

# Laser *Community*

THE LASER MAGAZINE FROM TRUMPF



## SPARKS FLEW

ED HANSEN EXPLAINS  
THE GROWING  
ENTHUSIASM FOR  
HYBRID WELDING

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## Delicate work

Uwe Stadtmüller has created  
a marvel of productivity

## Rough and ready

Different rules apply in the  
Zeiss nanoworld

# Tender touch

Gentle, non-contacting laser systems create  
a stir in surface finishing



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**IMPRINT**



What is it that drives the research and business communities to develop new solutions? It seems to me there are essentially two types of innovation. One has its origin in commercial or social pressures, while the other is driven by curiosity. But stem from the same basic question: What if...? Who would have thought the day would come when we would be able to photograph electrons and observe them as they move around inside molecules? I grew up with lasers, but even I never imagined we would achieve that! Yet we have — and it's all because researchers such as Professor Ferenc Krausz asked the question: "What if I could generate a flash of light so short that it could even capture the motion of an electron?" Efforts to answer his question led first to the femtosecond laser and then to the attosecond laser.

But it's not always just about peering into atoms. Sometimes the question is of a decidedly practical nature, such as "What if I could weld my fan guards remotely using a laser process?" This was a question that Uwe Stadtmüller found himself asking when he was faced with an escalating number of product variants and intense pressure on price. The solution gave his middle-market company a leap in productivity which has helped him secure long-term contracts. Andrea Funck, a restorer at Württemberg State Museum, had an even longer path to travel. Nobody was willing to actively address the needs of the niche restoration market, so it was left to her to keep her eyes open. Thanks to her persistence, a short pulse laser is now being used to clean 2000-year-old bronze arrow heads and free them from hardened layers of corrosion.

## What if...?

So "What if...?" is not only a question posed by daydreamers, but also by researchers and inventors. And it's a question that forces you to assess your own position: Do you really want to find the answer? Are you willing to venture into unknown territory? What if it all goes wrong? Fortunately, there are many people like Professor Ferenc Krausz, Andrea Funck and Uwe Stadtmüller who focus on finding an answer — and end up creating the next innovation.

But this is far from being an end in itself. It requires real determination to stay the course through periods of sustained uncertainty and volatility. You have to be willing to leave well-trodden paths and break through supposed limits. For our part, we are firm believers in this pioneering spirit. For example, over the last few months we've been working intensively on the development of EUV photolithography to create the microchips of the future — offering yet more proof that the laser still has a long way to go before it reaches its limits as a tool.

PETER LEIBINGER, D.ENG. H.C.

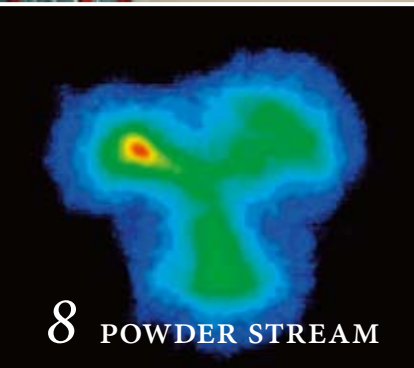
Vice-Chairman of the Managing Board

Head of the Laser Technology/Electronics Division

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## COMMUNITY

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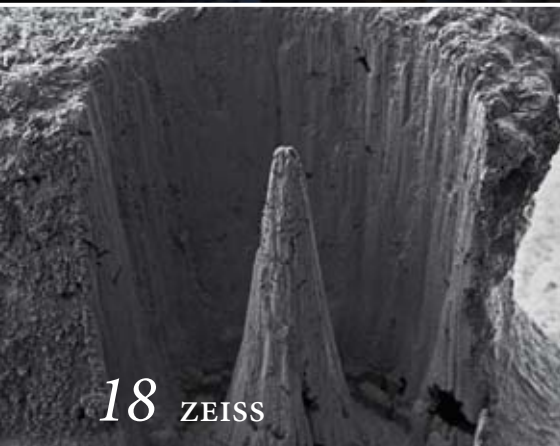
### Clean is the keyword

What's happening down under? Annaliese Kloe from Headland Machinery reports on the latest trends in Australia's laser industry. **PAGE 15**





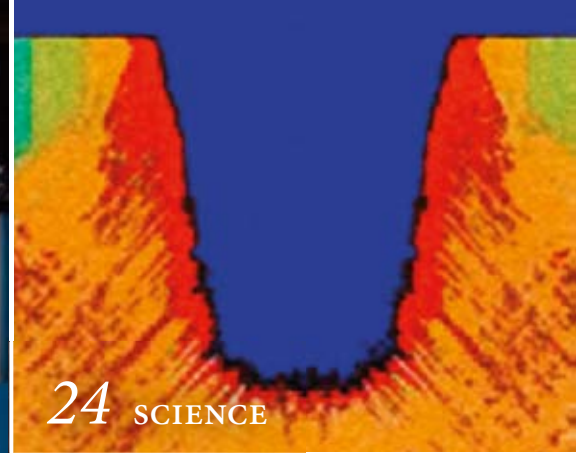
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## “Join this”

Ed Hansen explains why hybrid laser welding is becoming increasingly popular. [PAGE 16](#)

## Down in the core

One cubic millimeter of material can pose a major obstacle. [PAGE 18](#)

## Maximum points

The one-eyed productivity miracle from Osterburken. [PAGE 22](#)

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## Electron shower in glass

Ultra-short pulses strike the extremely hard glass used for displays – a simulation. [PAGE 24](#)

## “I know how lucky I am”

Prof. Ferenc Krausz already experiences the world on an attosecond scale. We asked him about his plans for the future. [PAGE 26](#)

### POWER PEAK

New ultra-short-pulse laser packs a bigger punch than ever before.  
[www.laser-community.com/3065](http://www.laser-community.com/3065)



## S P O T

### --- BIRTHDAY CELEBRATIONS

In September TRUMPF Photonics Inc. celebrated its tenth anniversary in Cranbury, New Jersey. The company has spent the last decade manufacturing high-tech laser components such as diode pump sources for high-power lasers. [www.us.trumpf.com](http://www.us.trumpf.com)

### --- EFFICIENCY BOOST

The Fraunhofer IWS has developed a remarkably fast laser-based process for structuring organic solar cells. The new process significantly increases the cells' conversion efficiency. [www.iws.fraunhofer.de](http://www.iws.fraunhofer.de)

### --- BIT BOOST

Researchers at the University of Southern California have succeeded in wirelessly transmitting data over a distance of a few meters at a speed of 1.7 terabits per second using orbital angular momentum. [www.usc.edu](http://www.usc.edu)

### --- IMAGING ATOMS

Researchers at Griffith University in Australia have succeeded in measuring the exact light absorption rate of individual atoms. This information can help to maximize light output, particularly in microscopy and astronomy. [www.griffith.edu.au](http://www.griffith.edu.au)

### --- SUPER LASER

California's National Ignition Facility has fired a laser shot with a peak power of 500 terawatts as part of its research into nuclear fusion. The hope is that a laser of this type will one day ignite a fusion reaction. [lasers.llnl.gov](http://lasers.llnl.gov)

### --- CHIP-LASER

A team of researchers at the University of Texas at Austin has developed a tiny semiconductor laser. The beam sources could massively speed up data flows within computer chips. [www.utexas.edu](http://www.utexas.edu)

### --- LASER FROM JAPAN

TRUMPF has opened a disk laser production facility in the Japanese city of Yokohama. This is the third TRUMPF production site of its kind after Schramberg and Farmington. [www.jp.trumpf.com](http://www.jp.trumpf.com)

“The Federal Government, industry, and academia must collaborate.”

*Proposal to the U.S. government;  
Susan Hockfield, former  
MIT president and co-author*

## Funding and strategy

### USA promotes advanced manufacturing

■ The USA is set to make a huge investment in promoting the research and development of new manufacturing technologies. In a report submitted to the U.S. government, the President's Council of Advisors on Science and Technology has proposed a multi-stage strategy. In a similar vein to equivalent European programs such as the “Photonik 2020” research agenda, the U.S. report specifically highlights the role of the laser. Europe has also provided a blueprint for the implementation of the U.S. program, which envisages the creation of 15 institutes across the USA to act as centers of innovation in manufacturing. These will provide the facilities for private companies, universities and public institutions such as NASA to perform research and development in joint, coordinated projects. One billion U.S. dollars have already been earmarked for the program. [www.whitehouse.gov](http://www.whitehouse.gov)



*With the help of smoke and a laser, the truck measures its own wake vortices while driving.*

## Tail light

### Measuring aerodynamics using lasers

■ Trucks are not generally renowned for their streamlined design. The German Aerospace Center (DLR) hopes to change that by using the road as a wind tunnel. With a smoke generator hanging underneath the front of the truck, and special cameras and a green laser installed at the rear, the DLR engineers send the special truck out on night-time journeys and analyze the air flow as it drives. This allows them to test a novel kind of underbody design under real-life conditions. The design features a diffuser to minimize the air suction beneath the vehicle, which impedes forward motion. The aim is to reduce aerodynamic drag and energy consumption. [www.dlr.de](http://www.dlr.de)



“I want structured surfaces to find uses in new products.”



Prof. Andrés Fabián Lasagni

Andrés F. Lasagni joined Dresden University as Professor of Laser Texturing in Manufacturing Technology. This native of Argentina focuses his efforts on methods for micro- and nano-finishing of large, curved surfaces. Here he favors the use of direct laser interference. The technique superimposes the light of multiple laser optics and burns the interference pattern into the surface. In Dresden, Lasagni is hoping to refine direct laser interference structuring to ready it for industrial use. [www.tu-dresden.de](http://www.tu-dresden.de)

“After eight years of hard work it’s finally pay-off time!”



Curiosity Mars rover

Curiosity has landed on Mars and deployed its mini laser gun — and Roger Wiens, who heads up the ChemCam team, is pleased so far. The first laser shots have delivered even better results than the experiments conducted back home. The telescopic mast-mounted ChemCam, which comprises the “head” of the rover, features a solid-state laser which is capable of firing five-nanosecond laser pulses at rocks up to seven meters away. The camera analyses the spectrum of the resulting plasma emissions, providing scientists with information on the rock’s composition. [www.nasa.gov](http://www.nasa.gov)

“Sand dunes and laser pulses are actually very similar.”



Dr. Daniel R. Solli

What happens to a laser pulse between the source and the optics? Daniel Solli and his team have developed a way to measure the spectral patterns that develop in picosecond pulses in optical fibers. It turns out they mimic wave patterns found in nature, such as those observed in sand dunes. Nonlinear interactions play an important role in this process: Overlapping frequency modes within a pulse either unite or suppress each other, until only one is left dominant. The researchers’ findings may open up new ways of reducing losses in efficiency or beam quality. [www.ucla.edu](http://www.ucla.edu)

#### PRODEX

November 20–23, 2012, Basel, Switzerland;  
Machine tools, tools and production  
measurement [www.prodex.ch](http://www.prodex.ch)

#### ESPACE LASER

November 28–29, 2012, Mulhouse, France;  
Exhibition on lasers in industry and medicine  
[www.espace-laser.biz](http://www.espace-laser.biz)

#### SEMICON KOREA

January 30–February 1, 2013, Seoul,  
South Korea; Largest technology trade show  
in that region [www.semiconkorea.org](http://www.semiconkorea.org)

#### PHOTONICS WEST

February 2–7, 2013, San Francisco, CA, USA;  
Conference and exhibition for photonics,  
biophotonics and the laser industry  
<http://spie.org/x2584.xml>

#### SOUTHERN MANUFACTURING

February 13–14, 2013, Farnborough,  
United Kingdom; Manufacturing technology,  
electronics and subcontracting exhibition

#### INTEC

February 26–March 1, 2013, Leipzig,  
Germany; Trade fair for manufacturing, tool  
and special-purpose machine construction  
[www.messe-intec.de](http://www.messe-intec.de)

#### BATTERY JAPAN

February 27–March 1, 2013, Tokio, Japan;  
World’s largest business platform for man-  
ufacturing and R&D of rechargeable battery  
[www.batteryjapan.jp](http://www.batteryjapan.jp)

#### LASER WORLD OF PHOTONICS CHINA

March 19–21, 2013, Shanghai, China;  
China’s platform for the photonics community  
[www.world-of-photonics.net/en/laser-china/start](http://www.world-of-photonics.net/en/laser-china/start)

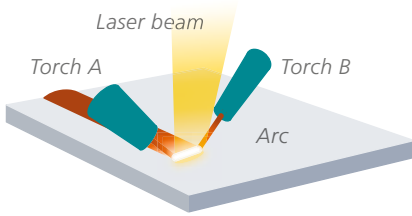
#### INDUSTRIE

April 16–19, 2013, Lyon, France;  
Business parlor for production technologies  
[www.industrie-expo.com](http://www.industrie-expo.com)

#### LASER WORLD OF PHOTONICS

May 13–16, 2013, Munich, Germany;  
Industry marketplace and knowledge  
forum for photonics  
[www.world-of-photonics.net](http://www.world-of-photonics.net)

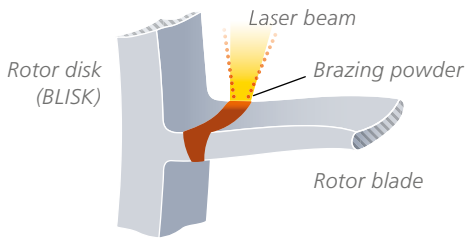
## CONCEPTS



### -- LASER ARC

A new method of deposition welding combines arc welding with a diode laser. The laser heats up the workpiece, which eases work for the arc. This method achieves a fourfold increase in the deposition rate.

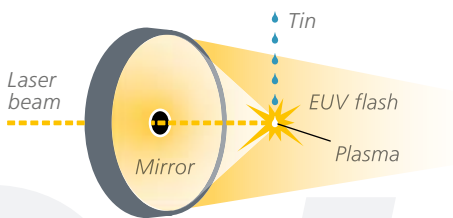
[www.lzh.de](http://www.lzh.de)



### -- TURBINE BRAZING

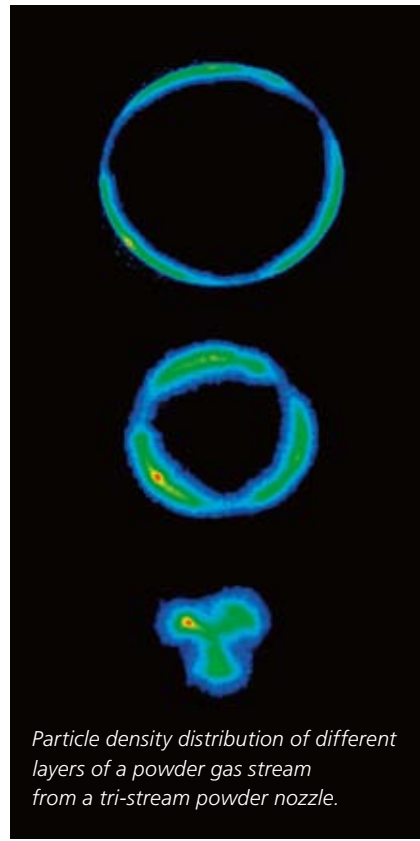
Rolls-Royce produces bladed disks (BLISK) for jet engines using laser brazing. The brazing powder is jetted into the laser beam and only the brazing material heats up, melts and alloys with the rotor disk. The blade is affixed to the solidifying brazing metal by adhesion.

[www.rolls-royce.com](http://www.rolls-royce.com)



### -- EUV LITHOGRAPHY

To pattern ultra-dense computer chips, Cymer uses a CO<sub>2</sub> laser to generate extreme ultraviolet light (EUV). The laser pulses convert falling droplets of tin into plasma, 50,000 times a second. The EUV light from the plasma is reflected via mirrors and onto the wafer using a reticle. [www.cymer.com](http://www.cymer.com)



## Powder image

Camera checks nozzle quality in laser deposition welding.

■ Researchers at the Fraunhofer ILT have developed a direct technique that can be used to check the quality of the powder nozzle during laser deposition welding. A laser diode illuminates the powder gas stream from the side while a camera positioned coaxially to the nozzle captures images of the stream. This makes the spatial distribution of the powder visible. "This is the first time we have developed a measuring technique that lets us determine the constancy of the powder mass flow, the symmetry of the stream, and the position and size of the powder focus," says project manager Stefan Mann. The powder nozzles degrade over time, however, and the only way to spot any changes had been to use the indirect method of comparing reference samples.

[www.ilt.fraunhofer.de](http://www.ilt.fraunhofer.de)



## Weld done

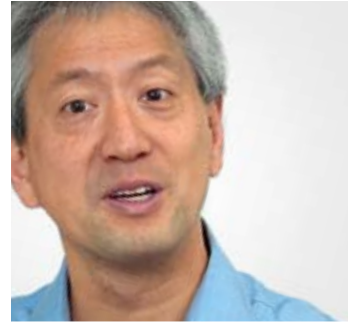
New aluminum welding method without filler material

■ Welding lasers and inductors are to work together in the future to prevent hot cracking in aluminum welds. These cracks, which form in aluminum and aluminum alloys during post-welding cooling, impair the quality of the weld seam. To avoid this, aluminum is generally only welded using filler materials. Researchers from the University of Kassel are now planning to combine laser welding and induction to create a method that does not require filler material. The inductors heat up the securely clamped component. The resulting thermal expansion builds up additional compressive stress which works against the strains in the weld as it cools. [www.uni-kassel.de](http://www.uni-kassel.de)



# Bright & shiny

An innovative diode laser that delivers more brightness and more power. Co-developer Dr. Tso Yee Fan explains the concept of very dense wavelength beam combining (WBC).



*Dr. Tso Yee Fan is Associate Leader of the Laser Technology and Application Group at MIT's Lincoln Laboratory. Back in the 1980s he was one of the developers of diode-pumped, solid-state lasers.*

*Diode stacks generate a lot of power. But how can the light be combined to form a single beam?*



## *What is so special about your high-power diode laser?*

The innovation builds on the well-known principle of wavelength beam combining. This enables an array of many diode lasers to generate an output beam that has the spatial characteristics of a single laser. In other words: While an array of lasers would normally deliver an array of output beams, what's output here is a single beam.

## *You say the basic concept is well known?*

The idea has been around a long time. This technique is well known in optical communication as wavelength division multiplexing, in which wavelengths from multiple lasers are coupled into an optical fiber to increase the amount of information that can be carried through the fiber. We have identified a way to make this work in a simple, efficient manner in high-powered laser diodes.

## *What does this progress mean for practical applications, such as laser-based material processing?*

The practical result is that much higher power can be coupled into thinner optical fibers than conventional approaches that involve coupling arrays of diodes to an optical fiber. We have already been successful in coupling multi-kilowatt power directly from diodes into fibers with less than ten percent of the core area needed in conventional approaches. In materials processing, this enables fiber-coupled diode lasers to deliver higher power at the workpiece.

## *What are you currently doing research on?*

I'm still working on improving beam combining for both fiber and semiconductor lasers. Another area of my current work involves cooling solid-state laser materials to cryogenic temperatures, as a way to increase their average power while maintaining near perfect beams.



# *Gently* done

The laser has proven to be a powerful cutting tool and can perform centimeter-deep welds – but its remarkable ability to process surfaces shows off its gentler side.



# A

*Preparation for welding:  
The laser removes  
thin functional coatings or  
impurities immediately  
prior to the joining process—  
without affecting the  
structure of the under-  
lying metal.*



Apply a laser to five centimeter thick stainless steel and it will burn a hole right through it. Whenever laser light comes into contact with a material, it takes just fractions of a second for it to produce a glowing micro-inferno that eats its way through the material at a rate of several meters a minute. That is the laser we know and love: Light transformed into fire.

Yet the very first commercially successful application of laser light was in eye surgery. That's because the real strength of a laser lies in its controllability—there is no other tool that releases so much energy yet can be so precisely metered. Penetration depth and heat input can be controlled with enough precision to allow lasers to ablate or activate surfaces right down to the micron in a process that is reliable, reproducible and automatable. While the 1980s and 1990s saw industry learning to appreciate the powerful side of the laser, it is its gentler side that has increas-

ingly been sparking interest in the new millennium—its ability to prepare for joining processes, clean materials, remove coatings, and refurbish and smooth oxidized surfaces.

### The cleaning skills of short pulse lasers

The BMW plant in Dingolfing, Germany, provides a good example: A few years ago, the Bavarian automaker was developing a process for welding axle differentials using lasers when the project team came up against one of the typical challenges of laser welding. The components used in the differential have a manganese phosphate coating which shortens the running-in period. The welding laser has no difficulty evaporating the coating, but the high process speed does not provide enough time for all the vapor to escape evenly and cleanly from the joining gap. Instead, it mixes with the steel melt and introduces turbulence into the process, causing spatter and inclusions.

“As long as you get the parameters right, there is no adverse effect on component functionality,” explains Max Beham, a BMW production specialist. “But we work at a very fast pace and are looking to increase our output rate even more, so we don’t have time to reset the parameters every time we encounter fluctuations in the process.” Yet that was exactly what they were forced to do. The manganese phosphate coating, which is applied in chemical baths, varies in thickness so that the laser parameters had to be manually adjusted at regular intervals.

Beham eventually found the solution for the welding preparation process in the form of TRUMPF short pulse lasers. The light from these lasers, guided by a scanner system, passes over the surface of the stationary crown gear. The high pulse peak power removes the coating from the weld joint without heating up the steel to any significant degree. “We’re very satisfied.





- Cleaning time: The laser uses a “light shower” to remove process residues from tools such as tire molds. This method prevents additional tool wear and even succeeds in removing deposits from fine structures in the mold.

B



C

- Preparation for gluing: The laser removes oxides, grease and other hindrances to successful gluing. It can also be used to expose the fibers of composites or to texture the surface of metals in order to strengthen the adhesive bond.



See the machine in action (video)  
[http://bit.ly/lc\\_tire](http://bit.ly/lc_tire)

It leaves a perfect surface for welding. Our tests have shown that the laser ablation does not cause any structural changes whatsoever — and that’s exactly how we wanted it,” says Beham. BMW is now integrating the short pulse laser systems directly into its welding stations, further boosting the degree of automation in its production line.

**Better bonding** The goal of weight reduction is not only boosting the use of laser welding, as shown by the BMW example, but is also increasing the use of lightweight construction materials such as aluminum and composites. These new materials require new joining techniques — and the laser is perfectly equipped to provide them. Aluminum is becoming more and more popular, and joining techniques, particularly in the aviation industry, increasingly include gluing as well as welding. However, the gluing process requires a bare metal surface — yet materials such as aluminum quickly acquire an oxide layer when exposed to air, and adhesives struggle to bond with the resulting “passivation layer.” Conventional methods use sandblasting or shot peening to remove this layer, before cleaning and degreasing the aluminum by chemical means and applying the adhesive. In contrast,

laser systems integrated in the production line evaporate the unwanted passivation layer and vacuum it up just before applying the adhesive. This eliminates the need for subsequent cleaning and means that nobody has to provide and dispose of blasting abrasives and chemicals.

And that’s not all. The fact that the pulsed beams can be so precisely controlled and metered means that the workpiece can also be checkered in the same pass. The laser uses a spot-by-spot technique to profile the surface with high-density squares, just microns deep. The melt accumulates on the edges of these squares. Adhesives and plastic sprays work their way into this pattern, which gives them plenty of space for bonding. And this method is not limited to flat sheets: By incorporating a multi-axis system or robot to guide the laser, it is possible to apply the method to virtually any component geometry.

Even modern fiber composite materials bond better after being exposed to laser light. In carbon fiber reinforced plastic (CFRP), the carbon fibers are embedded in a thermoset matrix, such as an epoxy resin, for example. To maintain the material’s strength, it is important to ensure that the adhesive preparation does not damage the carbon fibers. This is no problem for the laser

*“The ablation causes no structural changes whatsoever — and that’s exactly how we wanted it.”*

Max Beham,  
BMW production specialist



Border deletion (video)  
[http://bit.ly/lc\\_ablation](http://bit.ly/lc_ablation)



**D**

Scratch-free ablation:  
 The laser removes  
 all photoactive layers  
 around the edges  
 of solar cells faster  
 and more accurately  
 than a sandblaster  
 (left) and leaves  
 virtually no traces  
 in the glass.



thanks to its precise depth control. It simply roughens and activates the epoxy resin covering the fibers while cleaning and degreasing the underlying surface in the same step.

For the laser, roughening and smoothing are only a question of adjusting the parameters. To create a more aesthetically pleasing look for aluminum, for example, the laser can melt and smooth the surfaces prior to painting. The same principle allows lasers to create perfect plastic surfaces—an indirect effect achieved by polishing the interior of injection molds through remelting with laser light. The procedure in each instance is the same, involving carefully metered doses of energy directed at a precisely defined series of points or surfaces.

**Cleansing light shower** 4Jet is another company that relies on this basic technology: “We specialize in laser processing of surfaces,” says Jörg Jetter, Managing Director of 4Jet, describing what his company does. 4Jet has sold its machines to an impressive range of industries, from the dust-free solar industry to the more down-to-earth tire production business. “Whether you call it cleaning, de-coating, ablation or activation, we’re essentially talking about using a laser to gently treat thin coatings on high-grade surfaces,” says Jetter. Similar in principle to a baking tin, a tire mold is the negative impression of a tire tread. Under high pressure and at temperatures of around 170 degrees Celsius, tire production lines convert soft natural rubber into

a harder, stronger material by means of vulcanization. But like a baking tin, a tire mold is also left with a residue of rubber compounds and release agents each time a tire is produced. This residue gets stuck in the delicate scale-like structures in the negative tread pattern and blocks up the mold vent holes. To maintain the quality of the tires, the molds are cleaned after a few thousand production cycles. “The challenge is trying to remove a mix of different materials deposited in varying thicknesses over a range of steel and aluminum surfaces,” says Jetter. “And this has to be done inside of a mold which is craggy and difficult to access!”

4Jet reckoned that the laser would be a good solution. Prior to that, cleaning was a choice between sandblasting and dry ice snow. For sandblasting, the workers first have to disassemble the molds, which can take several hours. Another disadvantage is that the grains of sand used in sandblasting not only remove the residues but also abrade the lamellae and valves. Laser cleaning avoids all these problems. The optics of the laser—a CO<sub>2</sub> or solid-state laser, depending on the application—are lowered into the tire mould from above to shower the inside of the mold with laser light. Maintaining a constant working distance, the laser light vaporizes the residues, which are immediately vacuumed out of the mold. The seven-axis scanner unit reaches every part of the mold surface with the necessary energy density. Once again, it is only the unwanted material that is removed, while the workpiece

itself is left untouched. The laser also scores well in comparison to dry ice snow methods—it uses significantly less energy while offering the same



*“Whether you call it cleaning, de-coating, ablation or activation, we’re essentially talking about the same thing.”*

Jörg Jetter,  
 Managing Director of 4Jet





3D cleaning: The laser removes rust from iron with precision down to the micron. The scanner meticulously traces all the irregularities of the age-old surfaces.

E



process speed and reliability. “The capital cost of a laser is admittedly high, but the investment quickly pays off when you are producing 10,000 high-quality tires a day,” says Jetter. “For some new rubber compounds, the laser is actually the only cost-effective cleaning method.”



*“As restoration specialists, we keep our eyes open for any new technologies that might help us in our work.”*

Andrea Funck, a restorer at  
Württemberg State Museum

**Standard method for solar cells** The other mainstay of 4Jet’s business, which has since become something of an undisputed standard in the solar industry, is the edge deletion of thin-film solar cells using lasers. In order to electrically insulate the semiconductor module, solar panel manufacturers remove all the photoactive layers, all the way around the edges of the glass substrate. This is another application where a gentle laser is far superior to a rough sandblaster. This non-contact ablation method prevents damage to the delicate glass substrate and ensures that no micro-cracks are formed. And the laser offers particular benefits to the clean rooms of the solar industry. Laser ablation is a clean, dry method which does not require any chemicals, blasting media or costly downstream cleaning.

**Giving old treasures a new shine** Word has spread of the laser’s ability to treat delicate surfaces so gently, and interest is now coming from unexpected quarters. For example, the restoration department of the Württemberg State Museum in Stuttgart recently contacted TRUMPF to enquire whether a laser system might not help with their work. Their idea was to remove the tough layers of corrosion from metal archaeological objects in time for a major exhibition, the “The World of the Celts”, scheduled to take place in the German state of Baden-Württemberg in 2012.

Andrea Funck, who heads up the restoration workshops at the State Museum, explained the initiative as follows: “The restoration market is not attractive enough for anyone to invent

things specially for us! So we always have to keep our eyes open to spot any new technologies that might be useful in our work.” In collaboration with TRUMPF, the restoration experts carried out experiments on replicas before they dared to apply the technique to the irreplaceable originals. Once they were satisfied with the results, they used the short pulse laser to clean 2,000-year-old bronze arrowheads, iron sword blades and silver coins. “To ensure the surface remains completely unchanged, we defocus the laser to minimize the amount of heat applied to the object,” explains Dennis Decker, the application specialist at TRUMPF who was in charge of the tests. Since every object is unique and all the objects differ in terms of their age, metal composition, and the degree of weathering and corrosion, flexibility is absolutely essential. With the right parameter settings, the laser can split open the film of rust on an object, making it easy to remove the accumulated coating. “Laser use is still in its infancy in the field of archaeology, but we can certainly see the potential: Unlike sandblasting, lasers remove all the extraneous material from the object’s surface. Lasers could also help us to work faster in the future,” says Funck. From the relics of our ancestors to solar modules and tire molds, gentle laser light has shown itself to be capable of meeting the challenges posed by all kinds of different surfaces. ■

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# Clean is the key word

What is going on down under? Annaliese Kloe from Headland Machinery names the trends driving Australia's laser industry.

Throughout the last decade, laser technology has added an entirely new dimension to the face of Australian manufacturing. Taking advantage of all its capabilities, industry uses the laser for joining, cutting, surface treatment and laser marking, while universities conduct laser research to provide manufacturers with valuable information for the future. I cannot generalize or assume which application is most important to the whole of Australia, but inferring from the needs of our customers, right now I would opt for cutting as being of most value to Australian industry.

With a lot of value placed on innovative technology, automation is increasingly becoming important within the Australian laser technology sector. The reasons for this trend are that we are now seeing the benefits of what automation can offer — primarily increasing productivity with uninterrupted operations, enhanced material flow and improved process reliability. In recent times the emphasis and importance of the energy input has risen to the top of priorities. As in all industrialized countries, trends have generally been towards reducing costs, while simultaneously increasing production efficiency — and this is what laser technology achieves. Since its introduction, Australian manufacturers have eagerly adopted automation processes in their day-to-day work. Given the choice,

most manufacturers would choose automation instead of hiring a team of people to do the same thing.

Australia has a vested interest in developing its manufacturing sector. Industries are continually presenting their need to reap the benefits of laser technology: automotive suppliers, precision part manufacturers and traditional sheet metal manufacturers are increasingly interested in using laser technology applications. But if we are to single out one industry experiencing positive growth, it is the mining and energy sector. This sector presently plays a prominent role as an industry of major impor-

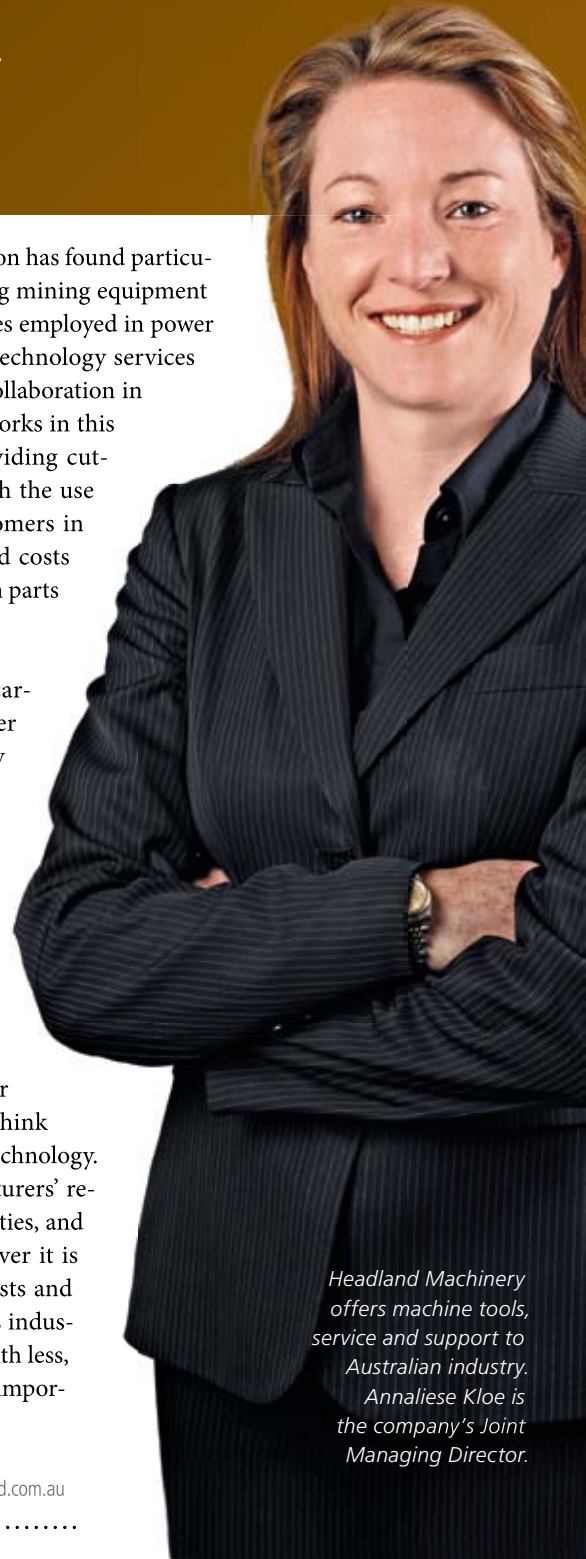
tance. Here, laser metal deposition has found particularly widespread use in repairing mining equipment or the blades in the huge turbines employed in power generation. Currently, mining technology services achieve high export rates and collaboration in national and international networks in this field is high, all the while providing cutting-edge technologies. Through the use of laser technologies, our customers in this sector benefit from reduced costs while achieving greater quality in parts manufacturing.

Looking ahead, the new carbon tax is definitely a big player in tomorrow's game. We're likely to see more issues like this stem from the push towards a cleaner technology environment. The Australian Government has already introduced a one billion dollar Clean Technology Investment Program to assist manufacturers to buy new equipment that will reduce carbon emissions. Laser technology is an application I think will feature in this era of clean technology. Automation increases manufacturers' resource utilization, overall capacities, and production capabilities. Wherever it is introduced, it lowers overall costs and energy consumption. Australia's industries seek to accomplish more with less, and the laser is undoubtedly an important tool in this. ■

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New driver  
for laser  
applications:  
The mining  
sector



Headland Machinery offers machine tools, service and support to Australian industry. Annaliese Kloe is the company's Joint Managing Director.

At ESAB Ed Hansen serves as global product manager for hybrid laser welding technology. He was formerly chief production engineer at a major U.S. shipyard involved in the development of hybrid welding technology.

Laser welding of pipelines (video)  
[http://bit.ly/lc\\_ESAB-e](http://bit.ly/lc_ESAB-e)



# “Join this”

A look inside the multi-faceted future of hybrid laser welding



■ *Hybrid laser welding started in the ship building industry. What progress has it made here?*

Major shipbuilders in Europe are systematically implementing hybrid laser welding. The technology generates enormous savings. Cruise ship manufacturer Meyer Werft, for example, has reported reducing total build time by 30 percent due to implementing hybrid laser welding.

*What's prevented more widespread adoption?*

Early adopters have been very secretive owing to the strong competitive advantage the technology creates. Without published case studies and data on economic return, it's been difficult to grow awareness and acceptance of the technology.

*What are the economic benefits?*

In one automotive industry example, we showed a reasonable, four-year amortization on the costs incurred when adding the technology to their existing production. But if the company were to redesign the product, amortization would take less than a year, thanks to reduced material use. In another example, one redesigned rail car's weight was reduced by 30 percent. This translates into 30 percent more payload for each rail car.

*What particularly cost-effective applications have you seen?*

Hybrid laser welding is particularly well suited for mass production welding at high capacity utilization. Depending upon the application, hybrid laser welding can be three to ten times faster than conventional processes. The technology can lower heat input by as much as 90 percent and this reduces the typical macroscopic distortion. Additionally, we've seen benefits in weight-sensitive applications. We've also seen significant fatigue life improvement in products exposed to cyclical loading, such as car suspensions, pressure vessels, and bridge components.

*What developments in laser technology have influenced hybrid laser welding?*

The continued development of high-power solid-state lasers with smaller form factors, greater efficiency, and lower cost has had a big effect on hybrid laser welding. Our transition to solid-state lasers in 2001 made it feasible to apply the technology to industrial settings. New tech-

nologies, particularly fiber delivery, let us integrate the process into conventional motion systems — robots, gantries and automation — which increased acceptance. Many laser improvements benefit other applications more than ours. We're currently limited in how much laser power or brightness we can use productively. But in the future I see less expensive, compact lasers which are easier for us to incorporate into existing production operations.

*What does the future of process control look like?*

So far, most advances in process control have focused on visible surface features. In the future, we'll look inside the weld and manage the process based on what we see below the surface, using a closed-loop, real-time control system. Improving weld stability inside the material and preventing the creation of discontinuities inside the weld will enhance quality control and allow us to reliably apply the process to thicker, larger sections.

*Every technology has its limits. Which are the current limitations of hybrid laser welding?*

The thinnest application we've seen is around one millimeter. The fastest is a pressure vessel, three to four millimeters thick, welded at 6.1 meters per minute. This by the way makes it almost seven times as fast as conventional butt welding. There's a big advantage to one-sided welds, particularly inside pressure vessels like those used for petrochemical tanks, hot water heaters, and in power plants. Using laser-augmented welding with filler wire, we can weld thicker segments with a non-penetrating hybrid laser variant. Our thickest one-sided, single-pass application was in half-inch thick steel, butt welded at 2.3 meters per minute.

*What applications show the most promise?*

We've seen significant interest from the energy industry. Over the next twenty years, production will be increased and many pipelines will be

replaced. Many of these applications use high-strength materials and manufacturers will have to automate to keep up with demand. Promising opportunities exist in bridge building, where designs are moving toward more cable-stayed suspension and long span bridges. Weight is critical here. As manufacturing moves to lighter products, structures get thinner and distortion becomes a bigger problem.

*How is this technology expanding in automotive manufacturing?*

Transportation — shipbuilding, rail cars, truck trailers, mobile equipment, automobiles — offers the biggest area of growth. New efficiency standards and high fuel prices are driving higher structural efficiency.

Hybrid laser welding is an enabling technology for the distortion reduction, mass reduction, and high-strength alloys important in steel and aluminum vehicle construction. In one recent project, an automotive manufacturer redesigned a product for hybrid laser welding and high-strength material. It not only improved the structure's crashworthiness; it also reduced the weight by 40 percent. Generally, automotive manufacturers find the cost per pound goes up when using high-strength materials, but when the overall weight drops, so does the total cost.

*What role will hybrid laser welding have in the future?*

It's exciting to think about the global effect hybrid laser welding can have in creating lighter, high-strength structures and reducing material consumption. Hybrid laser welding will change the way structures are built. I think we'll see larger scale adoption of the technology, particularly as costs drop and more welding codes incorporate the technology. ■

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# Down in the core

A parallel universe exists in which the laser is admired as a rough-and-ready tool in the field of material processing.

Ingo Schulmeyer makes a statement that would normally make laser manufacturers shudder: “The laser is much too imprecise, everything has to be reworked.” Yet here in Oberkochen, different rules apply. For Schulmeyer and his colleagues at Carl Zeiss Microscopy GmbH, five square millimeters is a soccer field and 0.001 cubic millimeters is a virtual wheelbarrow of material. People that develop and sell microscope systems such as the Auriga Crossbeam simply operate in different dimensions.

The core of the Auriga system is a scanning electron microscope combined with a focused ion beam. Various tools can be docked to the microscope to enable the user to carry out analysis and processing at nanometer scale. The ion beam can remove thin slices of the specimen to produce tomographic images, and additional gases can be used for etching or for depositing materials on the specimen. “With the ion beam, electron beam and gas, you have everything you need at the target area,” says Schulmeyer. “The problem is that it’s often difficult to penetrate through to this target area because what our customers want to see is often deep inside the sample.”

Schulmeyer gives an example to illustrate his point: “Imagine you have a treasure chamber measuring one cubic meter. You want to look inside. The problem is that the chamber is embedded in solid silicon and is 500 meters beneath your feet — and all you have is a hammer and chisel.” Jumping back to the original scale, this equates to lab assistants working for a chip manufacturer who are trying to find a fault in a microchip. They identify the defective region. It measures just a few microns, but it is located in one of the lower layers of the chip, half a millimeter beneath the surface of the wafer. “It would take the ion beam three years to remove just 0.3 cubic millimeters of mate-

rial,” Schulmeyer explains. That means that the sample must first undergo a lengthy preparation process. The time spent using a microscope is expensive — and waiting for results can be even more expensive. In some cases a production line has to be shut down or an important milestone in a development process postponed until the defect has been clearly identified. At the end of the day, efficiency and effectiveness are just as important in the micro world as in the macro world.

So Zeiss decided to find a proper rough-and-ready excavator to assist its customers — something like the ion beam, but more heavy-handed. The laser — a non-contacting, precision-controlled solution that induces thermal effects in a very small zone around the working area — seemed to be the perfect choice. So in 2009 Zeiss embarked on a series of feasibility studies in collaboration with the Fraunhofer Institute for Mechanics and Materials. It soon became clear that the laser would more than fulfill the researchers’ hopes — but only if it had its own separate chamber in the microscope. Schulmeyer explains the decision: “From our perspective, the laser is doing the dirty work! We blast our way through the sample with the laser pulses, and that creates a lot of debris which we don’t want littering the main chamber.”

Zeiss weighed up the advantages of various different beam sources. The fact that it needed to be a pulsed laser was clear from the very first description of the concept, but the questions of pulse duration and pulse rate still needed to be addressed. “In the end we decided on an industrial nanosecond laser. There’s almost no real advantage to pulses any shorter than that, and the nanosecond laser is a reliable

tool which has successfully moved beyond the teething problem stage.” There were three key things they needed from the laser: A very reliable and accurate scanner system, high-precision control software which was easy to program, and

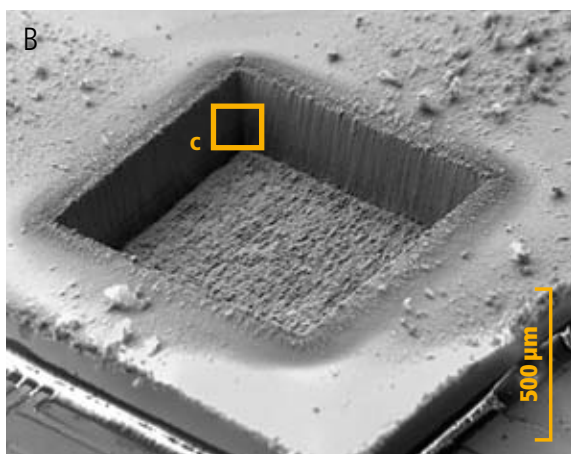


“Our clients often have to dig deep for the truth.”

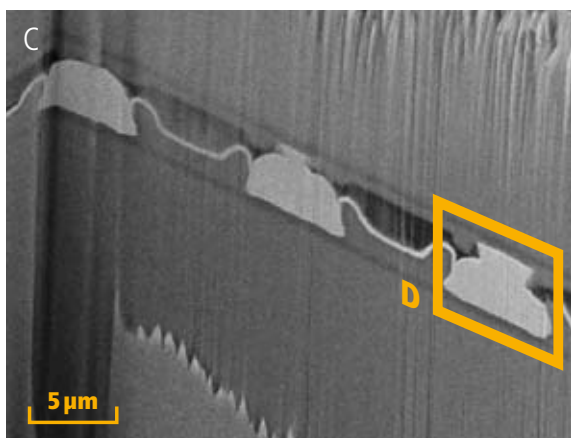
Ingo Schulmeyer,  
Crossbeam Product  
Manager, Carl Zeiss  
Microscopy GmbH



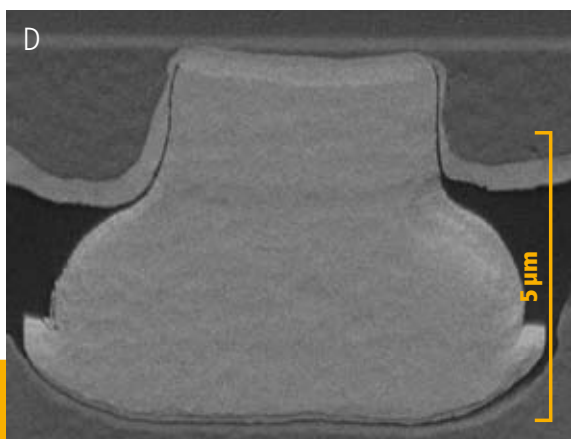
A typical example:  
Some of the “flip chips”  
on a larger semi-  
conductor component  
have defective contacts  
(red spots on the  
thermographic image).



The lab assistant selects  
the target area under  
the electron microscope,  
moves the sample  
into the laser chamber,  
and bores 0.3 milli-  
meters through the flip  
chip into the carrier chip.



Back in the main chamber,  
the lab assistant polishes  
a tiny section of the shaft  
wall using the ion beam.  
The soldered connections  
are visible in the cross  
section in the connecting  
level between the flip  
chip and the carrier chip.



Close-up of the defective  
area: The drop of  
solder has not made a  
proper bond and has  
formed a non-conducting  
separating layer.



a supplier with extensive experience in many different applications. TRUMPF met these requirements and the hard work soon got underway. The application engineers knew that process monitoring was out of the question because the laser would be removing such tiny quantities of material at such a rapid rate. They therefore carried out an exhaustive series of experiments in order to create a long list of parameters and ablation rates for a wide variety of materials, from plastics and granite to silicon.

**At the same time, the project partners** were busy perfecting the planned dual chamber system and the necessary positioning aids. Because the laser is housed in a separate chamber, the laser's control software first has to locate the tiny, invisible spot which the operator has previously selected as the “excavation site”. The scientists equipped the sample holder with four light-emitting diodes as reference points. These form the coordinate reference system for the CAD software which the operator uses to program the laser. They enable the two chambers to harmonize the location of the sample and eliminate any shifts in position resulting from tolerances.

The decisive factors then become the accuracy with which the laser emits pulses and the size of the heat-affected zone. Essentially, the workflow of this system comprises two stages: Firstly, the laser digs its way through the material until it has almost reached the target. Then the ion beam takes over, removing the last thin layer of material and polishing the surface. Every micron of distance that can be covered by the laser saves hours of ion beam processing time. Currently, the laser is able to penetrate to within 25 microns of the target area. This takes into account positioning tolerances as well as the effects of the heat-affected zone. This zone is currently calculated as five microns, though it often falls well short of this figure. “Our specification for positioning accuracy is currently 20 microns, but we are already working on ways of significantly improving this figure,” says Schulmeyer. ■



The Auriga Laser at  
work (animation)  
[http://bit.ly/lc\\_auriga-e](http://bit.ly/lc_auriga-e)

Watch and work:  
The Auriga Crossbeam  
laser microscope.

**Contact:** Carl Zeiss Microscopy GmbH, Ingo Schulmeyer,  
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Innovate or admit  
defeat – that is  
Uwe Stadtmüller's  
motto. And so far it  
has served him well.

*Two work cells containing turn and tilt  
tables with an industrial robot between  
them. A fairly standard set-up – or is it?*



# A thousand SPOTS

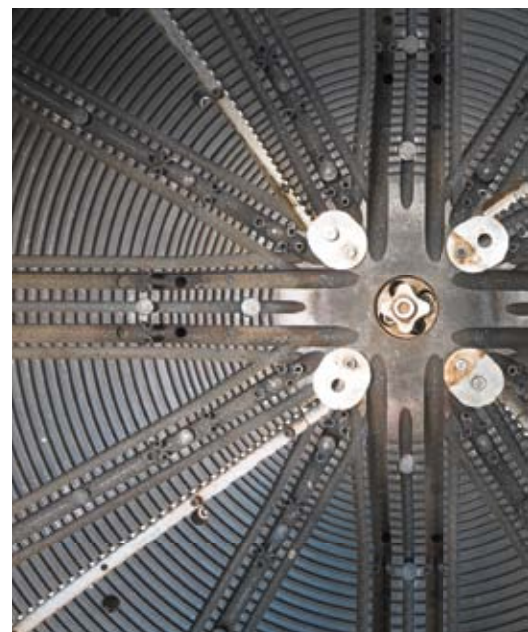
Remote laser welding in three-dimensional space is the latest high-tech trend in the automotive industry. Uwe Stadtmüller, in his middle-market business, has adopted this cutting-edge method to manufacture fan guards.

■ Uwe Stadtmüller, the founder and managing director of Stadtmüller GmbH, presses the start button. The door of the laser welding system — developed by Stadtmüller himself — closes, the wire cross braces and wire rings are pressed into position on a simple clamping mechanism, and the robot-controlled, camera-assisted scanner optics weld 760 wire joints and four slide-in connectors. After five minutes, the robot raises its head, swivels around 180 degrees and begins work in the second of the two adjacent cells. The optics system — a PFO 3D by TRUMPF with the light of a TruDisk 5302 from a 200 micron fiber — hovers over the next workpiece, which had been prepared while the laser was working in the other cell. As the process starts up again, the first cell opens and the machine ejects a freshly made fan guard unit, ready for painting. This grate-type fan cage is one of those wire mesh casings used in industrial fans as protective screens and fan motor mountings. It is a product which Stadtmüller's customers are determined to get for the lowest possible price. "The fan guard is necessary, somebody has to produce it, and whoever does it quickest and cheapest wins," he says. In 2000, Stadtmüller won for the first time. Back then Stadtmüller developed a resistance welding technique which joined the several hundred intersection points with a single burst of energy. This approach represented a huge leap in productivity for his entire process. Fan guards are typically produced from two sub-assemblies which are "wedded" in a third step and completed with some additional wire rings in a fourth step. The first sub-assembly is the supporting frame, for which the outer flanges, support braces and motor flanges are joined in an arc welding process. The second sub-assembly is the actual wire cage consisting of the criss-crossed wire braces and rings.

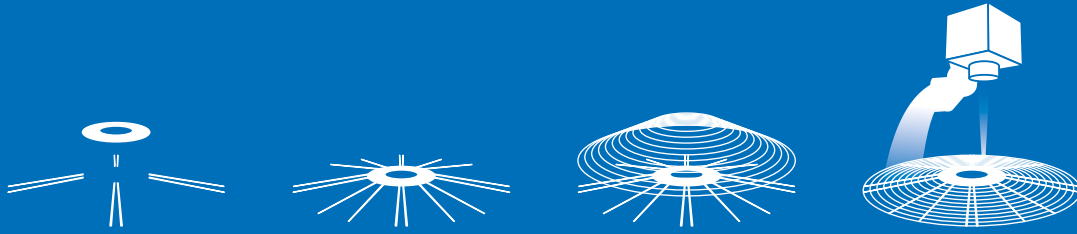
"It was a good technique — at least for a few years," says Stadtmüller. But nowadays the market is forcing his customers to provide fan systems in an increasing range of sizes. Twelve years ago, Stadtmüller GmbH was producing wire guards for 400 different types of fan units. Today that figure has climbed to almost 1,200. At the same time, average batch size has fallen from 1,500 pieces to fewer than 100. Stadtmüller was forced to invest more and more money in welding tools and to retool ever more frequently — with retooling taking up to 12 hours for each machine. "That was eating away at the productivity of my welding systems." It was also clear that the thermal distortion generated by the welding process was steadily

becoming a major cost issue. "My choice was clear: I either had to raise my prices or come up with an innovative solution," says Stadtmüller. That solution turned out to be a laser process which he hoped would provide three key advantages: A system that could complete all the welds in a single pass, eliminate welding distortion, and achieve maximum flexibility, since lasers do without type-specific tools and require virtually no retooling time. "Remote welding was an absolute must right from the start," says Stadtmüller. "Only a scanner system is capable of moving the focus quickly enough from one weld spot to another." And the three-dimensional shape of the parts makes the optics' job even harder: "The focal distance changes from one weld spot to the next. That's why we need a PFO 3D, which has the ability to move the focus spot in all three dimensions with tremendous precision." Yet even with a remote process, Stadtmüller was unable to switch to laser welding without having a clear idea of how exactly to carry out the individual

*A simple clamping mechanism? By the standards of Stadtmüller's industry, yes. Each wire ring is fixed in a circular array of grooves while the grid braces are held in place by radial slots.*



# ALL IN ONE



*As simple as this: Insert the support braces and flanges, position the motor flange on top, place the grid braces in position, lay the wire rings on top, let the robot do its job, and remove the finished workpiece. Repeat as many times as you like!*

welds. The intersection points are indeed tiny, yet welding all these points from the side with fillet welds would require the robot to change position far too often and would eliminate the speed advantage of the scanner optics. So Stadtmüller decided on a more direct route, approaching the weld vertically from above and along the brace straight through the wire ring.

**His ideas were initially met with skepticism.** “The feeling in the automotive industry — and indeed industry in general — is that robot-controlled scanner welding is a process that is only worth using in large-scale, fully automated applications,” he says. “But I felt differently.” His goal was not to increase the speed of his welding process, but rather to compress the process as a whole: “Scanner welding with the PFO 3D was never the ultimate objective — it was just the right means to the end.” Productivity calculations revealed that condensing the process into a single step and the flexibility gains alone would be sufficient to recoup the investment. All that remained was to find a solution for the weld spots. Welding the intersections from above meant cutting through the thin wire rings and then re-welding them. “The solution we came up with was contact

pressure,” Stadtmüller recalls. The resulting “yoke”, a fixture lowered onto the flanges, wire braces and wire rings to hold them in place, also presses them into the melt during the welding process. The third challenge was rather more unexpected: “I had imagined that we would simply program the system with the CAD data, press the start button and watch the finished fan guards pile up,” says Stadtmüller. Yet in the welding tests the laser kept missing its target, often by more than a millimeter, as Stadtmüller explains: “The PFO 3D itself was focusing just as accurately as we had hoped. But it turned out the target was not properly positioned in the focus spot. A robot arm always has a certain amount of play. Normally that is fairly minimal and doesn’t affect the job in hand, but in our case it was clearly a problem.” The process only works if the laser hits the wires within 0.1 millimeters of the target spot. Yet the accumulated tolerances of the robot and workpiece meant that the targets were frequently deviating from the CAD coordinates. Teaching would have been the standard solution, but with 760 weld spots this was clearly impossible. So Stadtmüller tried a different approach. Instead of guiding the robot to each welding point, he decided to use the PFO 3D system’s optional image capture function. This involves the scanner optics moving to their working position and focusing on all the intersection points in the working area without actually welding them. The software uses the image data to identify the points at which the rings and braces intersect and then compares this information against the CAD data to determine the actual target coordinates.

**The new laser system has now become an integral part** of the production process. The fan guard units are consistently within tolerance and Stadtmüller has even eliminated the need for sandblasting thanks to the fact that the laser does not leave behind any scaling or spatter. He is certainly satisfied with the results: “When we switch production to a different model it only takes us an hour or less to change the clamping mechanism and get back online, so we save 11 hours of downtime on every switchover.” One thing that fascinates him is the design potential that the process offers: “We have started to redesign the fan guards and we can already see that the laser technique will open up a whole new range of options for our customers. That’s our next innovation project!” ■

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“My goal was to reduce the whole thing to a single process step. And that’s something you can only do with a laser.”





The welding process  
(animation)  
[http://bit.ly/lc\\_fanguards](http://bit.ly/lc_fanguards)

Working from a distance of approximately 500 millimeters and with just a small number of working positions, the scanner optics can reach every weld point. The PFO 3D moves the focus spot at tremendous speed and with enormous precision in all three dimensions.

One of the challenges was to prevent the laser from cutting the wire rings during the welding process. The contact pressure exerted during welding ensures that the segments are firmly bonded to the braces.

To make it possible to complete every weld in a single production step, Stadtmüller had to redesign the supporting structure. The central motor flange is attached, something like a keystone, to the four pairs of main braces. The slide-type connection is then welded with a continuous seam.



# Electron shower in glass

Urs Eppelt

What happens when a picosecond laser pulse strikes a sheet of display glass? A simulation project at Fraunhofer ILT is advancing the use of picosecond laser ablation as a cutting technique.

■ The perfect glass for a display would be a two-dimensional, infinitely hard surface with no thickness whatsoever. Display manufacturers are constantly striving to move ever closer to this ideal; the glass sheets used in the modern displays are extremely hard and, in many cases, little more than 0.3 millimeters thick. This pushes conventional cutting processes to their limits. They produce mechanical stress in the thin layers of glass and form potentially critical microfissures which can only be removed by grinding the edges in a post-processing step.

Laser ablation with ultrashort pulsed lasers — a process in which laser pulses ablate material and cut the glass without subjecting the workpiece to thermal or mechanical stress — is increasingly being recognized as a promising solution. In practice, however, this method can sometimes yield surprising results such as unpredictable ablation rates and unexpected damage. That is why Fraunhofer ILT and TRUMPF decided to develop a simulation to enhance our understanding of the interactions between the glass and the incident laser pulses.

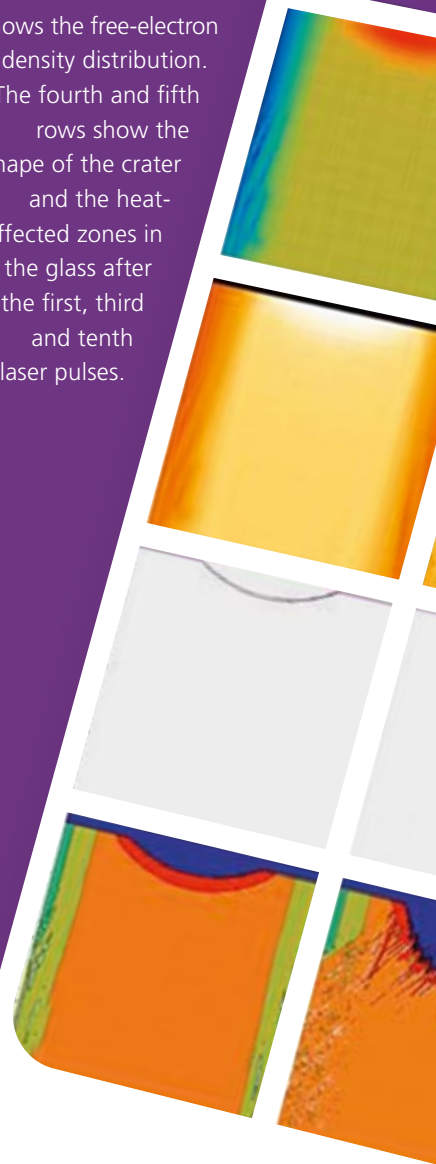
**Many wide-band-gap dielectrics** such as glass and water are transparent to near-infrared and visible laser light. However, the extremely high intensity of ultrashort laser pulses results in multi-photon ionization (MPI) followed by a cascade mechanism which produces a large number of free electrons. Once a critical electron density is reached, the dielectric exhibits a metal-like behavior and laser absorption is initiated. After

the laser pulse, ablation occurs as a result of the electrons releasing their energy. The process is therefore dependent on the distribution of free-electron density — and it was this aspect that the project team took as a starting point for their numerical model.

The model focuses on a two-dimensional cross-section through the workpiece, perpendicular to the cutting direction. In the first step, the maximum density of the ionized electrons is calculated as a function of laser intensity. In the second step, the laser beam is propagated into the workpiece to establish the intensity distribution and the distribution of free-electron density inside the material. The third step determines where the laser will produce ablation or permanent modification of the material by applying the predefined ablation and modification criteria, using the results of the second step. The result is a simulation of the ablation crater and the heat-affected zone. The simulation repeats the second and third steps for each further pulse, gradually displacing the surface of the glass with each pulse.

In a series of tests, the project group compared the results of the simulation program with the results of a real-life application using a frequency-doubled, mode-locked picosecond laser. The laser delivers pulses with a peak pulse energy of up to 60 microjoules and a pulse duration of 10 picoseconds in the green spectral region. During the experiments, the laser was operated at a pulse energy of 40 microjoules at a focal length of 63 millimeters and a beam waist diameter of 6.5 micrometers. The

The first and second rows show the intensity distribution in the laser pulse and the material. The third row shows the free-electron density distribution. The fourth and fifth rows show the shape of the crater and the heat-affected zones in the glass after the first, third and tenth laser pulses.





Video on display glass cutting, plus the full research paper  
[http://bit.ly/lc\\_display-e](http://bit.ly/lc_display-e)

substrate comprised 0.3-millimeter-thick borosilicate glass (Corning Eagle XG). The average ablation rate in the experiments was 2.9 microns per pulse — almost three times greater than the ablation rate of a femtosecond laser. The pulses steadily increased the size of the crater in the glass, with the angle of the crater wall exceeding 80 degrees after the tenth pulse. A cross-section of the crater walls reveals a ray-like modification region. The image produced in the experiment corresponds closely to the simulation results, as do the crater dimensions and ablation rates.

The simulation also provides information on what is actually happening inside the material. The first pulse hits the flat glass surface and releases electrons within the resulting optical penetration depth.

In accordance with the Gaussian profile of the laser pulse, the initial pulse leaves a parabolic crater in the planar surface. In the subsequent pulses, the crater walls diffract and deflect the incident electric field, scattering the field into the crater walls and ionizing the material

at an angle to the beam direction. This produces a ray-like interference pattern in the distributions of both intensity and electron density. Modified regions are formed by these interferences, particularly in the crater wall but also deeper within the material. Although these regions are not ablated, the free-electron density is sufficient to permanently change the material's refractive index and to generate defects such as F-Centers. These interferences are also a possible source of microfissures.

**The numerical model** used in the simulation has shown itself to be a promising tool for studying processes within the material, diagnosing sources of defects in the ablation process, and investigating the effects of parameter changes. The first series of simulations and experiments has already suggested a key damage mechanism: Peaks in intensity distribution create peaks in the distribution

of free electrons, thereby leading to thermo-mechanical loads or thermal damage in the material.

Even if the model does not succeed in revealing the exact damage mechanism, the results have shown that this is not absolutely necessary to predict the distribution and the magnitude of the resulting damage.

## *Interference patterns play a crucial role in the glass cutting process.*

Based on these findings, the model will be used to improve the micro-machining process in terms of both quality and speed. This will lead to changes in strategies for cutting glass with picosecond lasers and will help support and advance the development of the process and of laser manufacturing systems suitable for industrial use. ■



**Urs Eppelt** has worked as a research associate in the Modeling and Simulation group at the Fraunhofer Institute for Laser Technology ILT since 2004. Key areas of his work include beam propagation and process simulation in laser manufacturing systems.

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# “I know how lucky I am”

As a pioneer in attophysics, Professor Ferenc Krausz  
observes electrons as they move through atoms.  
We asked him what motivates him.





■ *Professor Krausz, what is the current world record for the shortest pulse of light?*

It currently stands at 80 attoseconds, but a team in the USA recently reported a laser pulse of just 67 attoseconds.

*What drew you to this field of research and why do you find it so fascinating?*

I enjoy making processes visible which we once believed nobody would ever see. Everyone knows how difficult it is to capture rapid motion, whether in photography or television. And people are fascinated by sequences of snapshots that show things like an object smashing through a pane of glass. So when I first encountered short pulse lasers I was immediately struck by a thought: If capturing images of fast-moving objects in the macroscopic world is so exciting and interesting, then it would surely be even more fascinating to do something similar in the microscopic world — a realm in which everything happens at even more extraordinary speeds. But that requires a light source capable of emitting pulses of sufficiently short duration. So that's been the focus of my research ever since I did my thesis at the University of Budapest in 1985, in which I developed a technique for measuring ultrashort laser pulses. I was immediately hooked and was never tempted to try any other line of work!

*It sounds like you have the kind of enthusiasm that could motivate other people, too.*

My curiosity spurs me on and makes it easier for me to motivate the young people I work with. And that's essential in today's research environment, because the era of scientists working in isolation is over. What we need is a team that brings together people with different kinds of experience and very specific, specialized knowledge — that's the only way we can make progress nowadays. It is extremely important to get young, talented scientists interested in your field of research. If you don't do that, then your research is destined to fail.

*What does it take to work in attosecond physics?*

Young researchers need patience, endurance and staying power. The more ambitious our goals, the more we need to demonstrate patience and the ability to get through lean periods. That's one of the key points I emphasize in the first interview with people who are looking to join my team. It's important that the people who join us are not just looking for quick successes. In our team, you don't measure your own performance by the number of publications, but rather on how much closer you are getting to the goal from one month to the next. There are very few opportunities to publish interim results on the way to reaching that goal, and some people find that hard to accept. →



“We make processes  
visible which  
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ever see.”

*Have you experienced lean periods yourself?*

Of course. Let me give you one example: We established the experimental conditions for generating the first attosecond pulses back in 1997. Those pulses were the shortest pulses that were physically possible because light is a wave and a wave must oscillate at least once. The duration was just a few femtoseconds, and that was a new world record. Theorists then showed

us ways of using this as a basis for generating attosecond pulses. But of course direct measurement of the pulse duration was out of the question. It took us four whole years, until 2001, to reach the point at which we were finally able to perform the measurements. Four years — that's the same amount of time it takes to produce a thesis.

*Nevertheless, your own career has been nothing short of lightning fast by the standards of university research!*

I have to admit that I don't see my career as having been particularly remarkable. I just know how lucky I am to have found a job so early on in which work doesn't really feel like work, but is just something I enjoy doing. Since then things have just flowed naturally onwards.

*How have things unfolded since those first attosecond achievements?*

Our 80 attosecond record was really a kind of by-product. As soon as we generated the first light pulses of a few hundred

attoseconds a whole new world opened up for us. All of a sudden we were able to observe the motion of electrons. If you'll permit me to compare it to photography, the attosecond pulses gave us a camera fast enough to capture this ultrafast motion, and that was something totally new. Electrons play a fundamental role. They ensure that the molecules in our bodies perform the functions they need to perform — and of course no electrical device would work without electron dynamics. That's why understanding and observing this particle is something that is both fundamental in a theoretical sense and also very relevant in practice. That was what really enthralled us, far more than just the idea of generating ever shorter pulses, which was essentially the means to an end. Our research focus embraces a far greater number of exciting scientific questions which are coming within the reach of our experiments for the first time. It also includes the development and validation of the measurement technology used in pertinent research.

*So do your results already have a certain degree of practical relevance?*

If you are intrigued by the issue of practical relevance, you'll probably be interested to know that, in collaboration with TRUMPF, I have founded a company to translate our research findings into products and solutions. At the moment, however, we're not focusing on attosecond pulses, but rather on the femtosecond lasers that we need to generate the pulses.

*How did that come about?*

It was back in 2004 when we started investigating how we could push the boundaries of laser technology. We quickly came up with an answer. Instead of using titanium sapphire as a gain medium, we wanted to experiment with optical parametric amplification. The problem was that we didn't have any reliable pump sources. We tried using our own resources to develop the picosecond lasers we needed as pump sources, based on disk lasers, but that was tremendously challenging. So we got in touch with TRUMPF in Schramberg and they presented us with a fully mature disk laser module which gave us the breakthrough we needed. Using this picosecond laser as a pump source, we pushed ahead with our research until we finally fulfilled our expectations. That intense and successful period of collaboration built up trust and yielded a business concept.

*What lies at the heart of your joint business concept?*

The idea is for TRUMPF Scientific Laser to use our research on optical parametric amplification when developing market-



ready femtosecond laser systems. These systems will primarily be aimed at the scientific market. Once these laser systems have been fully developed, we will also look into the possibility of applications in medicine and industrial manufacturing. Our experiments in the 1990s showed us that any further reduction in pulse duration only makes a difference — though undoubtedly a major difference — if you are processing dielectric materials. The shorter the pulse duration, the more delicate the structures you can reproducibly generate. In the case of our new femtosecond lasers, that means we can carry out materials processing at the nanometer level. That opens up a whole range of new possibilities in materials processing, both in regard to materials and applications.

*You're investigating a new world — does that fill you with pride?*

It's more a sense of privilege than an object of pride. The thing I am proud of is the extraordinary team I have working with me, and the ability of this team to get the best researchers from all over the world to join our team or cooperate with us on our various projects. By constantly delving into new areas, this team has managed to steadily push back the boundaries of experimental physics. If we are eventually able to trigger some truly fundamental developments, that will make everything even more worthwhile.

*And what if you don't succeed in producing fundamental changes on a practical level ...?*

Even then, cutting-edge research is still immensely valuable.

The fact that it produces such highly skilled professionals for academia and business would in itself be enough to justify every euro spent on top-level research. And that's before you even start analyzing the benefits of the research results. Just look at researchers such as the duo who founded TRUMPF Scientific Laser, for example. They were both members of my team for many years. Their qualifications and professionalism show just how important cutting-edge research is to the prosperity of Germany and Europe and their future as key industrial locations. I wanted to stay in close touch with them even after they decided to move into the world of business, and that was one of the main reasons behind my decision to initiate and support the founding of the venture.

*Research has become an international affair. Does it make any difference nowadays where research is conducted?*

Yes, it does. For one thing, researchers need to be somewhere where talented people are emerging who can form part of their teams. And you also have some situations that simply offer the ideal conditions. For me, that was the Max Planck Institute combined with the chair in Munich, a combination which is probably unbeatable anywhere in the world. And fortunately we still enjoy a unique situation in Germany where taxpayers and politicians are still willing to spend money on basic research. ■

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**LASER** Observing ultrarapid phenomena such as the motion of electrons requires ultrashort laser pulses in the attosecond range. This provides insights into the inner workings of atoms and could one day enable scientists to steer electron motion with light.

**LIFE** Born in 1962, Professor Ferenc Krausz, Ph.D., is the Director of the Max Planck Institute of Quantum Optics and holds the Chair of Experimental Physics at Ludwig Maximilian University in Munich.

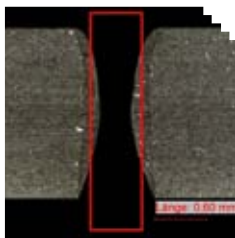
**ACHIEVEMENT** Professor Krausz is regarded as the world's leading researcher in the field of "attoscience" — the physics of ultrashort laser pulses in the attosecond range (one quintillionth of a second).



*Electron spotting (video)*  
[http://bit.ly/lc\\_krausz-e](http://bit.ly/lc_krausz-e)



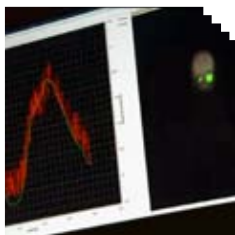
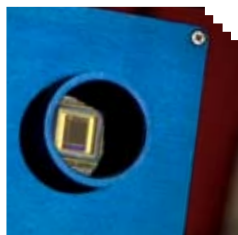




## -- CUTTING AT A DISTANCE

It would be so convenient if, during remote welding, the laser could use the same scanner optics to position the necessary cut-outs. It is time for a new process.

[www.laser-community.com/2411](http://www.laser-community.com/2411)



## -- REMOTE CONTROL

The only thing capable of controlling lightning-fast remote welding in real time is an even faster camera.

[www.laser-community.com/2220](http://www.laser-community.com/2220)



## -- ELEKTRONIC BOOM

Up-to-date electronic manufacturing without the laser? Unthinkable! Many products would be quite simply impossible.

[www.laser-community.com/2128](http://www.laser-community.com/2128)



## -- LASERS SPEAK CHINESE

"Wherever production rates are high, that's where you need lasers and laser systems. This increasingly applies to China, now and in the future," says Günther Weinmann, General Manager Laser Technology at TRUMPF China.

[www.laser-community.com/2173](http://www.laser-community.com/2173)



## -- JUST GET STARTED

Using its TruLaser Robot 5020 laser welding cell, the Dutch company Groku Kampen can now weld sinks into stainless steel countertops in just one-tenth of the time taken by conventional methods.

[www.laser-community.com/2993](http://www.laser-community.com/2993)

You will find these five articles only online. And we regularly post fresh articles about laser-based material processing on [www.laser-community.com](http://www.laser-community.com)

# BONUS TRACKS

# Where's the laser?

**ON YOUR FINGER:** Rings have been adorning people's fingers for more than 20,000 years. Originally made from wood or mammoth ivory, rings were later fashioned from more lasting materials such as gold which — unlike mammoths — was apparently here to stay. Casting is generally used to mold the precious metal into a ring, though layering methods are also now coming to the fore. Concept Laser, a German company based in Lichtenfels, uses a process it calls LaserCusing to melt and fuse layers of fine gold powder, just microns thick, to gradually build up an exquisite piece of jewelry. The process offers virtually limitless design possibilities and the elimination of wax models makes it faster and cheaper. Brilliant results with a radiant finish — the beauty of the laser-layered ring makes it easier than ever to answer "Will you marry me?" with a resounding yes!





# 100Kg

This would be the load a Golf VII could pick up before it reached the weight of a Golf VI.

This makes the Golf VII the first production car that is lighter than its preceding model.

This diet owes a lot to laser-oriented engineering using high-strength steels.

**TRUMPF**

*Laser Community*

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