. Nor can it rely on plasma cutters, which require regular cleaning throughout the day. Likewise, the use of chemical baths to prepare surfaces for welding or bonding—with frequent fluid changes and costly waste disposal—is no longer an option.

Here, as elsewhere in a mass production setting, lasers offer tool-free, contactless, selective and flexible processes. But with gigacasting, laser tech brings two extra advantages that are even more critical than usual.

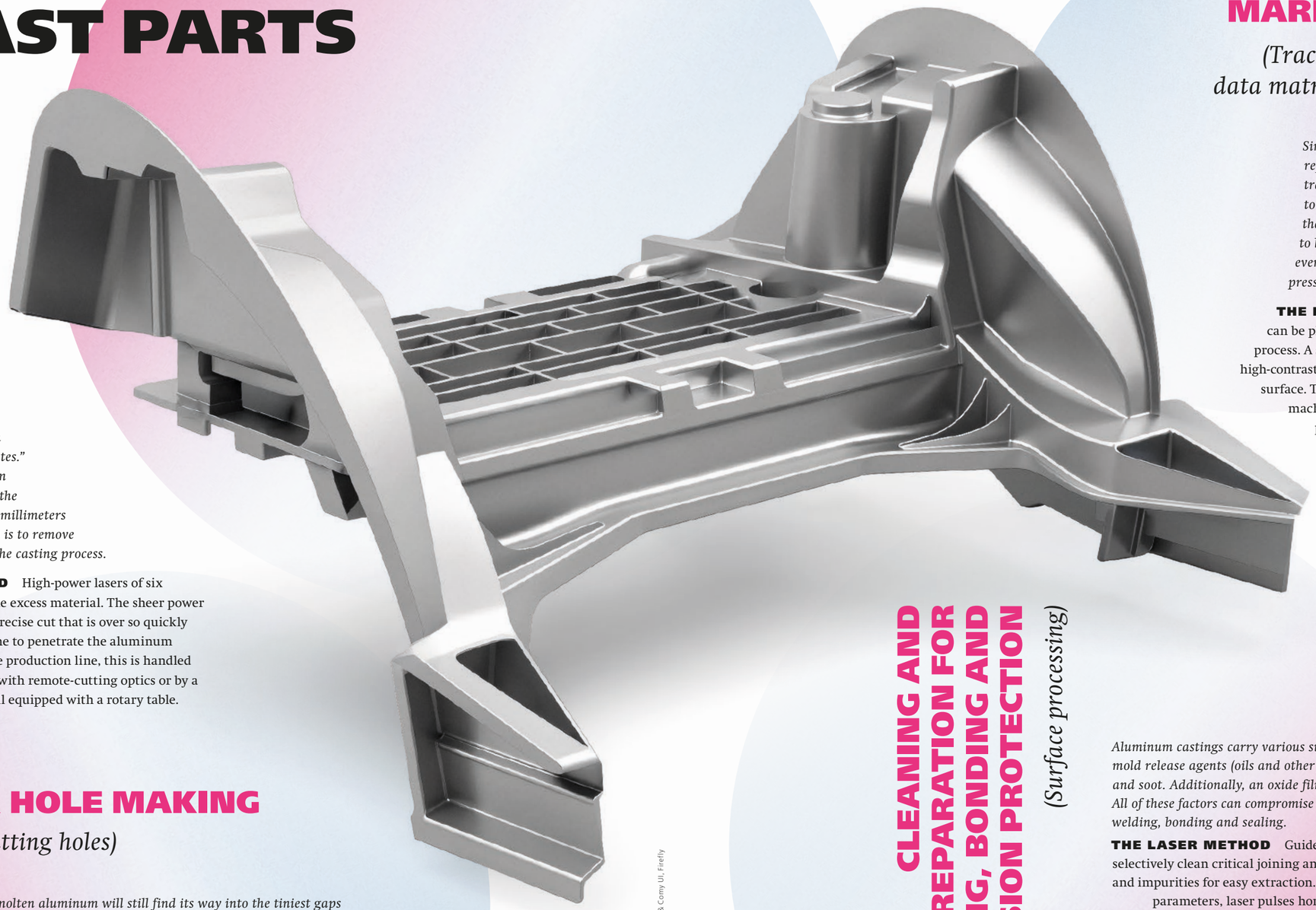
First, their high reliability. When long assembly lines slow or stop, it is already an issue in conventional body construction. But gigacasting is even less tolerant of downtime. Once the aluminum is molten and ready for casting, there is no time to wait or costs soon escalate.

Second, stress-free processing. Despite its size, a freshly cast aluminum part is vulnerable to damage within. Mechanical loads from milling and bending can result in distortion, especially when tools are no longer in top condition. The same risk pertains to the thermal stress that can be caused by plasma processing. For automakers, laser cutting eliminates both concerns. Mechanical stress is simply not part of the equation. And, with the major advances in aluminum laser processing over the past decade, heat input is no longer a meaningful issue either.

LASERS, WHAT ELSE? Laser technology has been driving innovation in the automobile industry for roughly 40 years, bringing levels of efficiency that were once out of reach. In the 1990s, lasers replaced bulky punching tools and slow spot-welding processes that required large overlaps. In the 2000s, lasers proved the only practical way of handling high-strength steels at scale, thereby enabling the industrial use of tailored blanks for lightweight construction. In the 2010s, laser remote welding pushed cycle times in body manufacturing down to previously unthinkable levels. Likewise, the introduction of hairpin welding for electric motors resolved a major quality and efficiency issue in the still nascent e-mobility industry. And now automakers are turning to gigacasting to reduce complexity and streamline production. If that doesn't sound like a job for lasers, what does? ■

GIGACASTING IS POISED TO ENTER THE ARENA OF HIGH-VOLUME PRODUCTION. EACH STEP OF THE PROCESS HAS TO BE 100 PERCENT RELIABLE—AND FASTER THAN EVER BEFORE. AND THAT'S PRECISELY WHERE LASER TECHNOLOGY PROVES ITS WORTH.

LASER PROCESSING OF GIGACAST PARTS



DEGATING

(Removing excess material)

When the cast part emerges from the mold and then quench bath, its outer edges are studded with between 10 and 30 protrusions: thin, rod-like features with flat, disk-like ends, known in the trade simply as "gates." This is solidified aluminum from the feed channels to the mold, typically two to six millimeters in diameter. The first step is to remove these rough remnants of the casting process.

THE LASER METHOD High-power lasers of six kilowatts or more trim the excess material. The sheer power allows for an incredibly precise cut that is over so quickly that heat doesn't have time to penetrate the aluminum and warp the part. On the production line, this is handled either by a six-axis robot with remote-cutting optics or by a cutting head in a laser cell equipped with a rotary table.

DEBURRING & HOLE MAKING

(Removing burrs and cutting holes)

Regardless of the clamping force applied, molten aluminum will still find its way into the tiniest gaps where the mold halves meet. This produces paper-thin, razor-sharp burrs that can easily make up a combined length of eight meters. Furthermore, such parts are far from finished. They still require dozens of drilled holes and cutouts for later assembly.

THE LASER METHOD Whether in a dedicated processing cell or robot-guided via scanner, lasers follow the burrs and trim off the excess material. For this precision operation, beam brightness is more important than raw power to achieve an optimal trade-off between processing speed and a quality result. Lasers with a beam parameter product (BPP) of 2 remove the burrs and drill the mounting holes.

A.I.-generated picture — Gernot Walter & Comy Ui, Firefly

MARKING

(Traceability: data matrix code)

Since a single gigacast component will sometimes replace hundreds of individual parts, seamless traceability is essential. Fortunately, this is easy to implement. A simple data matrix code is all that is required. Smart factories can then use this to link each component to a database containing every critical casting parameter—from vacuum pressure and flow rate to clamping force.

THE LASER METHOD Marking stations can be placed at various stages of the production process. A scanner-guided pulsed laser applies a high-contrast, machine-readable mark to the aluminum surface. This provides robots and other downstream machinery with the data they require for further processing.

CLEANING AND PREPARATION FOR WELDING, BONDING AND CORROSION PROTECTION

(Surface processing)

Aluminum castings carry various surface contaminants: residues from mold release agents (oils and other fluids) as well as casting powder and soot. Additionally, an oxide film forms rapidly on the aluminum surface. All of these factors can compromise downstream assembly steps such as welding, bonding and sealing.

THE LASER METHOD Guided by scanner, short-pulse lasers selectively clean critical joining and bonding areas, vaporizing oxides and impurities for easy extraction. Furthermore, when set to the right parameters, laser pulses homogenize the surface's crystalline structure on the micro level, thereby enhancing sealing quality and eliminating underfilm corrosion. In preparation for bonding, the laser creates a microtexture on the joining surface—a small trick that increases the specific surface area and drastically improves wetting behavior and adhesive strength.

WE'RE MAKING X-RAY LASERS AVAILABLE TO A WIDER USER GROUP!



ASU Knowledge Enterprise/Andy DeLisle

ASU Knowledge Enterprise/Andy DeLisle

Professor Sandhu, you aim to revolutionize X-ray laser technology. What's the plan?
In the field of X-ray science, the biggest advance of recent decades has been the development of the X-ray free-electron laser. XFEL facilities produce ultrabright X-ray beams that offer R&D scientists and engineers a really deep insight into matter of all kinds. The only problem with such facilities is their size and cost. An XFEL is a huge piece of equipment that costs billions of dollars, which is why there are fewer than ten of them worldwide. We plan to change that. In the initial phase, our team was able to scale down the facility to the size of a truck. This gives us what is known as the compact X-ray light source, or CXLS for short. And now we're taking this one step further with the construction of a compact X-ray free-electron laser, or CXFEL, which is a genuine X-ray laser.

XFEL technology is driving breakthroughs in medicine, materials science and chemistry. But only a handful of X-ray free-electron lasers exist worldwide. Arvinder Sandhu and his team are pushing to change that. Harnessing laser-based techniques should make such facilities accessible on a much wider scale.

Sounds great, but what's it for?
It'll mean that anyone who wants an ultrabright X-ray source can have one! Our aim is to slash the size, cost and complexity of such facilities, making them accessible to universities, research labs and, further down the line, to industrial facilities and hospitals.

What kind of industrial applications are we talking about here?
Take semiconductor manufacturing: modern chip architectures are extremely small and complex—and the next generation will have even greater 3D integration. For quality assurance purposes, semiconductor manufacturers require high-performance X-ray sources that deliver exactly the right amount of energy required for precise chip metrology and characterization. With a tunable X-ray source, you can scan a wafer to produce a kind of fingerprint of its individual elements. This tells you the precise position of individual materials, their structure and whether there are any defects or production errors.

How do you set about miniaturizing an XFEL?
Basically, we've downsized the electron accelerator by using lasers as an undulator instead of an array of magnets. All free-electron lasers work on the same principle: by accelerating electrons and interfering with their path of flight, they can be induced to emit radiation. In a conventional XFEL, electrons are initially accelerated along a long linear track to extremely high energies. These electrons then pass through a long array of magnets, which makes them oscillate or "wiggle." This generates X-rays. Conventional XFEL facilities need an accelerator that can stretch for hundreds or even thousands of meters. In place of this, we use a powerful laser field to make the electrons oscillate. This reduces accelerator length to just a few meters.

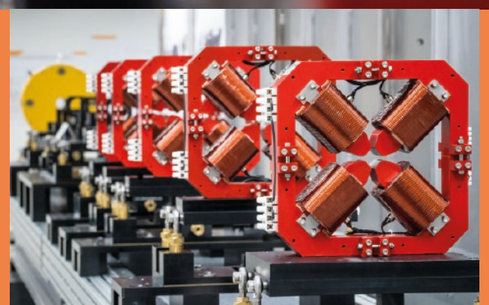
The CXFEL might be smaller, but is it also better?
It most certainly is! The CXFEL is designed to operate in the soft X-ray range, producing extremely short pulses on the attosecond scale—ideal for use in advanced spectroscopy applications.

Wait—did you just say attoseconds? Pulses a mere 10^{-18} seconds in length?
Yes, I did. And that will give us a whole new insight into the structure and dynamics of matter. But back to why the CXFEL is better: The problem with conventional XFEL sources is that they amplify fluctuations, preventing the generation of reproducible pulses. As a result, each pulse exhibits different spectral and temporal characteristics. But with the CXFEL, we'll be able to deterministically tune the X-ray pulse energy to a high degree of precision.

So what will you be able to do with this new precision?
We'll be able to track how electrons move in real time. In today's science, the focus is no longer merely on atomic structure. It's also very much about observing electrons as they move at their natural speed. This will mean, for example, that we can investigate how electron excitation in molecules triggers structural changes such as those that occur during damage to DNA or in biochemical reactions. In many cases, we know the outcome of such processes, but not the steps in between. Take the process of vision: when a photon strikes a rhodopsin protein in the eye, we perceive an image. Yet we still lack a clear picture of the steps between that initial impact and the final result—particularly regarding the rate of energy transfer at each step. That's something we'll now be able to study. With this new X-ray laser, we will finally be able to understand the structural changes that proteins undergo and how these changes determine their function within our bodies. ■



PHASE 1 The compact X-ray light source (CXLS) first generated X-rays on February 2, 2023, thereby demonstrating that such facilities can be scaled down to the size of a truck.



MAGNETS ARE NOT ENTIRELY ELIMINATED Powerful magnets focus and guide the electrons so that they collide with infrared laser pulses. This collision produces X-ray pulses of only a few femtoseconds in duration.



THE CXFEL TEAM Students have built most of the system, supported by a small group of scientists and engineers. The result is a world-class research facility in a university setting.

Lasers — *The answer to everything.*

What is revolutionizing the microchip industry?

Lasers

What keeps false eyelashes in place longer?

Lasers

What will clear space junk from our skies?

Lasers

What technology are archaeologists using to discover forgotten Mayan sites?

Lasers

What technology will help us solve the nuclear waste problem through inspection and decommissioning?

Lasers

What will make fuel cells economically viable?

Lasers

What is currently reinventing X-ray technology?

Lasers

What production technology benefits most from AI?

Lasers

What is the key to the success of nuclear fusion?

Lasers

What enables diabetics to monitor blood glucose levels without a finger prick?

Lasers

What eliminates pests and weeds without chemicals?

Lasers

What's essential for discovering new medical drugs?

Lasers

What enables gas-tight welding of aluminum?

Lasers

What reduces particulate emissions from brake discs through coating?

Lasers

What will power the next generation of satellite communication?

Lasers

What offers a safe way to cut up and defuse old bombs?

Lasers

What protects airports from lightning strikes?

Lasers

What technology is a game-changer in atmospheric research?

Lasers

What is used to measure gravitational waves?

Lasers

What is used to lithograph the new generation of microchips?

Lasers

What is crucial for improving cancer therapy with electron beams?

Lasers

What is used to texture steel in modern architecture?

Lasers

What cuts and surface-textures display glass?

Lasers

What enhances the recycling of batteries and e-waste?

Lasers

What removes biofouling from marine hulls?

Lasers

What decontaminates chicken meat without direct contact?

Lasers

What creates an anti-soiling surface on photovoltaic modules?

Lasers

What will help eliminate chemical baths for cleaning auto body parts?

Lasers

What's finally taking the pain out of dental drilling?

Lasers

What is used to drill the tiny holes for microplastic filters?

Lasers

What can be used to join any type of plastic?

Lasers

What's an easy way to make nanoparticles?

Lasers

What enables non-invasive monitoring of LNG?

Lasers

What is used to measure particulate matter in real-time?

Lasers

What's the secret behind the world's most sensitive microphones?

Lasers

What helps investigate consciousness and freedom of choice?

Lasers

What enables the filming of atoms forming into molecules?

Lasers

What is used to make window glass that lets light through but blocks heat?

Lasers

What can sort sperm in animal breeding?

Lasers

What transports molecular payloads to living cells and activates them there?

Lasers

What technology is used to give medical devices a regulatory-compliant marking?

Lasers

What propels an interstellar generation ship to a distant star?

Lasers

Our latest *Laser Community* is a Douglas Adams special. Forty-two issues in, it's become clear that "laser" is the default should you happen to forget the ultimate answer to everything!

The ultimate answer is, of course, "42." You can read all about it in the 1979 cult classic *The Hitchhiker's Guide to the Galaxy.*

Liquid flow for clean edges

When it comes to dicing wafers, chipmakers have traditionally faced a trade-off between speed and precision. A new ultrashort pulse laser process resolves this dilemma.

Within the liquid medium, all is quiet. The screech and vibrations of a diamond saw no longer disturb the peace. Instead, there is merely the flash of a laser. Hidden from view, laser beams, all aligned, carve a precise path through the wafer—dicing it with a rapid, synchronized and contactless cut into thousands of individual chips.

What sounds like a scene from a sci-fi lab is actually a new approach to one of the most critical steps in semiconductor manufacturing: dicing, the process of separating a wafer into individual chips. TRUMPF engineers have successfully scaled a liquid-flow ultrashort pulse (USP) laser process for industrial series production. Outperforming conventional techniques, this represents a real breakthrough: Laser beams can dice wafers far faster than mechanical saws, achieving an edge quality previously reserved for plasma processes.

THE CRITICAL CUT Dicing marks the point where the wafer is separated into individual chips for electronic components. What happens at the cutting edge has a direct impact on final yields, and on component quality and long-term reliability, making it a decisive factor in the cost-efficiency of the entire manufacturing chain.

Plasma cutting delivers the highest-quality edges, yet the process is complex and too slow for high-volume manufacturing. For many years, the diamond saw has therefore been the go-to solution. It is fast but also uses mechanical forces, which brings inevitable drawbacks: microfissures, chipping and material stress. With brittle materials such as silicon carbide, scrap rates can climb sharply. According to Christian Weddeling, who oversees wafer dicing at TRUMPF: “Conventional methods force the industry to choose between speed and quality. Our goal is to resolve this trade-off.”

PRODUCTIVITY BOOSTER The core of this new approach is an ultrashort pulse laser. With pulse durations in the femtosecond range, it deposits energy into the material faster than heat can spread. The result is near-zero heat input, minimal microcracking and clean edges.

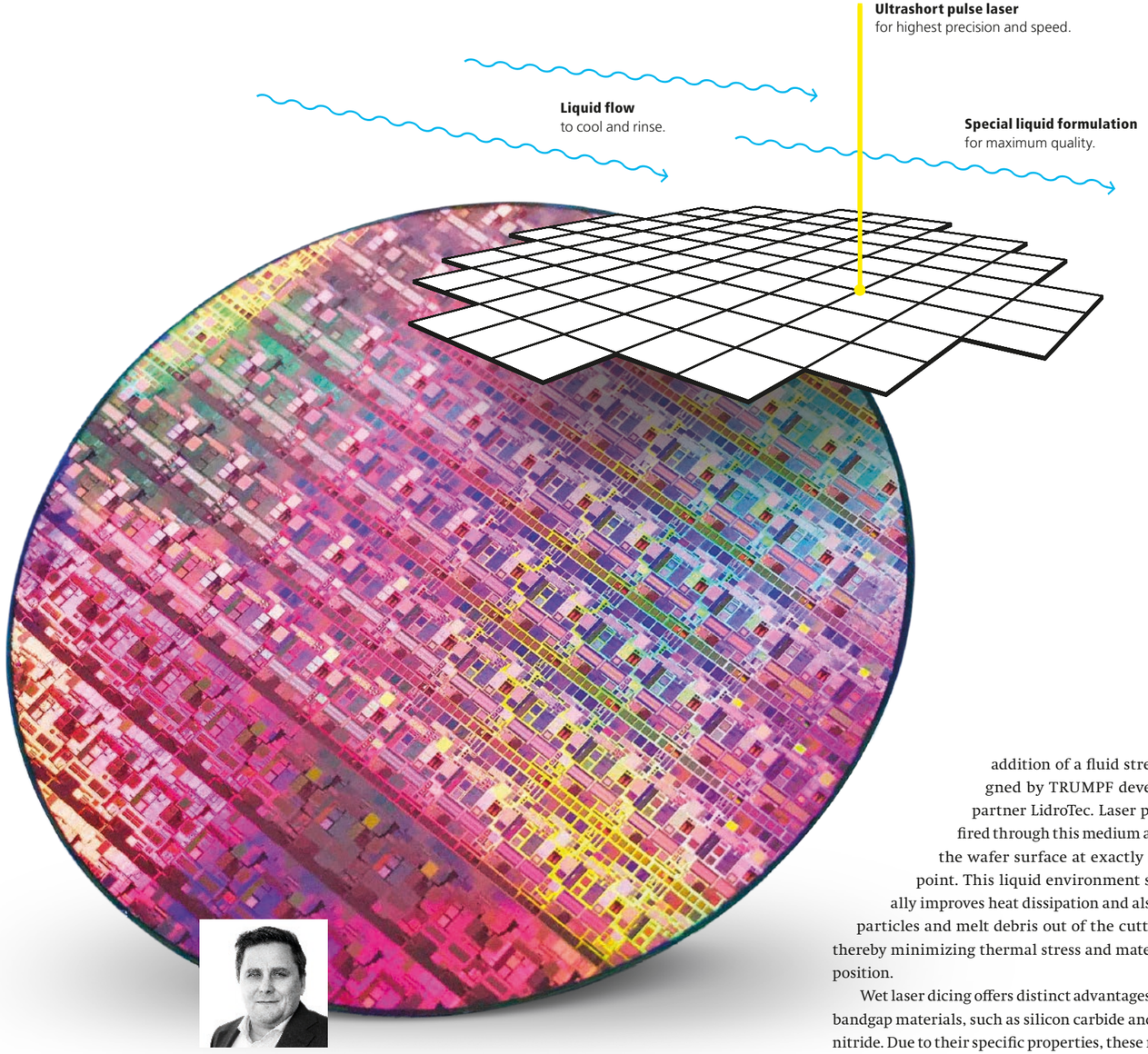
Yet precision alone is not enough—semiconductor manufacturing also requires a throughput that a single laser beam is unable to meet. This is where beam-shaping technology comes in. The energy distribution of a single high-power beam is optimized in such a way it significantly inceases effective cutting speed.

Trials show throughput rates more than triple those of conventional sawing methods—with edge quality on par with plasma cutting. “Scaling is achieved not by applying more energy to a single point but rather through an intelligent distribution of laser power,” Weddeling explains. “Splitting the laser beam gives us a simultaneous uptick in both quality and productivity.”

DICING IN THE THIRD DIMENSION The second key feature of this new process involves the addition of a fluid stream, designed by TRUMPF development partner LidroTec. Laser pulses are fired through this medium and strike the wafer surface at exactly the right point. This liquid environment substantially improves heat dissipation and also flushes particles and melt debris out of the cutting zone, thereby minimizing thermal stress and material redeposition.

Wet laser dicing offers distinct advantages for wide-bandgap materials, such as silicon carbide and gallium nitride. Due to their specific properties, these materials can withstand significantly higher voltages and temperatures than conventional silicon, yet they are also more brittle and prone to mechanical stress. Conventional sawing can result in scrap rates of up to ten percent. A laser, however, will dice even these sensitive materials with virtually perfect precision.

FROM LAB TO LINE The adoption of wide-bandgap semiconductors, 3D integration and heterogeneous chip architectures is set to grow—and, with it, the demands placed on wafer dicing. LidoTec’s singulation could well drive greater productivity and become a key technology for the next generation of semiconductors. With this new high-speed process, quality and speed go hand in hand. ■



“We are resolving the classic trade-off between speed and quality in wafer dicing.”

Christian Weddeling, head of Wafer Dicing at TRUMPF.

Contact: Christian Weddeling, Business Development Consumer Electronics at TRUMPF,
Phone: +49 7156 303-3079, christian.weddeling@trumpf.com

Gernot Walter, ryanking999 / AdobeStock, privat

"WE ARE BREATHING LIFE INTO THE MACHINES"

Everyone is doing something with AI these days and the buzzword cloud keeps growing. But how can AI really create value in laser processing? Prof. Carlo Holly has a crystal-clear answer. Or more precisely: four.

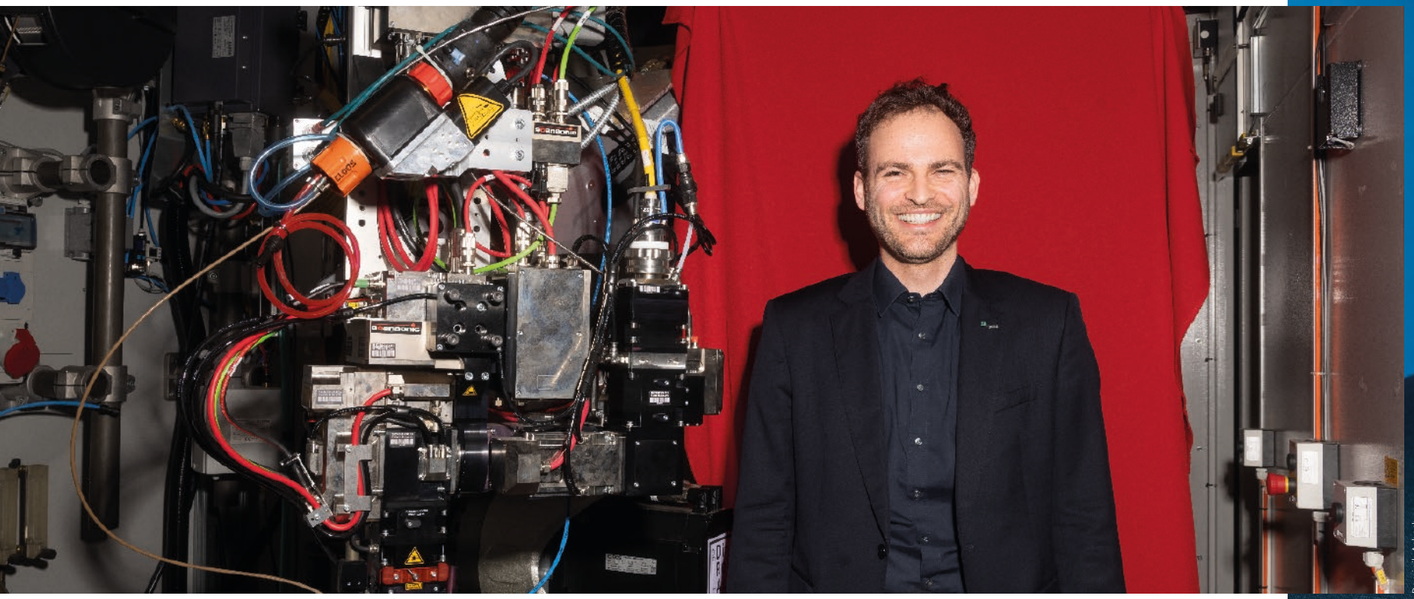
Professor Holly, I've been told you know where industrial laser processing is headed. What do you see coming?
An adaptive, self-learning AI laser machine with a closed feedback loop. This means that when the machine receives a new job—a new component, for example—it develops the right processing strategy all by itself, monitors and corrects itself on the fly, learns as it goes and produces the very first component with 100 percent accuracy.

Not bad. When will such miracle machines be available to buy?
All the pieces are already in place. If everyone pulls together, we can get straight down to making these machines a reality.

Excuse me?
We already have working prototypes for various applications sitting in the lab.

You're joking, right?
No, seriously! Or do you see me smiling? *(smiles)*

I do!
Okay, but it's still true, and I'm perfectly serious! Don't underestimate how exceptionally well laser technology and AI complement each other.





Carlo Holly heads the Department of Data Science and Measurement Technology at Fraunhofer ILT and is a professor of optical systems technology at RWTH Aachen University.

Dominik Asbach

Laser light is a dynamic, flexible tool that lends itself extremely well to digital control: just think of adaptive intensity distribution, pulse duration and power adjustment, and there are plenty more examples. Light can also be used for measuring as well as machining. Dedicated sensors deliver valuable data on the machining process, and we can use that data to train our AI models. It's also true that laser machining processes are tremendously complex. As well as interactions between numerous parameters, you have a whole host of other influencing variables, some of which are not yet fully understood. That means laser machining processes are difficult to fully describe and predict analytically. And it's here that the remarkable potential of AI really comes to the fore. Because this is exactly what AI does so well: it can map and analyze complex relationships within datasets and find unusual solutions to optimization challenges. So it is entirely realistic to assume that AI will enable many more innovations in photonics. We're already seeing how AI is unlocking all sorts of potential in laser processing. My team and I are working on solutions across the laser technology value chain, which can be broken down into four stages.

"AI finds unusual solutions. So it is entirely realistic to assume that AI will uncover many more optimizations in photonics."



Is an autonomous laser machine just around the corner?

What exactly do these four stages of laser AI involve?
The important thing to understand is that the stages build on one another and overlap, but each also offers its own distinct potential. Let's start with stage one, which involves applying AI right at the start of the value chain. This stage is about designing the process and the optical components. The best example is beam shaping—in other words: How can I ensure my optical system delivers the optimum intensity distribution for the process at hand? And how do I actually put that into practice? This is where diffractive optical elements, or DOEs, are such a good idea. Systems that have several DOEs and specific requirements for the desired beam profile are tough to design, because you're dealing with a mathematical optimization problem that has many millions of degrees of freedom. This is where we can benefit from AI, or more precisely an optimization method from the field of machine learning that we combine with physical wave-optical models. We can use that to calculate the DOEs for the optical system.

So you simply finish the optics design faster?
It's far more than that. We end up with designs that we could never have achieved without AI. That means AI is massively expanding the possible solutions for designing these wave-optical systems. Ultimately, that gives us machining processes with more complex beam shaping that significantly improve efficiency and machining quality.

Okay, so what is stage two?
Passive observation of what happens during laser processing. The machine collects data using sensors such as cameras or coaxial process monitoring systems: How long and wide is the weld seam? Are there unusual patterns in the melt? Spatter? The AI analyzes this stream of images, interprets and classifies it—essentially what a human could also do with enough time and effort. But AI also detects subtle patterns that remain hidden to us. The benefit is that the quality of laser processing becomes visible inline—errors and deviations no longer have to be discovered afterward. That is a huge advantage in day-to-day production and one that we can continue to build on. At this stage, however, AI only looks at what is happening or what has just happened.

I think I can guess what stage three is …
Correct. Now the AI starts looking ahead. It predicts optimal processing strategies.

How can an AI come up with a processing strategy?
One way involves what we call surrogate models, which we develop for this purpose. These are digital substitutes for real processing operations. They contain parameter data from real-world experiments: laser power, feed rate, spot diameter, material data and so on. The AI trains itself using this information, proposes its own experiments, runs them in its digital environment and develops a real understanding of the process. Once the AI has learned enough, we deploy it in laser processing.



Dominik Asbach

For his work on combining AI and photonics, Carlo Holly was named one of the hundred most influential personalities in photonics by the magazine *Electro Optics* in 2025.

"The machine operator simply defines what they want to achieve and the machine translates that into process parameters and gets to work."

Dominik Asbach

And how does this predictive AI actually benefit the laser machine?
Basically, by enabling it to produce one-off pieces or respond to new conditions and constraints: I can show the AI which properties a component should have, it tells the machine what to do—and it works on the first attempt. Or perhaps I want to maximize speed in an existing process, and the AI will propose a suitable approach. Interestingly enough, you sometimes get unconventional proposals from an AI because it identifies patterns and relationships that a human process engineer wouldn't necessarily spot. The upshot is that the laser machine develops its own processing strategies, responds to any deviations and independently optimizes existing operations—with little or no testing on real components.

Now we're getting closer to the miracle machine you mentioned at the beginning.
Stage four, yes. This is where we figuratively breathe life into the machines: the adaptive, self-learning AI laser machine with a closed feedback loop. It observes, predicts and regulates itself during the processing operation. The machine operator simply defines the target parameters—what they want to achieve—and the machine translates that into process parameters and gets to work. The value creation potential speaks for itself. We're working on reaching the fourth stage in as many laser applications as possible, and we've already shown that autonomous operation is possible for some processes.

You said you already have such a prototype.
We have experimentally demonstrated that autonomous laser machining is achievable, both for laser welding and for microstructuring using ultrashort pulse lasers. If manufacturers now equip their machines with the right domain-specific AI solutions and suitable system technology and sensors, then it's possible we could see these kinds of autonomous machines coming onto the market a few years from now. At this stage, it's crucial that researchers and machine builders continue building on each other's ideas and collaborating closely. ■

AI HITS THE SPOT

When welding battery modules for prototypes, Audi uses AI-powered machine vision based on TRUMPF's EasyModel AI.



The street-legal Concept C showcases Audi's vision of the future of EV sports cars. This prototype paves the way for a potential production model arriving in 2027.

Audi AG

From spectacular prototype to series production: the road to the next generation of vehicles starts with design but ends on the factory floor. That's why AI has long been a fixture of laser welding at Audi. "We leverage AI at multiple stages of the welding process," explains Jan-Philipp Weberpals from the Laser Beam Processes Tech Unit at Audi in Neckarsulm, Germany For machine vision systems, detecting key characteristics of safety-critical components has always been a complex, high-stakes challenge. Traditionally, this requires repeated tuning during the development process. EasyModel AI transforms this process, making it significantly faster and more agile. It cuts out the inefficiencies: Audi can now train the AI's detection filters in-house and readjust them on the fly, whenever needed.

EVERY POINT COUNTS

When it comes to fabricating EV battery modules, it is vital to be able to precisely determine the position of each part. To guarantee functionality and safety, each weld point must be placed with absolute precision.

Therefore, whenever maximum precision and process reliability are required, Audi turns to EasyModel AI. This is about more than just the stability of the production process—it is also about safety in production. "In extreme cases, inaccurate positioning of weld points can lead to defects and significant scrap costs," says Weberpals. This sets a high bar for machine vision. The decision to use EasyModel AI is driven not by the number of weld points to inspect but rather the degree to which process tolerances threaten to disrupt production. "Whenever those tolerances are particularly difficult to control, I turn to machine vision," Weberpals explains.

IN-HOUSE TRAINING

Audi has been using smart systems like TRUMPF's VisionLine Detect for years. The latest evolution, EasyModel AI, lets the team custom-train detection filters that reliably spot weld points and other features—even allowing for variable lighting, reflections and complex geometries. This enables them to tune image analysis precisely to the real-world conditions on the shop floor.

For Weberpals, the real breakthrough is the control they now have over the technology. "We can build our own detection filters and adjust them on the fly by retraining whenever we need," he explains. And that's a major time-saver, particularly during initial development and prototyping.

"With EasyModel AI, we can now build our own detection filters and adjust them on the fly by retraining whenever we need."



Dr.-Ing. Jan-Philipp Weberpals, Laser Processes / Resistance Spot Welding Tech Unit, Audi AG

David England

Weberpals also highlights the user-friendliness of EasyModel AI. "You can train detection filters with a no-code approach, so you don't need any programming skills. It's essentially liking painting by numbers," he says. "That's key on the shop floor, where the priority has to be running production—not software development."

SERIES IN VIEW

Audi is prioritizing the early integration of AI-based machine vision in vehicle projects so that it is validated under realistic conditions. Alongside improved accuracy, AI-powered image analysis makes processes more robust and helps maintain strict cycle times. "That," says Weberpals, "is a key requirement for series production."

Audi is still transitioning this technology for implementation in series production. In other words, with upscaling now validated, the shift from prototyping to a broader rollout in future vehicle projects is therefore within reach. ■

Contact: Dr.-Ing. Jan-Philipp Weberpals, Audi AG, jan-philipp.weberpals@audi.de



OVERVIEW OF THE ECONOMY

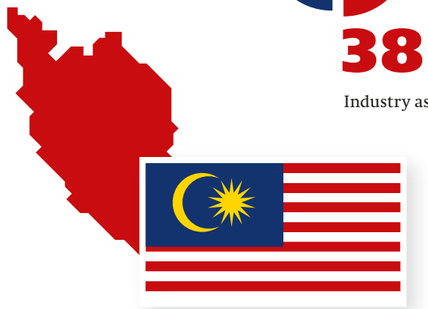
Malaysia is one of Southeast Asia's largest economies, with a robust industrial sector and a **strong focus on export trade.**

The country is deeply integrated in the **global electronics and semiconductor supply chain** and is one of the world's leading hubs for microchip manufacturing and testing.

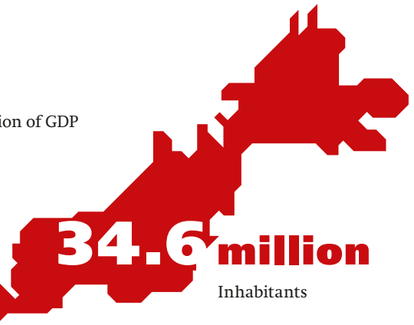
Foreign direct investment reached a record high in 2025. Key trading partners include China, Singapore, the US and Japan.



38%
Industry as a proportion of GDP



WELCOME TO MALAYSIA, LAND OF LASER TECH!



34.6 million
Inhabitants

13,900
US dollars Nominal GDP per capital



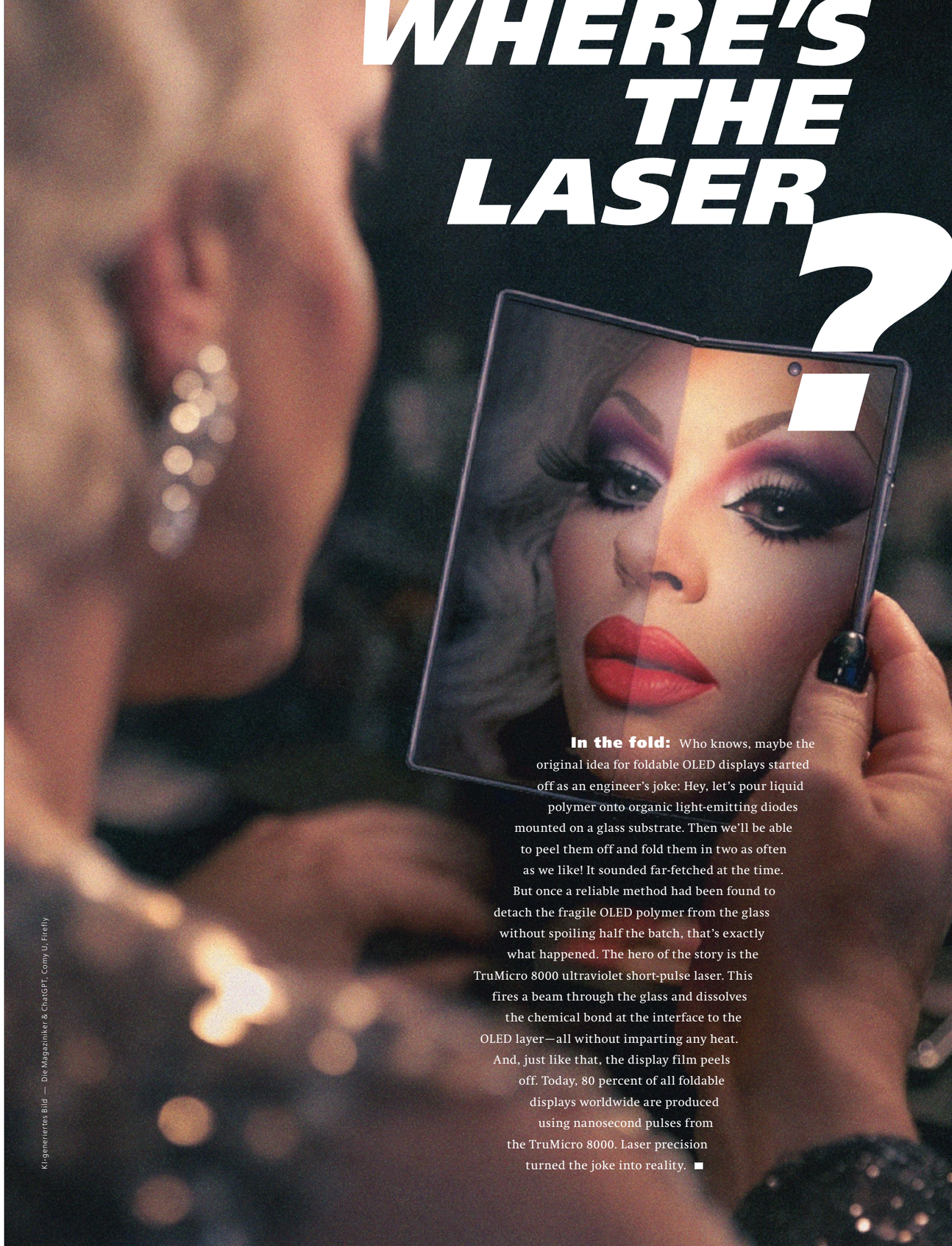
LAND AND LASER

Malaysian engineering companies primarily function as **system integrators and service providers** for industrial laser systems, relying on imports for high-end laser sources and precision optics.

Universities such as Universiti Kebangsaan Malaysia and Universiti Malaya offer **academic programs in optics, laser technology and integrated photonic systems**.

The **high-tech semiconductor ecosystem is driving demand for laser technology** across assembly, testing and packaging (ATP), as well as more broadly for optical modules.

Adobe Stock / f11photo, Shutterstock / Abdul Razak Latif



In the fold: Who knows, maybe the original idea for foldable OLED displays started off as an engineer's joke: Hey, let's pour liquid polymer onto organic light-emitting diodes mounted on a glass substrate. Then we'll be able to peel them off and fold them in two as often as we like! It sounded far-fetched at the time. But once a reliable method had been found to detach the fragile OLED polymer from the glass without spoiling half the batch, that's exactly what happened. The hero of the story is the TruMicro 8000 ultraviolet short-pulse laser. This fires a beam through the glass and dissolves the chemical bond at the interface to the OLED layer—all without imparting any heat. And, just like that, the display film peels off. Today, 80 percent of all foldable displays worldwide are produced using nanosecond pulses from the TruMicro 8000. Laser precision turned the joke into reality. ■

KI-generiertes Bild — Die Magazinmixer & ChatGPT, Comy U, Firefly

[Capacity for AI training]

+15,000%

(or more)

Getty Images News / Mario Tama

The Stargate Project—pictured here in Vernon, California, April 2026—is the largest of many data centers currently under construction worldwide for the purposes of AI training. Experts estimate that the data center boom will boost AI training capacity by at least 15,000 percent by 2030—and probably by much more. A key enabler of this massive expansion is laser technology, which has accelerated modern microchip production in both frontend and backend processes, while increasing yield per wafer. In so doing, lasers have helped chip production keep pace with the soaring demand.

Source: https://epoch.ai/blog/can-ai-scaling-continue-through-2030 (August 2024). Developments since 2024 validate the article's core assumptions. Should this trajectory hold, a gain of approximately 25,000 percent by 2030 is a possibility.

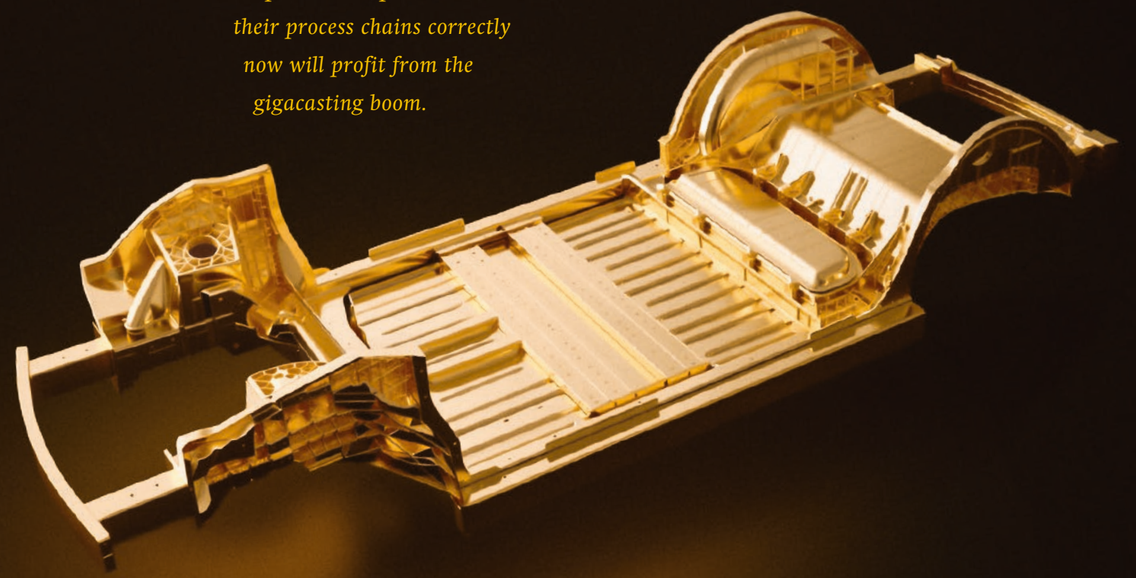
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LASER COMMUNITY.

Of people and photons

Aluminum die casting is set to dominate automotive body manufacturing. Companies that position their process chains correctly now will profit from the gigacasting boom.



Making money with giga