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TECHNOLOGY FOCUS

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MATERIALS PROCESSING

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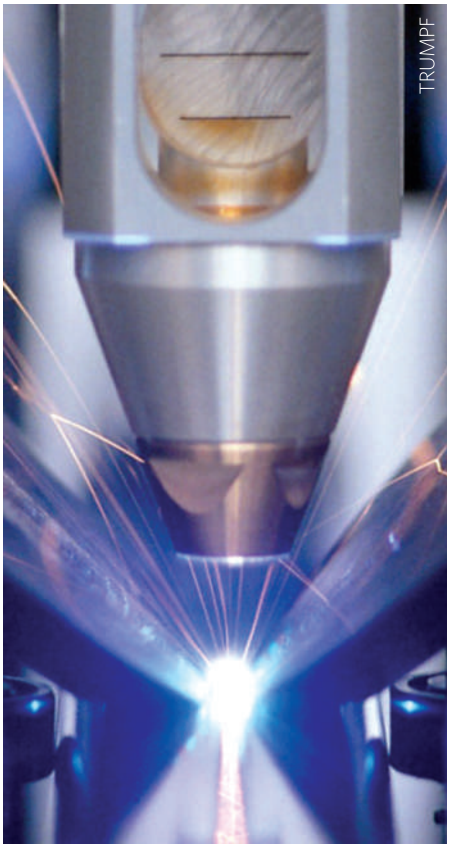

COVER IMAGE
The laser has become a popular and valuable tool for many kinds of materials processing.

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Limited visibility

In recessions, the manufacturing industry is always hit hard. So out of all the companies in the photonics industry, companies making laser systems used in manufacturing have been some of the hardest hit by the current financial crisis. What makes this downturn different from others in the past is the speed with which it has hit. Companies are reporting respectable results for the financial year up to the end of 2008, but then disastrous results for the first quarter of 2009 (see page 259).

All industries into which laser-processing equipment is sold have been affected, even the photovoltaics sector, which has, until now, seen double-digit growth for several years. But the news is not all bad. In hard times, the technologies that survive and ultimately flourish are those that have economical advantages over others. With this in mind, many laser-based manufacturing technologies should emerge from this recession stronger than ever. In almost every manufacturing environment, the laser can do things that traditional tools cannot and it can do them faster, cheaper and more efficiently. This is why the laser materials processing industry is faring better than the traditional machine tool industry in the current economic climate.

One example where laser technology is making itself indispensable is in the area of plastics welding. With the advent of diode and fibre lasers, system performance has improved and this non-contact technique gives higher-quality seams than are possible with conventional techniques (see page 270). For rapid prototyping, laser sintering enables complex shapes to be made that were previously not possible; it can not only make models but can also be used to manufacture functional products out of metal (see page 265). And for those metal parts that require strengthening, laser shock peening is now a proven successful process, especially in the aerospace sector (see page 267).

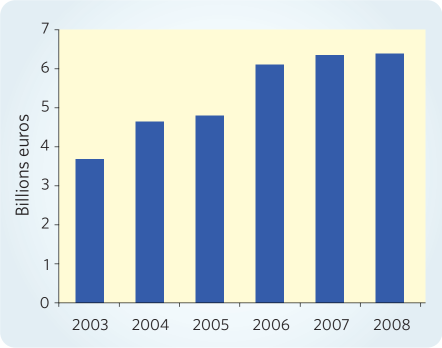
CONTENTS

Gloomy outlook ahead

Although many laser systems manufacturers have announced positive financial results for the end of 2008, they warn of bad news to come. The current economic crisis has hit many firms hard and, as is common in such situations, acquisitions and staff redundancies abound.

Positive results include IPG Photonics' revenues, up by 21% for 2008; Micronic's sales, up by 8% for 2008; and Ultratech fourth-quarter sales, up by 15%. But for some the figures are not so promising. Rofin Sinar has reported a 21% reduction in net sales and a 55% reduction in net income for the first quarter of fiscal 2009 compared with the same period in 2008. The company saw a decrease in sales of its products for macro applications (welding, cutting and surface treatment) of 32% and a decrease in micro (fine processing of small targets) sales of 14% for the first quarter of fiscal 2009. Günther Braun, CEO of Rofin Sinar, says, "With very few exceptions, we experienced diminished demand across all industries, even in the photovoltaic industry, which is something we have never seen before."

Laser materials processing systems are used in a huge variety of industries, each with their own dynamics, so identifying market trends is difficult. However, it seems that both macro and micro materials processing have been affected.



The world market for laser systems (in billions of euros) has flattened in recent years and may well decline in 2009.

"While many companies are reporting growth in 2008 compared with 2007, order logging started to decrease by mid-2008," says Arnold Mayer, whose company, Optech Consulting in Switzerland, specializes in tracking the laser materials processing market. "Production volumes started to decrease in the third and fourth quarter of 2008 and we will only see the full effects of the crisis in the financial results for 2009."

Many companies, mainly in the microprocessing markets, are already making redundancies. For example, laser micro-engineering systems supplier ESI has cut its workforce by 12%; Swedish photomask manufacturing equipment vendor Micronic has cut 96 staff despite growth in 2008; and lithography tool supplier Cymer has announced 100 job cuts just a few months after making 85 people redundant (see news story below).

Mayer points out that the laser microprocessing market so far has weathered the downturn better than the semiconductor equipment market, as it also includes equipment for manufacturing solar cells and flat-panel displays. And although the crisis is also severely affecting macroprocessing markets, Mayer says it could be worse. "The laser macroprocessing market is still developing better than the machine tool market," says Mayer. "This downturn has taken hold vigorously, and companies have felt an effect within two quarters. Nobody knows how long or deep this downturn will be."

Cymer reports job losses

Cymer has announced a net income of US$36.5 million for 2008 compared with a net income of US$88.4 million for 2007. The fourth-quarter performance was particularly poor with net income of US$4 million compared with US$21 million in the same quarter of the previous year.

Bob Atkins, Cymer's chief executive officer, says, "Cymer employees executed well in a very difficult business environment. We extended our argon fluoride (ArF) immersion market leadership and made continued progress towards the development and commercialization of our extreme ultraviolet (EUV) light source technology."

For the full year 2008, the company shipped a total of 100 light sources, for advanced chip-making applications.

Commenting on the outlook, Atkins states, "The current business environment is quite uncertain, characterized by shrinking lithography-tool demand, and decreasing chip-maker factory utilization in the second half of 2008. Looking at the first quarter of 2009, demand for new light sources and installed base products has declined further since our mid-January preliminary revenue estimate."

In the meantime, the company has taken some cost-cutting measures. These include a 10% reduction in personnel or an approximate 100 headcount reduction; temporary 10% reduction in employee base pay; and considerable reduction in non-essential operating and capital expenditures.

Based on the limited information that exists, the company currently anticipates that its first-quarter 2009 revenue could decrease by 30 to 35% compared with revenue for the fourth quarter of 2008.

IPG responds to downturn

IPG Photonics, the fibre laser specialist, has reported that revenues for the full year 2008 increased by 21% to US$229.1 million from US$188.7 million in 2007, and net income increased by 23% to US$36.7 million from US$29.9 million last year. For the fourth quarter of 2008, revenues increased by 6% to US$58.2 million and net income increased by 9% to US$9.1 million compared with the fourth quarter of 2007.

The company saw particular strength in Germany, where it increased fourth-quarter sales by 48% year over year, and Japan, where it saw 25% sales growth. Despite the strength in Japan, overall sales to Asia were down 10% as a result of weakness from marking applications in China. Overall sales in Europe and the Rest of the World were up, with North America relatively flat for the quarter.

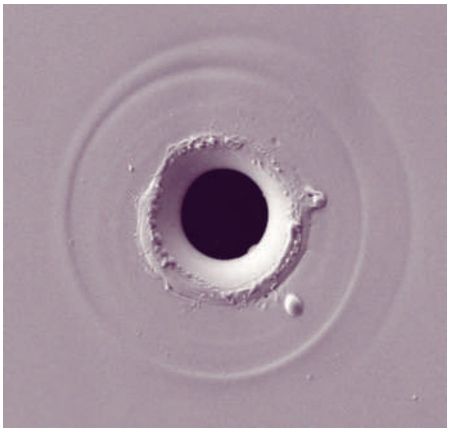
Despite the positive revenue figures, IPG certainly has not been immune to current turmoil in the world economy. Over the past six months (October 2008 to March 2009), IPG's stock has halved in value from US$16 to US$8.

To cope with the current global financial crisis, the company has put in place several cost-cutting procedures. "First, we are decreasing our costs of goods by lowering component costs through technological improvements and implementation of in-house production of several critical parts that have been previously outsourced. In addition, we are cutting expenses by freezing new hiring, cutting overtime, curtailing bonuses, lowering headcount through attrition and implementing tighter spending controls," says Valetin Gapontsev, IPG's chief executive officer. "With these initiatives, we estimate that we can generate $4.0 to $6.0 million in annual operating expense savings."

For the first quarter of 2009, IPG Photonics expects revenues in the range of US$45 million to US$50 million.

Preserving non-crystallized metallic glasses

Appl. Surf. Sci. **255,** 6641–6646 (2009)



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Researchers from Spain and the United Kingdom have demonstrated that it is possible to use both microsecond and picosecond pulsed lasers to machine amorphous nickel alloy samples without crack or defect formation. Amorphous alloys are metallic glasses that have short-range atomic ordering and hence non-crystalline microstructure. These materials have been preferred to crystalline alloys for applications in microelectronics mechanical systems and die components because of their ease of formability and excellent mechanical properties. To maximize their potential, it is essential to maintain their non-crystalline nature during micromachining processes. The study by Iban Quintana and co-workers involves creating single-pulse craters and drill holes on amorphous and polycrystalline nickel alloys using both microsecond and picosecond pulsed lasers with different average laser powers. Craters with a bigger diameter and a more pronounced redeposition of molten material around their edges are obtained in amorphous alloys under microsecond-laser processing. The researchers report no crack formation around the hole drilled in amorphous alloys, showing no evidence of crystallization but high surface integrity, unlike the case in polycrystalline alloys. "This is the first comparative study of the machining response of an amorphous material and its crystalline counterpart. We show that the non-crystalline microstructure of amorphous alloys can be preserved under microsecond and picosecond laser processing and that amorphous alloys give significantly better results than polycrystalline alloys under equivalent processing conditions," Quitana told *Nature Photonics*.

Laser annealing for silicon photonics

Appl. Phys. Lett. **94,** 082104 (2009)

Conventional SiGe growth techniques require high temperatures and are often expensive and time-consuming. In view of the growing demand for Ge-on-Si devices in the optoelectronics sector, alternative low-temperature fabrication approaches are desirable. A group of researchers from Singapore has now developed a low-cost, ultrafast scheme for forming epitaxial SiGe structures on a silicon substrate. In a technique based on laser annealing with a 248-nm pulsed KrF excimer laser, C. Y. Ong and colleagues demonstrate crystallization of an amorphous germanium layer deposited directly on a Si^+ pre-amorphized implanted Si (PAI-Si) substrate. The team observe that when the sample is annealed with an appropriate energy density, polycrystalline SiGe is formed by explosive recrystallization. For an energy density of 0.9 J cm^{-2}, the entire amorphous layer melts into the crystalline Si substrate, leading to a liquid-phase epitaxial regrowth of SiGe and therefore a fully strained and activated epitaxial SiGe.

Multispot writing in fused glass

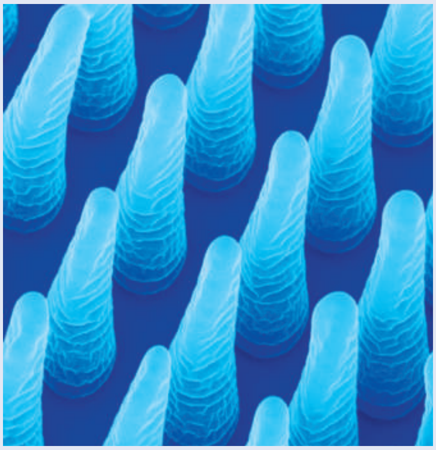
Opt. Express **17,** 3531–3542 (2009)

Owing to its highly deterministic and nonlinear absorption process, infrared femtosecond laser writing offers the means to create buried, localized structural modifications in transparent materials. By moving the sample with respect to the laser's focal point, three-dimensional structures can be inscribed. However, the fabrication of complex structures often involves long processing times. Cyril Mauclair and co-workers from France and Germany have now demonstrated that the problem of speed can be solved by parallel photoinscription that uses multiple laser spots with reconfigurable patterns. The trick is to use a periodical binary phase mask to spatially modulate the wavefront of the laser beam. By varying the period (cycling frequency) of the binary phase, the team show that a simple grating phase mask and therefore dynamic double-spot operation can be achieved. The team use a liquid-crystal spatial light modulator, addressed optically, to create the binary phase mask. A 800-nm Ti:sapphire laser emitting 150-fs pulses at a

Rapid-micropatterning hydrogel

Adv. Eng. Mater. **11,** B20–B24 (2009)

Generally, fabrication of two-dimensional periodic arrays of micropatterns on hydrogels involves sequential procedures and is thus lengthy. A direct patterning approach based on multibeam laser interference taken by researchers from the United States and Germany looks set to speed up and also improve the throughput of the process. "Periodic structures can be processed in one step in a few milliseconds over large areas using high-power lasers on a wide range of materials including ceramics, metals and polymers", Andrés Lasagni told *Nature Photonics*. The approach by Lasagni and co-workers relies on multibeam interference and the use of a 10-ns pulsed Nd:YAG laser at 355 nm and a 95-fs pulsed Ti:sapphire laser at 800 nm with a repetition rate of 1 kHz. The hydrogel they study is polyethylene glycol diacrylate (PEG-DA), a biocompatible hydrogel that is useful for a number of biomedical applications. The team find that the use of femtosecond laser pulses allows the creation of structures with a higher aspect ratio and resolution than for longer-duration pulses. They attribute this to polymerization induced by two-photon absorption and to the increased energy difference between the interference minima and maxima with increasing beams. In the case of nanosecond pulsed patterning, interconnections between periodic structures are found, possibly owing to the low polymerization threshold of the material at short laser wavelength.



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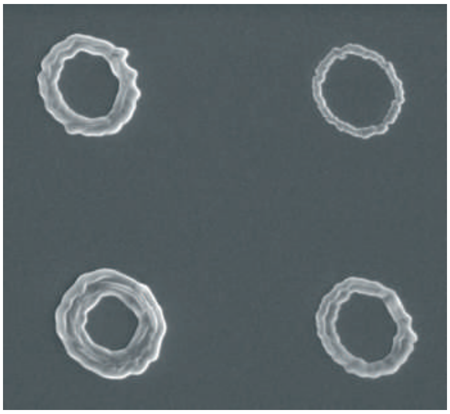
This rapid fabrication technique is expected to diversify the biomedical applications of hydrogels.

repetition rate of 10 kHz and with a power of 30 mW is used for the process. By controlling the motion of the sample, the team succeeded in manufacturing three-dimensional light dividers and fabricating wavelength-division demultiplexing devices in fused silica. They are confident that with sufficient energy, more machining foci can be used.

Optical tweezers boost direct-write nanolithography

Opt. Express **17,** 3640–3650 (2009)



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By integrating a Bessel beam optical trapping scheme into a laser nanolithography process, researchers from Princeton University in the United States have shown that arrays of identical arbitrary patterns of nanostructures can be generated with high uniformity and high positional accuracy. Despite advances in nanofabrication technology, generating arbitrary nanopatterns with high throughput has proved challenging. Now, Euan McLeod and Craig Arnold demonstrate parallel fabrication of arrays of patterns by using two lasers for patterning: one Bessel beam converted from a 7-W continuous-wave laser beam at 1,064 nm to optically trap a microsphere lens (probe) near a surface, and one 355-nm pulsed laser with pulse energies of 150 nJ to 8 mJ to illuminate the trapped bead and surrounding surface. Arrays of simultaneous traps are created using beam splitters, which separate the trapping laser beam into four parallel beams. Through the parallel writing scheme, the team say that they are able to eliminate errors due to mechanical vibrations and imperfect positioning equipment. Moreover, patterns with varying feature sizes can also be generated by using spheres of different sizes in the array. Fabrication of 100-nm structures can be achieved when the microsphere probe is self-positioned near a surface by the Bessel beam optical trapping. The team report that they have obtained a feature size uniformity and relative positioning accuracy of better than 15 nm. They are also confident that the use of more powerful and narrower Bessel beam optical traps will further improve the uniformity and accuracy of the proposed technique.

Thermochemically welding silver alloys

Opt. Laser Eng.
doi:10.1016/j.optlaseng.2009.02.003 (2009)

A study presented by a team of Italian researchers shows that high-power diode lasers could serve as an alternative technology for welding silver alloys, replacing conventional techniques. Silver alloys are known to have high reflectance in the visible and near-infrared wavelengths, making it difficult to weld them using a diode laser. However, it is also known that thermochemical interactions in these alloys can boost the absorption and maximize the transfer efficiency between the laser source and substrate. Using a diode laser with a wavelength of 940 nm and maximum power of 1.5 kW, Annamaria Gisario and co-workers investigated the interactions between the laser and two different silver–copper alloys. They confirm that thermochemical effects induced by diode lasers could lead to a chain of sustainable exothermic reactions — formation of an oxide layer, which results in an increase in absorption and substrate temperature and thus further formation of an oxide layer. The researchers say that a good welding strategy for reducing defects is a pre-heating step at constant power, decreasing power along the laser pattern and appropriate laser scanning speeds.

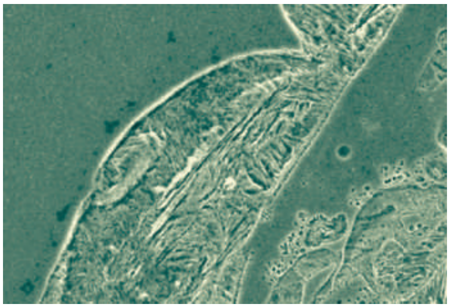
Burst-mode benefits

Appl. Phys. Exp. **2,** 042501 (2009)

Groups of femtosecond laser pulses provide more control over the pulsed laser deposition process in nanomaterials and thin films, according to researchers from IMRA America in the United States. The approach by Makoto Murakami and colleagues uses a burst of femtosecond laser pulses. Groups of 700-fs laser pulses each with a pulse energy of up to 10 μJ and a total average power of up to 2 W are produced by a chirped pulse amplification system based on optical fibre technology equipped with an acousto-optic modulator. A burst of pulses is released at a repetition rate of 0.1–5 MHz with a separation of 20 ns between neighbouring pulses within each burst. Three different bursts of pulses — 1 pulse per burst, 5 pulses per burst and 10 pulses per burst, at repetition rates of 1 MHz, 200 kHz and 100 kHz, respectively — are used to produce the same pulse energy of 0.4 μJ and average power of 0.4 W. The team demonstrate that the use of a custom-designed optical pulse train enables them to tune the size of nanoparticles in the deposited film in a continuous manner and produce high-quality thin films. Interestingly, the researchers report a reduction in particle size with increasing number of pulses in each burst, even when the same total average power and individual pulse energy are used.

Sloping design perfects dissimilar joint

Opt. Laser Eng.
doi: 10.1016/j.optlaseng.2009.02.004 (2009)



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Copper–steel conductors are attractive for power-generation industries because of the combined high mechanical resistance of steel, and the conductivity and resistance to corrosion of copper. But joining these two materials using conventional and laser welding techniques has not been easy owing to the mismatch in material properties. This problem can now be overcome, according to a group of researchers from China. In the butt-welding scheme by Chengwu Yao and co-workers, the Cu–Fe dissimilar joint is designed in a scarf joint geometry and a CO_2 laser with a maximum output power of 15 kW illuminates the steel side. The researchers show that through the use of the laser they can control the dilution ratio between copper and steel, and hence obtain different microstructural features in the interface between the two metals. In particular, they report that a transition zone with a large proportion of granular phases is formed near the intermixing zone when the welded joint has a high percentage of copper. Defect-free joints with high tensile strength can be achieved when the copper is dissolved in small amounts in the molten steel. The team envisage that their findings will help to optimize the laser welding of joints of dissimilar metals.

Beating the downturn

Laser systems manufacturer Trumpf believes it can survive in the current economic climate with its strategy of diversification in both the laser technologies it is able to offer clients and the wide range of end-user applications that it serves. **Nadya Anscombe** finds out more.

In tough times it sometimes helps to be different. Trumpf, the German materials processing specialist, is different from many large engineering companies in that it is still privately owned. It is this fact, together with the company's strategy of having products covering a diverse range of applications, that is keeping the company thriving while many have fallen by the wayside.

The past financial year (2007/08) saw Trumpf's laser division grow by 16%, with the entire Trumpf group reporting sales of 2.14 billion euros and adding 700 new jobs in Germany and abroad. Jens Bleher, managing director of Trumpf Laser and Systems Technology, believes that the success in his division is because the firm has such a broad spectrum of laser sources — from CO_2 lasers, disk lasers and rod lasers up to and including fibre lasers. "This is how we differentiate ourselves from the many competitors in the market, some of whom offer only one or two platforms and then, of course, praise these as the latest and the greatest," he says.

He also believes that being a family-run business helps in this economic climate. "The family takes a long-term view of the company and makes decisions that will sustain the company," he says. "We are not dependent on the stock exchange and the money the company makes does not leave the company but instead gets reinvested."

Jens Bleher, managing director of Trumpf Laser and Systems Technology.

The company now has more than 8,000 employees worldwide. Most of Trumpf's growth over the years has been organic, with one or two strategic acquisitions along the way. With its recent purchase of UK fibre laser company SPI Lasers, Trumpf has now become a one-stop shop for anyone looking for laser systems for materials processing. Whether you need a laser for cutting, welding, marking, surface treatment or microprocessing, Trumpf has a solution for each application.

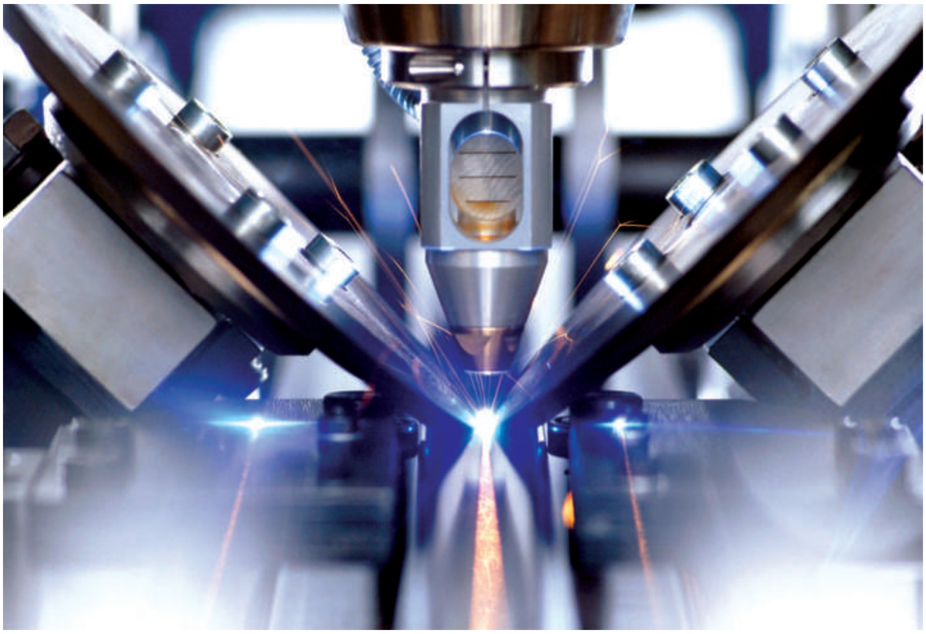
Whether this strategy will deliver similar growth this financial year (2008/09) remains to be seen, but Trumpf believes it is this diverse range of products that means the company can survive in the current economic climate. The automotive industry, one of Trumpf's largest clients, has been hit very hard in the past year. Bleher admits that this has also affected sales of laser systems into this industry. "But it has not affected us as strongly as some might think," he says. "Our lasers go into new product lines and our customers are still launching new products." He admits that Trumpf is having to adapt its own manufacturing capacity, with reduced working times for some of its staff. But he points out that this only brings the staff down to normal working times, as they have been working extended hours to cope with demand until now. In fact he believes that the economic downturn could even benefit laser technology in the long term. "Displacement of conventional technology in manufacturing is being led by the laser," says Bleher. "In general manufacturing there is still room for growth for laser technology. Many companies are beginning to recognize the economic advantage of investing in this technology."

Disk lasers

A disk laser is a diode-pumped solid-state laser where the gain medium (laser crystal) has the geometry of a thin disk rather than a rod or slab as is the case in conventional solid-state lasers. The benefit of the disk geometry is that the disk has a large surface area which allows improved cooling of the gain medium. This helps combat detrimental thermally induced optical effects, such as thermal lensing, which degrade laser performance at high powers. The concept of the disk laser was first demonstrated by Adolf Giesen and colleagues at the University of Stuttgart, Germany, in the early 1990s. It has since been commercialized by companies including Trumpf and proved to be a popular design for kilowatt-class lasers.

Trumpf has now increased the power of its disk laser up to 16 kW. Offering a beam parameter product of 2–8 mm mrad, the new-generation TruDisk lasers maintain beam quality regardless of increases in power, resulting in a scalable design. The company claims that the TruDisk's integrated power sensors and real-time power feedback control guarantees continuous, steady and reliable power at the workpiece.

A unique modular design allows individual diodes and laser components to be serviced onsite, an impossible feat for comparable technologies. Greater access to fibre optic cables allows the system to be serviced while the laser is in operation. This permits parallel fibres to maintain production without interruption. The design also makes it possible to upgrade laser power with additional diodes. This increases production capabilities as needed without requiring an additional laser unit. The company claims that the diode life expectancy is over 50,000 hours and that the system has a wall-plug efficiency of up to 30%.



TRUMPF

An example of welding with a Trumpf laser.

For example, Trumpf has seen particularly high growth in sales of lasers to the photovoltaics industry and also some areas of the electronics industry. These are markets particularly suited to the disk and fibre laser.

Trumpf pioneered the commercialization of the disk laser (see Box), but until its purchase of SPI Lasers last year, the company had only a limited offering in the fibre laser field. This was seen by some as a rejection of fibre laser technology, and Trumpf's purchase of SPI Lasers took some people by surprise. But for Trumpf, the acquisition makes perfect sense. "We continue to believe that higher powers are and will remain clearly the domain of the disk laser," says Bleher. "It is the right design for industrial applications in the high multi-kilowatt continuous-wave power range. The disk is a robust and easily scalable platform that cost-effectively allows good to very good quality beam generation. It has great potential for the future."

TRUMPF

A solid-state laser cutting a series of fine patterns in a medical instrument.

In contrast to the fibre laser, the power density inside the resonator of a disk laser remains far below the critical destruction threshold of the laser medium, even at high powers. The disk laser user need not fear a beam source failure in the event of reflection from the component because it was especially designed to be insensitive to reflection. For this reason, Trumpf believes that, for higher powers, the disk laser allows better system use and considerably higher productivity.

The company is marketing its fibre lasers in a lower power range than its disk lasers and therefore feels that the two ranges fit very well together. For fibre lasers, applications include welding and cutting when very precise contours are needed in thin sheet metal. "We will continue to offer our TruFibre 300 product and will integrate SPI Lasers' products into our line and extend it," says Bleher. "SPI has been a supplier of ours for several years and we will continue this relationship. SPI even supplied some of our competitors and we intend to keep these two business models. Two brands, two companies."

Bleher is not keen to enter into a discussion about which laser — disk or fibre — is best. As he points out, many of Trumpf's customers just want a system that is appropriate for their application and the laser technology itself is not the primary concern of the customer. "Every technology has its advantages that we need to exploit based on the customer's needs," says Bleher. "That is why Trumpf uses every available technology and continues to develop them."

As well as fibre and disk lasers, Trumpf also sells CO_2 lasers and most recently has added direct diode lasers to its portfolio. For two-dimensional laser cutting, the CO_2 laser remains the gold standard for Trumpf. "At present, we don't understand why people feel that the 1-μm wavelength of the solid-state laser is preferable. The cutting behaviour of the CO_2 laser with a 10-μm wavelength offers a high degree of flexibility when cutting sheet metal of different thicknesses," says Bleher. In addition, the high edge quality is an argument for the CO_2 laser as a universal cutting machine.

But he also sees that the key technology of the near future is undoubtedly the diode. "Diode-pumped solid-state lasers and direct diode lasers will play an increasingly important role, in our opinion. The diode will become the central element for all lasers," says Bleher. "In fact it already is."

At the beginning of this year, Trumpf announced record output performance from its TruDiode diode direct laser series: 100 W output from a single fibre optic and a divergence of less than 120 mrad. Because of their high beam quality, even in the multi-kilowatt range, lasers in the TruDiode series are intended for welding applications where lamp-pumped solid-state lasers are currently used. With a wall plug efficiency of 40%, diode lasers work far more efficiently than lamp-pumped solid-state lasers. Another advantage is the small size of the diode module, at only 8 × 6 × 3 cm, which contributes to the very compact and space-saving design of the TruDiode series.

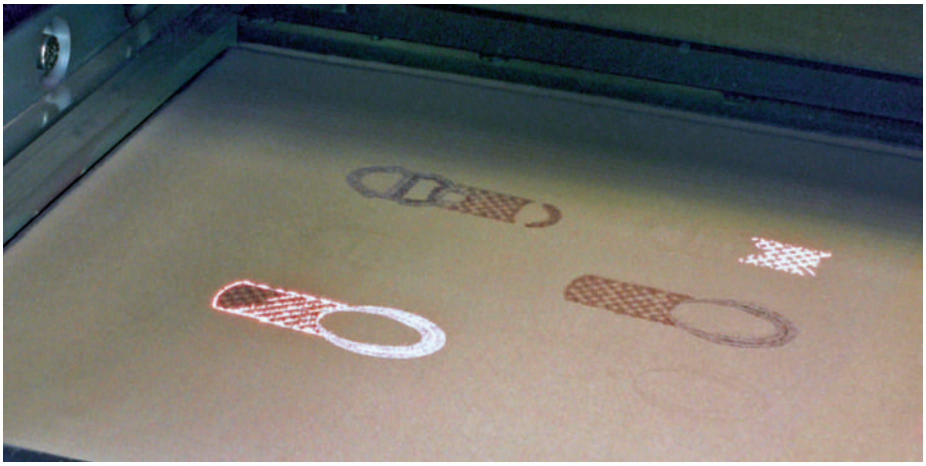
With continued innovation such as this, Trumpf aims to offer its clients a broad and comprehensive range of products to suit their application. "We are currently not of the opinion that a 'disruptive technology' will appear in the near future," says Bleher. "By that I mean a new laser technology that will replace all other beam sources. A broad range of different laser technologies will continue to be used in the future. For this reason, a laser manufacturer needs to be proficient in all types of lasers and be able to offer his customers the relevant technologies. Trumpf will continue to develop all varieties of laser technology in order to offer its customers the best laser for every application in material processing— regardless of the beam source." ❐

LASER SINTERING

Layer by layer

Christof M. Stotko

With its intense power and flexibility, the laser has revolutionized sintering technology and made possible the rapid manufacture of prototypes and components from electronic data.



EOS

Figure 1 | Laser sintering in action. A laser beam melts a layer of metal powder which then solidifies. By repeating the process a three-dimensional part can be made.

Manufacturers have traditionally used machine tools to produce prototype components by removing material from solid blocks of metal (or plastic), or from castings, forgings or extrusions. When machining a solid, it is not unusual to take away over 90% of the original material, which is both inefficient and expensive in terms of the material used and the swarf that has to be removed and recycled.

In contrast, building a prototype by 'growing' it layer-by-layer has enormous advantages in terms of lowering manufacturing costs and lead times. Such additive layer manufacturing (ALM) has now come of age thanks to laser-sintering technology.

By using a laser to solidify fine metal or plastic powders, fully functional parts can be produced directly without the expense of producing mould tools. There are even laser-sintering machines for direct manufacture of sand cores and moulds for metal casting.

Although other rapid prototyping techniques such as stereolithography, laminar paper modelling, fused deposition modelling and three-dimensional printing are useful for visualizing what a component will look like, the resulting models are too soft or brittle to be used for the intended application.

The ever-increasing complexity of components used in industry is one of the key drivers for the development of advanced laser-sintering technology. Many parts have difficult-to-machine surfaces and internal walls that are easy to produce using ALM. It is even possible to design parts with internal features that can only be made by additive techniques, as subtractive machining would not be able to access some areas.

In the early days, laser sintering, in common with other ALM processes, was regarded as just a rapid prototyping tool, but today it is becoming widely adopted for fully fledged rapid manufacturing. This is termed 'e-manufacturing' — the fast, flexible and cost-effective production of products, patterns or tools directly from electronic computer-aided design (CAD) data.

The technology is making inroads in many areas of manufacture. For example, a plastic injection mould tool is traditionally milled, and conformal cooling channels are then drilled in straight lines near to the surface. Now, the mould can be laser-sintered in a single operation, including the conformal cooling channels, which can accurately follow the contour of even the most complex mould surface. This reduces injection-moulding cycle times and improves the quality of the plastic components that are produced. Another area of saving is product assembly, which can often be eliminated by using ALM to make complex components in a single operation.

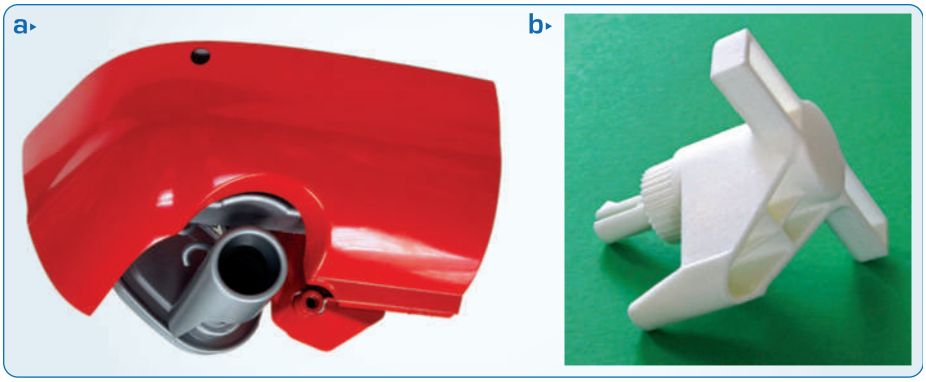
To start the laser-sintering process, a very fine layer of powder is spread over a build platform in the process chamber. The layer is typically 20 μm thick for metal and 100 to 150 μm thick for plastics, depending on the required resolution and surface finish. The powder is solidified by a laser (Fig. 1) that is driven using data derived from the CAD model of the component, which has previously been sliced horizontally into layers of the same thickness.

The platform is lowered by the same amount as the layer thickness, a fresh coating of powder is swept over the previously laser-sintered layer, and this in turn is laser sintered. The process continues until the component is complete.

It is noteworthy that this is not conventional sintering using pressure and heat below a material's melting point to bond and partly fuse the powdered particles. In laser-sintering machines, a laser directed by a lens-based optics system melts the metal particles at the laser beam focal spot.

The mechanical properties of finished metal components are as good as, if not superior to, their cast and wrought equivalents. This is largely due to the very small pool of molten material produced, which allows cooling to take place in microseconds after the laser has moved away. Metal parts produced on laser-sintering machines have a homogeneous grain across the entire part. They can be welded, machined, shot-peened, polished and coated afterwards, if required.

An important characteristic of the laser source is the wavelength, which should be well matched to the absorption characteristics of the powder material. The current standards are CO_2 lasers with a wavelength of roughly



EOS

Figure 2 | Laser sintering and cars. **a**, Close-up of the laser-sintered prototype bumper section for the Jaguar XJ. The painted model was used to visualize the fit and finish of key components before production. **b**, The laser-sintered plastic tool that assists operators working on the new Jaguar XK production line to position window lift mechanisms during assembly.

10.6 μm for processing plastic materials, and ytterbium fibre lasers with a wavelength of about 1.1 μm for processing metals.

Normally, continuous-mode operation is used. Additional important criteria are a laser with excellent beam quality and focusing ability, and good stability in terms of beam power and position.

The diameter of the focused beam in a state-of-the-art laser-sintering machine for metals is less than 0.1 mm. The laser must be sufficiently powerful to guarantee good laser sintering. For processing plastics a range of machines is available, from small, entry-level machines with a small build volume and a 30-W laser, up to systems that use two 50-W lasers working in parallel.

The development of laser-sintering systems so far gives an indication of what can be expected in the future. Component quality and productivity have been considerably upgraded, partly through increasing laser power and improvements in the optical system such as the laser control. The range of machine sizes and types has widened and will continue to do so.

Furthermore, the range of powder materials continues to increase, while new machine options and peripheral devices continue to improve productivity and user-friendliness. In general, laser-sintering technology will keep maturing in terms of quality, productivity, reliability and economics, making it more and more accepted for an increasing variety of applications. Two highly important application areas are the automotive, and medical sectors which will now be briefly described in turn.

DEPUY SPINE

Figure 3 | Prototype plate bender, used to contour plates for spinal surgery, built by DePuy using a laser-sintering system.

AUTOMOTIVE SECTOR

Jaguar Cars is making increasing use of laser-sintering technology at its Whitley Engineering Centre near Coventry, UK, to speed the development of new vehicles by making plastic parts directly from CAD models, eliminating the expense of producing mould tools. It is using the technology for the production of prototype trim and even engine parts from nylon powder (polyamide PA 2200).

The resulting components, such as the air-intake manifold, door inners, fascia substrate, interior air vents and exterior light housings, are robust enough to be used on test vehicles running around a test track, allowing more data to be collected early in the development process. Other rapid prototyping techniques that use materials such as epoxy resin and the thermoplastic ABS produce relatively fragile parts that are best suited for visualization only.

Take the V8 air-intake manifold prototype for a recently introduced Jaguar car. In the past, hundreds of thousands of pounds would have been invested in hard tooling for its manufacture. Following every design change, it would have cost thousands of pounds to alter the tool, a process that took several weeks each time. For substantial changes, a completely new tool might be needed.

Using laser-sintering technology, two design iterations of the manifold were produced and 17 were subsequently built in nylon for less than £1,000 each and in a lead time of one and a half days per manifold. This represented an enormous financial saving in the development of this vehicle component alone and has halved the time needed to perfect it, from one year to six months.

An example of a laser-sintered component for the XJ saloon is a bumper section built in two pieces (Fig. 2a) that was used for visualizing the assembly of key parts such as the exhaust pipe and tow eye fixing. The aesthetics of this part of the vehicle could therefore be evaluated before progressing to hard tooling.

The nesting flexibility afforded by the plastic laser-sintering machines makes it easy to incorporate dozens of parts in each sintering cycle. An interesting component that is regularly added around other parts is not a prototype at all, but a complex plastic assembly aid that assists operators working on the Jaguar XK coupé and convertible to position the window lift mechanisms during build (Fig. 2b).

The manufacturing plant required a stock of 3,000 of these parts, as once fitted, the assembly aid remains on the vehicle throughout the build process.

MEDICAL SECTOR

In the medical sector, one of the world's largest producers of implants and instruments for spinal surgery, DePuy Spine of Raynham, Massachusetts, is using a metal-sintering system to reduce lead times for making new and customized equipment for minimally invasive surgery.

The traditional process of prototyping, design revisions, materials selection, cadaver testing and manufacturing normally results in a lead time of many months. This has been greatly reduced using a metal laser-sintering system. In the first year, DePuy processed 2,000 prototype parts in the machine, including benders (Fig. 3), extractors, surgical screws, clamps and reduction devices. Delivery times for surgical tool prototypes have shrunk from several months to less than a week in some cases.

Surgeons can be very demanding about their requirements for tools such as blades, racks, tweezers and calipers. When they review the parts, they may ask for different handle angles or different spring strengths. It is very easy to adjust the CAD design and make another iteration. DePuy claims that laser sintering lets it make virtually anything surgeons ask for. ❐

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SURFACE TREATMENT

Shock tactics

Richard D. Tenaglia and David F. Lahrman

Laser shock peening is a surface treatment process for increasing the strength and reliability of metal components. Traditionally applied to aircraft parts, the technology also shows great potential for automotive and medical applications.

Laser shock peening, or more simply laser peening, is an effective method of increasing the resistance of gas turbine engine compressor and fan blades in aircraft to foreign object damage and improving high-cycle fatigue life. The successes achieved in preventing fatigue failures in turbine blades are driving efforts to expand the application of laser peening to other aircraft structures, helicopters, land vehicles and military equipment, and general industrial uses.

Laser peening forces a high-amplitude shock wave into a material surface using a high-energy pulsed laser. The effect on the material comes from the mechanical 'cold working' effect produced by the shock wave, not a thermal effect from heating of the surface by the laser beam. In fact, the laser beam only makes contact with a temporary protective coating placed on the surface of the part, and no significant heating occurs because of the very short duration of the laser pulse (see Box 1).

The common laser system used for peening is a high-energy, pulsed neodymium-glass laser system with a wavelength of 1.054 μm. Suitable laser peening systems produce short laser pulses, from about 8 to 30 ns in duration, with a beam energy in the range of 10 to 50 J. Although laser systems with lower energy and small spot size or with ultra-short pulse durations have been considered, these systems typically do not provide enough power to create the desired effect. Either circular or square-shaped laser spots may be used, depending on the configuration of the laser system and optical components. The laser spot size may be adjusted with lenses, but it is typically an area in the range of 0.03 to 0.28 cm^2 that is applied to the part. The laser-peening parameters are typically selected to achieve a power density or laser irradiance of 5 to 10 GW cm^{-2}. A two-beam laser system may be used advantageously to laser peen the opposite sides of thin parts, such as the edges of turbine engine airfoils. Laser peening one side of a thin blade completely and then the opposite side can result in excessive distortion, but this can be avoided by using an alternating scheme in which a laser spot is applied first to one side of the blade and then a second beam is applied to the opposite side. Figure 1 shows a two-beam laser system that operates at 50 J per beam.

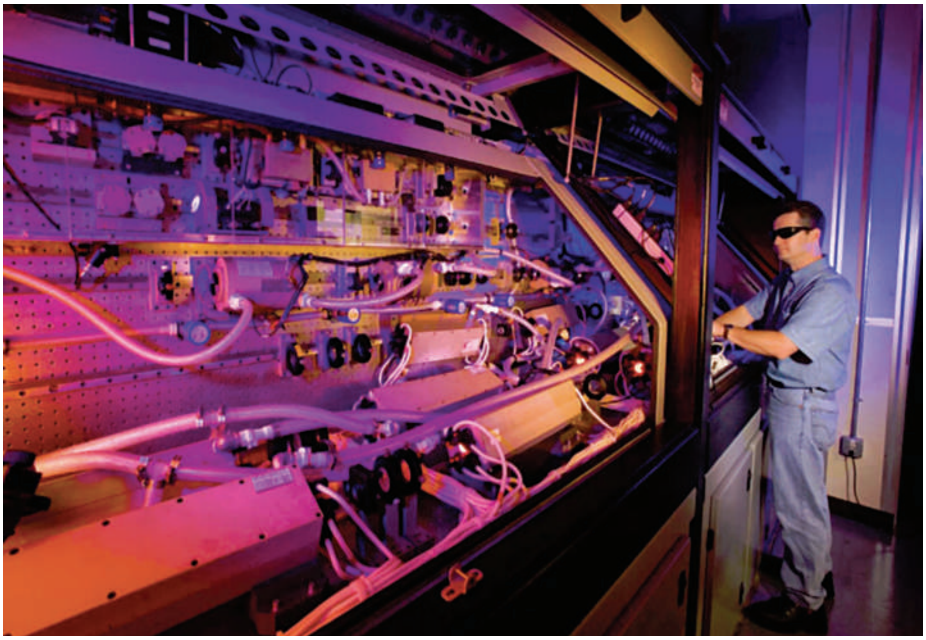
LSP TECHNOLOGIES

Figure 1 | A two-beam, pulsed neodymium–glass laser system (LSP Technologies) that operates at up to 50 J per beam.

In the early 1990s, laser systems were not commercially available with the power or laser repetition rate to make laser peening practical. Typically, laser fluence in the range of 100–200 J cm^{-2} is required to create the desired effect in most materials. Early laboratory-based systems had a repetition rate of only one pulse every 8 minutes. As a consequence, the coverage rate for laser-peening parts was far too slow. The first generation of laser-peening systems was designed with a series of laser amplification stages (all using flash lamps) and an advanced electronic control system. This boosted the laser beam from an oscillator to produce two beams having beam energy up to 50 J per beam and a laser repetition rate of one pulse every 8 seconds (0.125 Hz).

To create the first practical industrial laser-peening systems, the life and reliability of the laser system components had to increase. The electronics for the pulse-forming networks were redesigned to produce a laser repetition rate of one pulse every 4 seconds (0.25 Hz) and assembled into modules for easy replacement in case of failure. The materials used for the flash lamp reflectors and the procedures used to produce the laser rods were optimized to boost efficiency and to extend component life. With support from the US Air Force

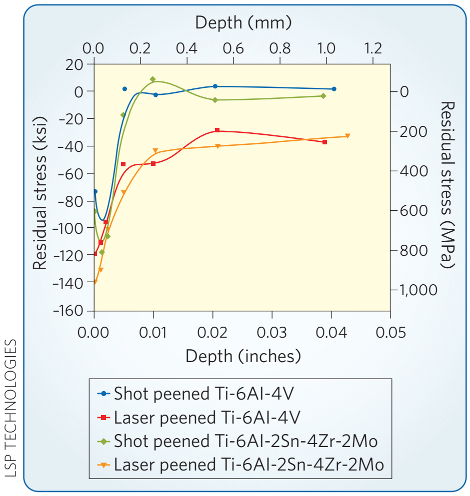

Figure 2 | Comparison of residual stress profiles for laser peening and conventional metal shot peening (ksi, kilopounds per square inch).

ManTech programme, LSP Technologies refined laser peening technology by building a system with industrially hardened environmental controls and many quick-change features for parts requiring repair or routine maintenance, and boosting the laser repetition rate to one pulse every 0.8 seconds (1.25 Hz). Each increase in repetition rate required further improvements to the optical system components to avoid damage during operation. Even higher laser repetition rates for laser-peening systems are possible (3 to 5 Hz), although at lower energy levels and using smaller spots. However, laser repetition rate is not the complete answer to boosting the coverage rate. One must also consider the requirements for applying and replenishing the opaque overlay coating and handling the parts. Depending on these requirements and the laser system used, practical laser-peening coverage rates are typically 10–20 cm^2 min^{-1}.

The latest laser-peening systems incorporate improved diagnostics to monitor and control the beam's spatial profile (to assess the energy distribution within the laser spot) and temporal profile (to measure the uniformity of the laser pulse timing). These systems also include electronic features for optimizing the shape of the laser pulse to create a uniform shock wave at the surface of the part. This provides a more uniform compressive residual stress distribution in the part being treated.

Laser peening produces a number of beneficial effects in metals and alloys. Foremost among these is an increased resistance to surface-related failures, such as fatigue, fretting fatigue and stress corrosion cracking. Many metals and alloys have been laser peened successfully, including titanium alloys, steels, aluminium alloys, nickel-base superalloys and cast irons.

The material property changes are derived from the deep compressive residual surface stresses imparted by laser peening. Figure 2 shows an example of the stresses achieved in two titanium alloys and compares these with the shallower compressive stress profiles produced by metal shot peening (the conventional technology, which involves firing small metal spheres against the surface of a part). The compressive residual stresses produced by laser peening extend more than 1.0 mm deep into the surface, whereas the compressive stresses for metal shot-peened samples are present to a depth of only about 0.2 mm.

Box 1 The laser-peening process

To prepare a part for laser peening, an overlay opaque to the laser beam is applied to the material surface to be treated. Opaque overlays can be of a variety of forms; paint (dry or wet), black tape and metal foils (sometimes with adhesive backing) have all been used with varying but similar results in terms of the pressure pulses generated. The opaque overlay protects the surface from direct thermal contact with the laser-induced plasma and provides a consistent surface condition for interaction with the laser beam, independent of the actual material being treated. Direct contact of a metal surface with the plasma will, in most cases, form a thin melt layer on the surface of the metal, ranging from a surface discoloration to a surface melt layer 15 to 25 μm thick, depending on the laser irradiation conditions and metal properties.

A material that is transparent to the laser beam is then placed over the opaque overlay. The simplest and most cost-effective transparent overlay is water flowing over the surface from an appropriately placed nozzle. The water is not used to cool the part but serves the key function of confining the plasma generated when the laser beam interacts with the opaque

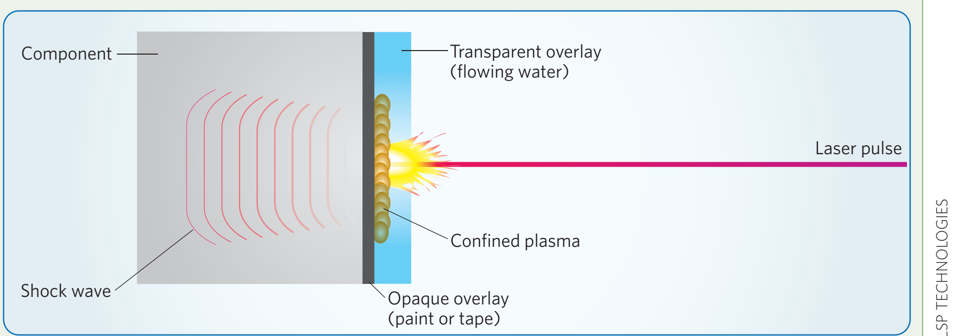

Figure B1 | Schematic of the laser-peening process.

overlay surface. The confinement increases the pressure developed by the plasma on the surface. This pressure can be up to 10 times the surface pressure developed if the plasma is unconfined and allowed to accelerate away freely from the material surface.

With the two overlays in place, the laser pulse is directed through water and interacts with the opaque overlay, as shown in Fig. B1. The laser energy is absorbed in the first few micrometres of the opaque overlay surface, vaporizing the material and forming a plasma. The plasma temperature rises rapidly through further heating from the incoming laser beam, but thermal expansion of the plasma is limited by the transparent overlay material. The pressure in the confined plasma increases rapidly (up to 6,900 MPa), causing a shock wave to travel into the material through the opaque overlay, and outward through the water overlay. Before the water can be ejected from the surface, the high-pressure shock wave is essentially 'tamped' or concentrated into the material surface. One may think of laser peening as a technique for micro-forging the surface of a material, spot-by-spot, in a highly controlled manner with laser light energy.

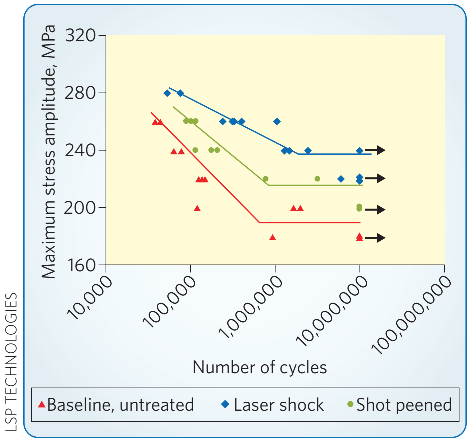

Figure 3 | Comparison of the fatigue property improvements for laser peening and shot peening.

Figure 4 | LSP Technologies' RapidCoater system positioned for processing a turbine engine blade.

Figure 3 shows a comparison of laser-peening and shot-peening fatigue properties for 7075-T7351 aluminium. For these tests, the specimens were fabricated with a notch to increase the stress concentration, thus making the test more severe. The data illustrate the typical fatigue enhancement of laser-peened parts, including a 30–50% increase in fatigue strength and about a tenfold increase in fatigue life.

Production applications of laser peening focused initially on aircraft engine parts such as turbine engine airfoils or integrally bladed rotors because of the benefits of preventing fatigue failures and improving damage tolerance for critical parts. GE Aircraft Engines (GEAE) used laser peening in 1997 to address a problem experienced with the B-1B Lancer F101 engine. Foreign object damage caused by hard objects ingested into the engine led to failures of first-stage titanium turbine engine blades. In some cases, sections of blades that broke loose caused irreparable damage to the rest of the engine. To avoid grounding the B-1B fleet, manual inspection of all the fan blades was required before each flight. The time-consuming inspections involved rubbing the leading edge with cotton balls, cotton gloves and even dental floss. If a single snag was detected, the blade was replaced before the next flight. More than one million man-hours per year were required to complete the engine inspections and keep the B-1B aircraft flying.

Laser peening was found to restore the fatigue performance of damaged blades to a standard equal to or better than the performance of new blades. Sensitivity to foreign-object damage up to about 6 mm deep in F101 blades was virtually eliminated. Using laser peening in this way avoided the costs of blade replacement, repair of secondary damage to engines and the severe consequences of catastrophic engine failures. Because of this success, laser peening was applied to solve problems caused by foreign-object damage for F-16 Falcon/F110 engine blades. In 2003, the use of laser peening was extended to more complex engine parts and laser peening began to be used during production of an integrally bladed rotor for Pratt and Whitney's F119-PW-100 engine, which powers the F/A-22 Raptor. The Metal Improvement Company also now operates laser-peening facilities and has used these to improve the performance of Rolls-Royce Trent series engine blades.

In addition to turbine engine components, numerous potential uses of laser peening for airframe structures exist, including fatigue-critical components such as F-16 bulkheads, wing attachments, flight control mechanisms, wheels, brakes and landing gear. The peening treatment is also commonly applied to improve the strength and reliability of welded ageing aircraft parts, fasteners and fastener holes, titanium and aluminium welded parts, and cost-effective castings for replacing forged parts.

Mobile laser-peening systems are now deployed at repair depots for treatment of large structures. The challenges for developing such a system primarily lie in providing control of the operating environment for the laser system. A mobile system must have embedded capabilities for vibration isolation, air and water temperature control, and air and water filtration, as well as protecting the operator and nearby personnel from laser light energy. LSP Technologies is developing a robust mobile system that is suitable for use in industrial settings and which is expected to be introduced in 2009.

Beyond the aerospace industry, numerous other industrial applications for laser peening are also emerging. Laser peening offers opportunities for weight reduction, increased reliability and improved fuel economy in automotive and truck parts such as transmission gears and axles, rotating engine parts and impellers. Medical applications include treatment of orthopaedic implants to improve the fatigue performance of hip and knee replacement joints and spinal fixation devices. Laser peening is also under development for applications in equipment for land-based power generation.

The future of laser shock processing is one of continuing advancement in applications, technology development and scientific research. The biggest barrier to wider application of laser peening in manufacturing has been the cost of high-power laser systems and, to a lesser extent, the slow throughput of the process. This situation has improved rapidly with the development of production laser-peening systems that are more reliable and easier to maintain, and with advances in processing technology such as LSP Technologies' RapidCoater system (shown in Fig. 4) for automating the application and removal of the process overlay coatings. The variety of potential uses continues to increase and is expected to expand rapidly over the next five years.

Many researchers are working on advanced modelling methods to predict and tailor the residual stress profiles that can be achieved with laser peening. Once these models are correlated and validated with fatigue performance, design engineers will be able to consider design life credits for incorporating laser peening into their component designs. ❐

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WELDING

Welding plastic with lasers

Manuel Sieben and Frank Brunnecker

Laser welding of plastics is now a convenient and flexible technique that is proving popular for joining automotive parts and medical equipment as well as consumer products.

Most people are familiar with the welding of metals. Less well known is that welding is also an established technique in the production of plastic components — a method that is now indispensable to industry overall. Joining thermoplastics involves heating the material in the welding zone above its melting point so that it becomes plasticized. Unlike the welding of metals, plastics are usually welded without dispensing any additional material into the joint line.

A wide range of methods are used today for plastic welding. The difference between the technologies is not so much in how they work, but in the nature and type of energy source involved. Processes include friction welding methods (vibration and rotation welding), ultrasonic welding, microwave welding, high-frequency welding, hot-plate welding and laser welding. The method best suited for a particular application strongly depends on the properties of the plastics used as well as the application and its associated requirements. For instance, if the direct hot-plate welding technique is to be used (in which the plastic is brought into contact with a heated plate) the plastic should not stick to the hot plate; polycarbonate has this tendency and is therefore unsuitable for this method. Vibration welding is only suitable for flat components because the relative movement of the components causes damage otherwise. Although laser welding also has some restrictions, it does have many advantages over other techniques.

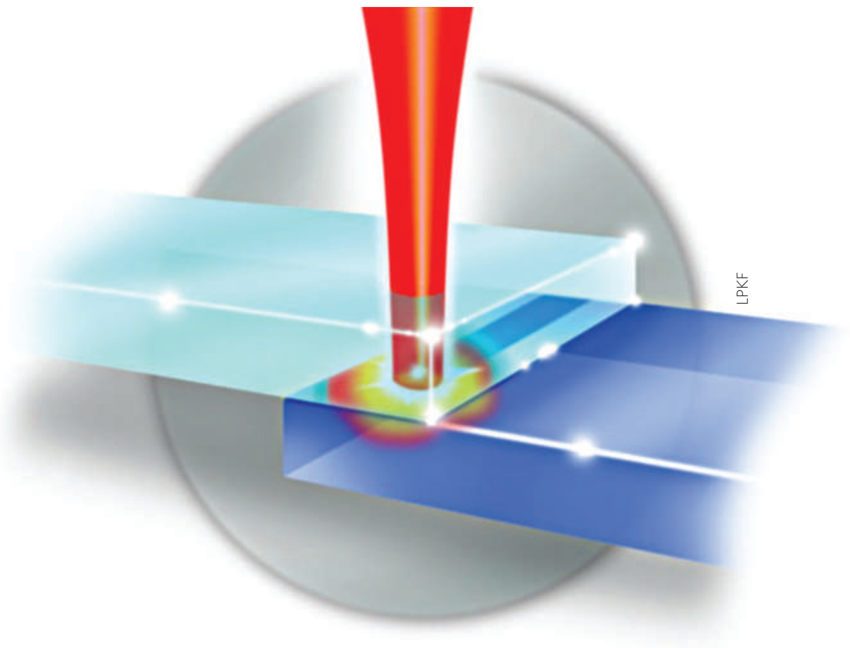

Figure 1 | Principle of laser transmission welding of two plastic components. The laser beam passes through the upper plastic layer but is absorbed by the lower one, generating heat that fuses the two components together, which then cool and harden.

LASER WELDING

People who recall the early years of laser welding technology tend to remember machines that took up a huge amount of space and required a great deal of maintenance. The solution to both of these problems lay in the further development of the laser sources. The breakthrough came with the replacement of the Nd:YAG laser by the modern diode laser which today typically offers a service life exceeding 20,000 hours, guaranteeing many years of problem-free industrial use. A prejudice that still lingers concerns the costs of a modern laser welding system, but the cost efficiency has been proven by usage in the highly cost-driven automotive industry.

The laser sources required for laser plastic welding are characterized by high output powers and continuous-wave operation. Wavelengths in the near-infrared range have proved particularly suitable for this purpose because in this wavelength region most engineering thermoplastics are transparent in an unpigmented state. These criteria were best satisfied in the past by Nd:YAG lasers with a wavelength of 1,064 nm. But because these solid-state lasers needed a lot of maintenance, they have been replaced by high-performance diode lasers. Modern systems achieve efficiencies of over 50% and completely dispense with complex and expensive water cooling — and thus benefit from reduced energy consumption.

When very fine seams are required, however, the diode laser reaches its limitations. Spot diameters of about 1 mm are realistic. To create even smaller weld seams, fibre lasers can be used. Because of their better beam quality and efficiency when compared with Nd:YAG systems, fibre lasers are clearly the better choice for this application, and seam widths of below 100 μm are achievable. These small seams are especially attractive for the medical industry and other fields following the trend of miniaturization. For example, microfluidics and 'lab-on-a-chip' systems are applications that cannot be welded by other technologies.

Laser welding of thermoplastics has moved on from niche applications to become a highly interesting alternative to conventional methods. The hundreds of applications confirm the place that this technique has already earned itself in the industrial sector. Welding plastics using laser technology not only reduces the use of consumables, it also produces very good quality results compared with other welding techniques. Laser welding is a non-contact method that keeps mechanical stress on the components to a minimum. The only stress affecting the product being joined is the vertical joining pressure. There are absolutely no vibrations that could damage the plastic housing or any internal components. This is the key property that makes it so attractive for the production of electronic housings of all kinds, an application that largely drove the initial development of laser welding. To avoid any risk to the internal electronic components, electronic housings cannot be welded using ultrasonic methods. And because screwing or gluing the parts together is expensive, laser welding becomes the best choice.

TRANSMISSION LASER WELDING

Transmission laser welding is a very popular technique. The two parts to be welded together must have different transmission properties: that is, one of the components is transparent to the wavelength of the laser beam, whereas the other component absorbs the energy of the laser beam. Most lasers used today operate in the near-infrared range. During the joining process, the component is clamped, commonly using a sheet of glass. The laser beam passes through the clamping tool and the upper component, and when it hits the surface of the second component the light is absorbed and converted into heat (Fig. 1). This heat is then also passed into the transparent component by thermal conduction, causing the material of both components to melt. On cooling, the plastic hardens again to create a cohesive join. Absorption additives have now been developed to solve the problem of how to join two highly transparent components with the same transmission properties. An example is Clearweld, produced by Gentex Corporation. These green–yellow absorbers can be bound within suitable solvents and applied to the boundary surfaces. They have high absorption at the emission wavelengths of the laser beam used in each case. When the laser beam hits these absorbers, the absorber is heated up and plastifies the material by thermal conduction to produce a reliable join. The heat changes the optical properties of Clearweld, leaving behind a highly transparent seam (see Fig. 2). Transmission laser welding can be subdivided further according to the various means of guiding the laser beam along the joint line: simultaneous (described above), quasi-simultaneous and contour welding (both described below) are now all established in today's market.

QUASI-SIMULTANEOUS WELDING

Quasi-simultaneous welding — a mixture of contour and simultaneous welding — is particularly good for small components. The laser beam is guided along the welding line by a galvanometer scanner (Fig. 3). The beam is controlled in the x and y direction, and because of the high speed of the beam, the material along the whole welding seam melts 'quasi-simultaneously'. The programmability of the scanning unit makes this method very flexible: applying the process to new products or making corrections only requires that the machine is reprogrammed without having to change the optics or masks. Quasi-simultaneous welding is particularly good for components up to a maximum size of 400 mm × 400 mm, for larger components it tends to be unsuitable. Another restriction is that the third dimension of the component must not exceed the focusing depth of the laser. This method is therefore particularly good for welding flat parts, such as sensor and electronic housings.

CONTOUR WELDING

Contour laser welding makes it possible to join large components such as car body parts, car lights and solar panels. During contour welding, the laser beam is guided once along the weld line using a positioning system such as a robot. The robot either holds the laser itself, or is equipped with a fibre-coupled system and moves a focusing lens. This method is flexible and can be used in theory to join any size of component. Contour welding produces very shallow join depths, and the width of the welding seam is smaller than that produced using comparable processes. This makes it particularly interesting for transparent components and sunroofs, headlights, tail lamps or instrument units where weld seams are visible. Contour welding can also be used to process parts found in car engine compartments, with the advantage that the method produces no debris, so parts such as air-intake manifolds or liquid containers can be processed without having to carry out any post-process cleaning.

HYBRID WELDING

A recent development is 'hybrid' welding, which uses two emission sources to increase welding quality. Hybrid welding is an advanced form of classic contour welding and has already captured market share in many applications. This technique was jointly developed in 2005 as a result

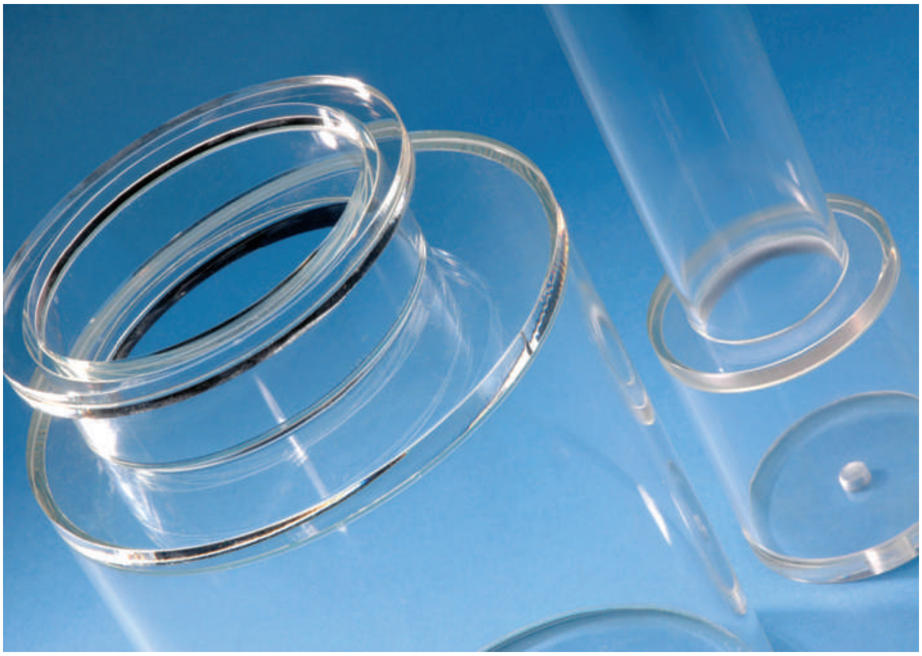
LPKF

Figure 2 | Example of high-quality laser welding of transparent plastic parts using the Clearweld technology. A light-absorbing dye is sandwiched between the components to be joined. On illumination with a laser it heats up, melting the interface between the parts. Advantageously, the dye becomes colourless in the process leaving a weld seam that is invisible to the naked eye.

LPKF

Figure 3 | Scanner-based welding system integrated into a conveyer line. The approach allows efficient mass production.

of cooperation between LPKF Laser and Electronics AG and the Bavarian Laser Centre (Erlangen, Germany). Instead of relying solely on energy provided by a laser, hybrid welding combines a laser beam with a secondary source of light that is polychromatic (wideband emission). Halogen lamps have proved to be suitable as the secondary source. In hybrid welding, the secondary radiation fulfils two different tasks. First, the spot diameter of the halogen light is much larger than the laser beam. So, when both sources are focused on the same point, they give a total radiation profile that decreases strongly on the outside with an intensity peak at the centre coming from the laser beam. When this set-up crosses a point on a welding line, the material is first slowly warmed, then melted by the laser beam, and then cooled slowly when it again passes into the area only influenced by the halogen light. The biggest advantage of hybrid welding is that it prevents a welding seam from cooling down too quickly, and so stops stresses building up in the material. Another advantage is the continuous spectrum of the halogen spot: whereas laser light passes almost completely unhindered through the transparent upper component, the upper layer absorbs a large proportion of the secondary radiation. This means that the upper transparent component is not exclusively warmed by indirect thermal conduction as is the case with the other laser welding methods. Direct absorption gives rise to a more homogenous temperature.

Hybrid welding is particularly suitable for components such as rear lights, tachometer units and other products where welding seams cannot be hidden. These joins mostly involve polymethylmethacrylate (PMMA) or polycarbonate as the upper component, and are currently usually joined by hot plate, vibration or ultrasonic welding. However, the advantages of the new hybrid welding technique are compelling and are attracting more and more attention. Conversion to the hybrid welding technology means that an entire processing step can be removed from a production line because annealing is no longer required. The system also has advantages in welding products where the priority is high productivity for small batches of products. By using a clamping roller to provide the required clamping force, hybrid welding completely dispenses with the otherwise essential upper tool (Fig. 4). This saves production costs, and the associated absence of any wear or contamination that otherwise increases the proportion of rejected goods.

LASERVISION

Figure 4 | A hybrid system with an example application of an automotive tail light.

LPKF

Figure 5 | Electric shaver welded by laser.

TOMORROW'S TRENDS

Different trends can now be observed in the market: the reduction in the cost of laser sources is increasingly making laser welding economical for more cost-sensitive applications such as consumer products (Fig. 5). There has also been growth in demand from the medical technology sector where guaranteed hygiene is often very important. Laser welding easily satisfies this stringent demand: unlike most conventional methods, laser welding produces absolutely no fluff or particles, a compelling argument for its use in the manufacture of infusion bags and similar products. The production of microfluidic systems is another large market involving the construction of the finest possible channels, which are difficult and expensive to produce using methods other than laser welding. The joint line here not only combines the components but can simultaneously create fluidic channels.

The size of components being welded is also growing steadily. It is now possible to use lasers to join plastic car body parts, rear lights or similar components. The automotive industry continues to be the main market for laser welding equipment. The current crisis affecting this industrial sector has made the search for cost-cutting measures even more important. The economic efficiency of traditional processes is now undergoing stringent analysis, and laser plastic welding is proving to be the most cost-effective alternative in many cases. If this trend continues, modern laser welding machines are set to capture even more of the market for plastic welding. ❐

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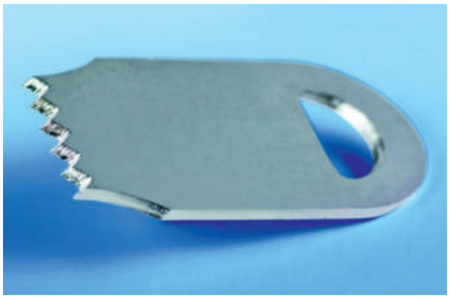
Profiling tool for metallic devices



ROFIN-BAASEL UK LTD

Designed for high-precision profiling and cutting of metals used for making medical devices, the ES-CUT150 system is the latest release from ES Technology Ltd in the United Kingdom. The system, equipped with a 150-W pulsed YAG laser, is able to cut through metals up to 5.0 mm thick, and create a kerf width of only 18 μm with minimum burr, on materials such as stainless steels, titanium, aluminium, gold, silver and brass. The system operates at an accuracy of ±10 μm and speeds up to 35.0 mm s^{-1}, offering high-quality profiling at high speeds. The position of the workpiece to be processed is controlled by a servo-driven x–y table, and computer-aided design (CAD) data for the part to be produced can be imported quickly into the system. Other benefits include a computer-based operator–user interface, a full integrated standalone design, and an optional facility for fine dust removal.

www.estechnology.co.uk

Plug-and-play fibre laser

Following the recent opening of an application facility in Silicon Valley, California, in February 2009, IPG Photonics has announced a new line of fibre lasers designed for high flexibility and reliability at low cost. In addition to the fibre-delivered direct-diode lasers, the company now also supplies cost-effective customized fibre lasers that offer plug-and-play operation with rapid fibre replacement and switching capability. The new, compact YLS-CL series gives users choice over delivery fibre shape, output fibre core sizes and beam shapes. Compared with the direct-diode systems, the custom lasers offer high flexibility and reliability. Available at 2, 3 or 4 kW of output power, the lasers are specifically designed for cladding, brazing, hardening and annealing applications in the automotive, aerospace, oil and heavy industries. Mass production of this new-line fibre lasers is scheduled to be in the second quarter of 2009. The company says that the new line will be price-competitive.

www.ipgphotonics.com

Green laser offers high-precision micromachining

Coherent, a Californian company based in Santa Clara, has unveiled a new pulsed green laser: the AVIA 532-23. The announcement extends Coherent's AVIA 532 high-power laser series into the region of more moderate output power. Operating at a wavelength of 532 nm, the new AVIA laser is a frequency-doubled, Q-switched, diode-pumped solid-state laser that offers an average power of 23 W. It produces pulses with a pulse width of less than 40 ns at a repetition rate of 100 kHz. Just like other products in the series, the device comes with drift-free resonator optics and pump laser diodes with aluminium-free active area. It also features the ability to deliver constant pulse energy over time and at varying repetition rates, and promises uniform pulse energy when the laser is operated in burst mode (operation with groups of closely spaced pulses). Designed with excellent beam quality factor $M^2 < 1.3$ and high repetition rate of up to 300 kHz, this laser is capable of minimizing the heat-affected zone on a workpiece and is a cost-effective tool for a wide range of demanding, high-precision micromachining applications, such as solar-cell manufacturing, micromachining of micro-secure-digital (SD) cards, microelectronics package processing, and silicon wafer sawing and scribing.

www.coherent.com

Modular design for photovoltaics

4JET GmbH, a German supplier of laser systems for surface treatment of thin-film solar panels, has extended its range for products serving the photovoltaic industry with the INLINE system. Equipped with several laser technologies, the modular design of the INLINE system performs abrasion-free laser edge deletion, pattern-4 isolation cutting, selective perforation of semitransparent solar panels for building integration, marking and molybdenum exposure of thin-film panels, all from within a single unit. The design of the unit allows full-area processing including the inside of coated glass surfaces. Diode-pumped solid-state or fibre lasers are used, depending on the application. The laser edge deletion process provides a clean surface that has a resistance of several gigaohms and removes the need for further treatment before the lamination process. The system is suitable for processing amorphous silicon, cadmium telluride (CdTe) and copper–indium–gallium diselenide (CIGS) thin films, as well as all typical glass formats in use including G8 formats with 2,600 × 2,200 mm dimensions. The INLINE's combination of a high level of automation, cost-efficient design and abrasion-free precise ablation process not only reduces the cost of processing a panel, but also improves panel quality. Other features include an optical positioning system, vapour evacuation, integrated power measurement and optional modules for process validation.

www.4jet.de

Beam shaper suits industrial needs

MOLTECH GMBH

MolTech GmbH, based in Berlin, has released a new collimator model, the πshaper 37_34_1064, that provides highly efficient laser-beam shaping for high-power lasers. The device is designed to be compatible with powers of up to 6 kW from fibre-coupled solid-state or diode lasers, and near-infrared fibre lasers. It transforms a Gaussian or similar intensity distribution of the source laser beam to a flat-top beam with nearly 100% conversion efficiency and also accepts divergent TEM_{00} or multimode laser beams. The collimator maintains the diameter of the output beam at 30–34 mm over long distances with a uniformity of within 5%. Although it is designed for operation wavelengths of 1,020–1,100 nm, other optional wavelengths at 830 nm, 980 nm and so on are also available. The device is based on a Galilean design and no internal focusing of a beam is involved. Together with the ease of integration in systems and high damage threshold, the πshaper is attractive for applications in welding of metals and plastics, annealing, hardening, cladding, marking and engraving, and ablation.

www.pishaper.com

Combining fire and water

Swiss company Synova is commercializing an innovative materials processing technique that uses a water-guided laser beam to allow 'cold laser cutting'. **Nadya Anscombe** talks to the company's chief technical advisor, Alexandre Pauchard, to find out more.

What makes your company's laser MicroJet technology unique?

The technique combines the advantages of water and laser cutting for the first time in one operation. In the machine tool industry, water has been used for many years to cool a workpiece and remove waste. It has also been used as high-power jets for cutting. In our technology, the water does not cut, but instead a narrow jet simply guides the laser beam to the workpiece, cools the workpiece and removes waste. The water jet acts like an optical fibre, completely surrounding the laser beam and guiding it by internal reflection. This prevents the divergence of the laser beam and means the cutting head can be up to 10 cm away from the workpiece, giving the system great flexibility. The water jet is very thin — between 30 and 150 μm in diameter — and this allows precision cutting of sensitive material with negligible thermal influence.

What advantages does it have over conventional laser materials processing technology?

A conventional focused laser beam has a limited working distance of just a few millimetres, owing to beam divergence. In addition, the conventional laser generates a heat-affected zone in the material, causing damage. Contamination can also be an issue, as the molten material can be redeposited on the surface. Unlike conventional laser cutting where thermal damage is a problem, our cut is cooled by the water jet between laser pulses, producing what is effectively 'cold laser cutting'. This method significantly reduces deformation and heat damage, allowing the material to retain its original structure. With our system, complex three-dimensional cutting is also possible because of the long working distance and fibre-like delivery of the laser beam. It can be used effectively with complex profiles and contours where normal access would be impeded or impossible.

What are the main markets for your technology?

Our technology has a diverse range of applications. For example, in the photovoltaics industry our systems are used for omnidirectional cutting, drilling, scribing, grooving, edge grinding and marking. The semiconductor industry uses our systems for applications including wafer dicing, via-hole drilling, isolating and edge grinding of thin wafers. It can also be used in the medical industry for making stents, in the watch industry for fine cutting and in the automotive industry for the production of fuel injection nozzles. There has definitely been a slowdown in capital expenditure in most industries, but our sales into the automotive industry have not been as badly affected as other materials processing technologies. This is because fuel injection nozzles need to be changed regularly on all cars, so there is still a demand for making them. Our systems can make the nozzles much faster than conventional electro-discharge machining, so even in tough times it makes economic sense to invest in new equipment. And in the semiconductor industry our systems are replacing the well-established diamond saw technology because ours can cut any shape — hexagon or circle — so our system has a clear advantage.

Synova's Alexandre Pauchard: "With our system, complex three-dimensional cutting is possible because of the long working distance and fibre-like delivery of the laser beam."

What laser technology do your systems use?

The wavelength of the laser we use is limited by the absorption characteristics of water. Water has a minimum in its absorption coefficient at 530 nm. By a happy coincidence this wavelength corresponds to that of frequency-doubled YAG lasers. At a working distance of 2.5 cm, water has a 0.1% absorption in the green area of the spectrum, so this region is ideal. For some applications we use the standard YAG wavelength of 1,064 nm, where absorption by water is about 40%, and this is still acceptable for most applications. The maximum average power we use at the moment is about 200 W. We would ideally want up to 500 W power from a green laser, but this just does not exist at the moment. We are investigating the use of disk lasers, which would increase the available power at the required pulse width and allow even faster processing. We have also started using shorter pulsed lasers (10-ns duration), but because the water cools the workpiece, there is no need to go shorter than this.

How about future development of the technology?

As well as using different laser sources, we are also looking at using different liquids, instead of water, to guide the laser beam. This allows a process we call laser chemical processing. Together with the Fraunhofer Institute for Solar Energy Systems in Freiburg, Germany, we are developing a technique for the selective doping of silicon solar cells. Using phosphoric acid instead of water, our system is able to perform local diffusion at high speed and accuracy without the need for masks or any high-temperature processes such as annealing. The laser melts the surface of the silicon; the phosphoric acid mixes with this molten material; and the doped silicon then recrystallizes. Research has shown that this process can produce high-efficiency silicon solar cells with up to 20.4% efficiency. Its industrial implementation is expected to greatly reduce the cost of manufacturing selective-emitter solar cells. This technology is now close to maturity and we hope to introduce it to the market by the end of the year.

INTERVIEW BY NADYA ANSCOMBE

Nadya Anscombe is a freelance science and technology journalist based in the United Kingdom.