INDUSTRIAL Laser Solutions FOR MANUFACTURING®

May : June 2012

Marking medical devices

Welding clear polymers

Surface polishing

Laser metal bending

Remote seat welding

Laser brazing

Cutting THE ROVER SEATS

WWW.INDUSTRIAL-LASERS.COM

PennWell®

COVER STORY p.2

Metal seat structures for the 2012 Land Rover Defender are laser cut by Cab Automotive Ltd. (Source: Cab Auto)

INDUSTRIAL Laser Solutions FOR MANUFACTURING®

MAY/JUNE 2012
VOLUME 27 : NUMBER 3

Features

Departments

PRINTED WITH SOY INK

industrial laser solutions Online!

MORE FEATURES, NEWS, AND PRODUCTS
@www.industrial-lasers.com

FEATURED ARTICLES

Laser drilling long distances for energy applications

ILS EXCLUSIVE: Foro Energy develops hardware to deliver up to 20kW of fiber laser power through a multi-kilometer fiber for energy drilling applications

BY MARK ZEDIKER, BRIAN FAIRCLOTH, AND JOEL MOXLEY

Coordinating laser systems controllers for ultraprecise applications

A new approach synchronizes servo and galvo controllers in laser positioning systems used for high-speed marking, engraving, and micromachining.

BY SCOTT SCHMIDT

DABbling

A blog by DAVID A. BELFORTE

David shares his insights and opinions on current activities affecting industrial laser materials processing.
www.industrial-lasers.com/blogs/dabbling/index.html

update

Cutting seats for LAND ROVER

TIPTON, WEST MIDLANDS, UK – CAB Automotive is a privately owned Tier 1 supplier of interior trim parts to the automotive industry, with capabilities including product engineering, development, manufacturing, and assembly of automotive headliners, interior trim, parcel trays, seating and trunk trim, and rail seating solutions for mass transit carriage, railcar, and coach. CabAuto manufactures components such as the parcel shelf for the Jaguar XF; molded carpets and headliners for Aston Martin; and seating, headliners, and bespoke storage solutions for the Land Rover Defender.

The company previously subcontracted out its entire laser cutting operations, but decided that commercial factors made it favorable to move this work in-house. It chose a Bystronic laser from World Machinery and Lantek Expert CADCAM to nest the parts and create the CNC programs. With the Bystronic laser cutting system, CabAuto can now do all its laser cutting in-house.

The principal project for which the laser system is used is making seating components for the Land Rover Defender, making 10,000–15,000 parts each week, with material ranging from 1–8 mm thickness, in steel, aluminum, and Hypress steel, explained manufacturing engineer Lee Macdonald. "Once the components have been cut, the parts are formed, welded and assembled, to make the seat frames. Due to the fast-moving and cost-sensitive nature of our business, we need to achieve rapid and reliable CNC programming and high levels of material utilization," he said.

The Lantek software allows both automatic and manual nesting, and its parallel processing technology gives speed improvements of at least 30%. During nesting, the system considers material type and thickness and can manage kits of parts — nesting parts within one another if possible — and manage the reuse of offcuts through a database to optimize material utilization. Features in the software can save both material and time by reducing wasted moves on the laser, increasing the number of parts in a sheet, and speeding up the handling of components once they have been cut.

From its 110,000 ft.^{2} facility, CAB Automotive turns over in the region of £24 million and is a major employer in the area. It is accredited to ISO/TS16949 and ISO 14001, and operates fully in accordance with established automotive procedures. The company maintains a well-equipped on-site laboratory alongside extensive CMM facilities and a modern BSR testing rig. Capabilities include product engineering, development, manufacturing, and assembly of automotive headliners, interior trim, parcel trays, seating and trunk trim. The firm also does rail seating solutions for mass transit carriage, railcar, and coach.

CabAuto's performance as a world-class interior component manufacturer is built upon a recognizable culture of quality driven by a passion for innovation, durability, and refined comfort.

Standing the heat: Laser processing alumina

RUGBY, UK – Alumina ceramic (Al_2O_3) is used to manufacture many items, including medical prostheses, ballistic armor, laser tubes, and circuit boards. Its popularity is due to its strength, durability, corrosion resistance, thermal stability, and excellent dielectric properties. These characteristics also make Al_2O_3 difficult to process — while strong in compression, the material is prone to cracking from thermal stress, and traditional techniques such as diamond grinding can be costly and time-consuming.

Rapid technological advances mean it is now possible to use Nd:YAG and fiber lasers to achieve a high standard of finish, providing the necessary levels of control using variable parameters such as spot size, peak power, pulse duration, and frequency.

Optimized laser and processing parameters help minimize heat input, significantly reducing the risk of thermal stress, which can lead to cracking. Large

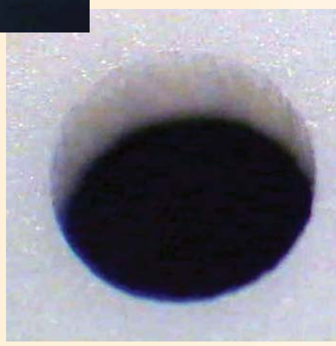


FIGURE 1. (top) 1 mm alumina ceramic (96%), 300 mm/min, air assist gas; (bottom) Trepanned hole (0.5 mm dia.), 0.6 mm alumina ceramic (99.7%), 200 mm/min, air assist gas.

update continued from page 5

scattering of the laser beam, which can be seen at some common wavelengths, can be overcome through a combination of high peak power, short pulses, and short wavelengths (1 μm).

For example, JK Lasers' single-mode 200 W fiber laser (JK200FL) with built-in modulation can achieve good quality cuts in Al_2O_3 up to 1 mm thick (**FIGURE 1**). It is possible to achieve pulse widths as short as 5 μs by gating at a high frequency (50 kHz); depending on the purity of the alumina, this can provide dramatic improvements to process quality.

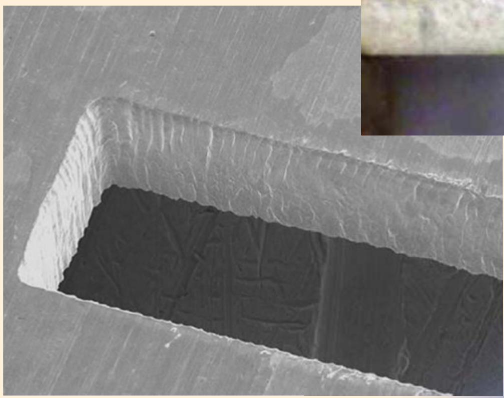


FIGURE 2. (top) 1.2 mm alumina ceramic (96%), 250 mm/min, air assist gas; (bottom) 0.5 mm alumina ceramic (99.7%), 650 mm/min, air assist.

FIGURE 2 shows examples of edges that have been cut with a lamp-pumped pulsed Nd:YAG laser (JK100P). The combination of high peak power (10 kW), short pulses (15-200 μs) and high repetition rate (2000Hz) make this laser well-suited to cutting Al_2O_3 up to 2 mm thick. It is possible to cut up to 3 mm with multi-passing.

The results demonstrate that both fiber lasers and lamp-pumped pulsed Nd:YAG lasers can machine Al_2O_3 between 96%–99.7% purity. With no evidence of micro-cracking or dross along the cut edge, these lasers offer manufacturers a viable alternative to traditional processing techniques.

For more information, visit www.jklasers.com.

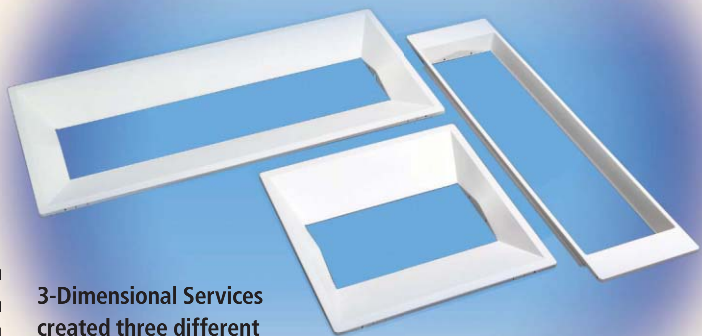
Fast prototyping brings lighting products to market quickly

ROCHESTER HILLS, MI — A lighting manufacturer set itself the task of leading what it calls "the LED lighting revolution," aimed at making traditional energy-intensive lighting technologies obsolete with a line of LED architectural lighting products that allow optimal distribution of light with minimal power consumption, incorporating breakthroughs in optical, electronic, and mechanical design as well as thermal management. A growing number of companies are seeking to establish themselves as players in this young market, so this company knew it had to quickly get its new lighting product to market.

Essential to that aim was getting the required prototype parts, and that help came from 3-Dimensional Services. The firm specializes in design, engineering and analysis, in-house tool construction, and complete build of prototype first-off parts and low- to medium-volume production runs, which enables them to provide actual prototype parts up to 70% faster than conventionally equipped prototype shops.

While the company created the lighting modules for the new product line, 3-Dimensional Services was tasked with creating the metal fixtures that would house them. Low-carbon steel blanks were laser cut to near-finish dimensions on one of their 5-axis lasers.

Three different sizes of fixtures were needed, the largest of which measured 2 x 4 feet, which required three different forming tools. Three 3-piece forming tools consisting of punch, die, and draw ring were designed. Machining programs were generated from these designs and offloaded to the company's CNC machines, and developed from the resulting designs. The parts were cut from aluminum rather than from tool steel, because the softer metal could be machined faster, very accurately, and to a high-quality finish — for the parts' intended environments, they needed to have a Class A finish, with no wrinkles, nicks, or flaws.



3-Dimensional Services created three different tools along with three additional tools for bending operations, plus other processes, to produce the LED light fixtures.

Next came forming on three of 3-D's numerous presses, from 20 to 75 for each of the three sizes, which were taken back to a 5-axis laser for final trimming. The parts were then transferred back to the hydraulic presses for secondary bending operations, in which some of the trimmed edges were flanged or hemmed — this required three bending tools (one for each part size), created using the same technology and with the same speed as the three original forming tools. The parts underwent final checks, then were powder coated and shipped. All of this was accomplished within the 3-4 week timeframe the customer had specified.

3-Dimensional Services Group consists of 3-Dimensional Services, Urgent Plastic Services, and Urgent Design & Manufacturing. Together they design, engineer and build functional prototype parts and low- to medium-volume production parts faster than conventional prototype shops. For more information, contact the company at www.3dimensional.com.

technology report

Remote laser welding

THE CAPABILITIES OF REMOTE OPTICS MUST BE WEIGHED AGAINST PRODUCT DESIGN RESTRICTIONS

GEERT VERHAEGHE

The key drivers for automotive seat production are lightweight and low-cost structures on a global vehicle platform. The requirement for reduced CO_2 emissions through weight reductions is driving the need for joining thinner and higher-strength steels and/or multi-material structures. However, the most competitive low-cost structure can only be achieved by adopting a modular manufacturing approach that can be tailored to a customer's individual needs. To achieve these competing requirements, conventional processes such as spot and arc welding are being pushed to the limits, and in some cases have already reached their full potential. Even for a relatively young process such as laser welding, the pressure is on to reproducibly deliver quality at ever higher productivity. This is the reason Faurecia continuously investigates how laser technology can be used in a smarter way — and why a major shift took place recently to produce work pieces with remote laser welding (instead of using the conventional fixed optics), which offers flexibility and productivity in an environment where thinner and increasingly higher strength steels are part of the seat structure design.

Faurecia Automotive Structures (FAS) is part of global Tier 1 supplier Faurecia, which manufactures seat structures, vehicle interiors, exhaust systems, and front-end structures for the world's key OEMs. In terms of seat structures, a distinction is made between the front seat structures (FSS), as shown in **FIGURE 1**, and rear seat structures (RSS), which can either be individual seats or, for most medium-class vehicles, a seat bench structure, as shown in **FIGURE 2**. The RSS can be a single part or divided in segments (60-40 or 40-20-40). Regardless of their make-up, RSS have a very different design compared to FSS, which is determined by the vehicle's dynamic performance requirements. In general, RSS comprise thin-sheet panels welded onto a strong substructure, whereas FSS comprise a backrest frame attached to a cushion structure by the recliner, and mounted on tracks attached to the car body for forward-backward movement.

Historically, FAS has been involved with laser materials processing since 1999 with the very first welding of recliner parts using CO_2 lasers. In the following

for automotive seat production

years, the number of applications grew steadil, until FAS first used CO and lamp-pumped Nd:YAG lasers for FSS backrest structures and tracks. Between 2003 and 2006, a revolution took place in the laser world with the advent of both fiber and disc lasers. In 2008, FAS reviewed its position and adopted a completely different mindset in its joining technology. Where in the past, metal arc gas (MAG) and resistance spot welding (RSW) were conventionally used for seat structures, remote laser welding was being pushed to the foreground as the preferred solution to weld different modules of a seat structure, offering flexibility in producing the required product performance, using a variety of material grades and thickness at a high productivity rate, and thus minimum cost.

With this mindset change also came a big step in terms of laser materials processing, with remote laser processing replacing fixed optic welding due to the process' flexibility and productivity advantages. Now, a standard remote laser processing system at FAS is comprised of a 6kW Trumpf TruDisk laser, a 200 μm processing fiber, and a 450 mm focal length PFOscanning optic. (PFO stands for Programmable Focusing Optic, which is the Trumpf trade name for its remote processing scanning optics.) The PFO is mounted on a six-axis articulated robot arm from ABB used in two processing areas arranged in an L-shape configuration, as shown in **FIGURE 3**. The changeover to remote laser processing and the chosen cell configuration insures maximum equipment usage and improved quality at a lower cost, while offering a flexible production line capable of meeting the customers' needs.

For a RSS, the use of remote laser welding is obvious: a large number of short (stitch) welds all positioned in the same plane is shown in **FIGURE 4**. The welds are made in an overlap configuration, joining a thin-sheet back panel, typically between 0.6–0.8 mm in thickness, to a subassembly that comprises mostly thin (typically between 0.8–1.5 mm in thickness) pressed sheet parts.

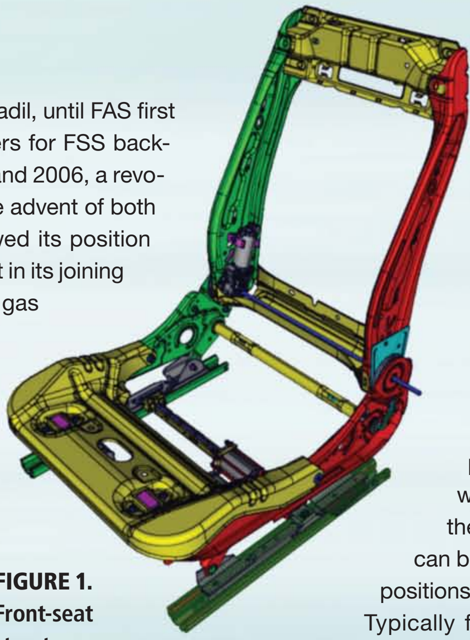
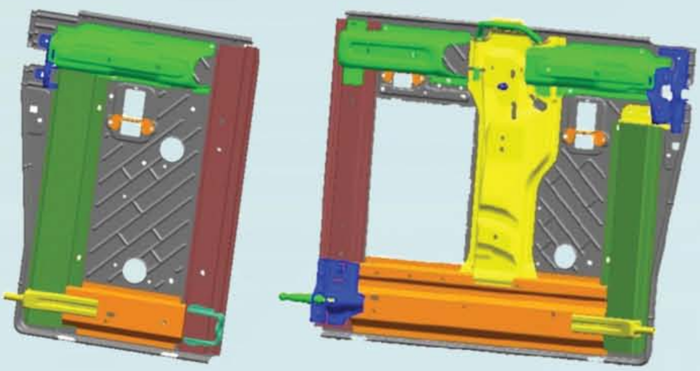


FIGURE 1. Front-seat structures.

The substructure is designed to give the RSS its required mechanical performance, e.g., stiffness and luggage impact. As all the welds are in the same plane, a 2D remote processing optic can be used. The main challenge for this application is in the design of the clamping arrangement, which must provide a minimum joint gap between the overlapping sheets to guarantee a consistent weld quality, and sufficient access for the laser beam so that the entire RSS can be welded with a minimum number of positions of the scanning optic.

Typically for a FSS (**FIGURE 1**), 30 welds are needed to weld the backrest subassembly to the recliner mechanism. Currently, laser welding is not used at FAS to manufacture any of the cushion assemblies. The welds that constitute the backrest structure (including recliner) are positioned in many different planes, which allows the use of a 3D scanning optic. For a given backrest structure (including recliner), the challenge remains the programming of all welds with a minimum repositioning of the scanning optic. The use of an external positioning axis can thereby assist. The RSS assembly is mostly

FIGURE 2. Rear-seat structures.



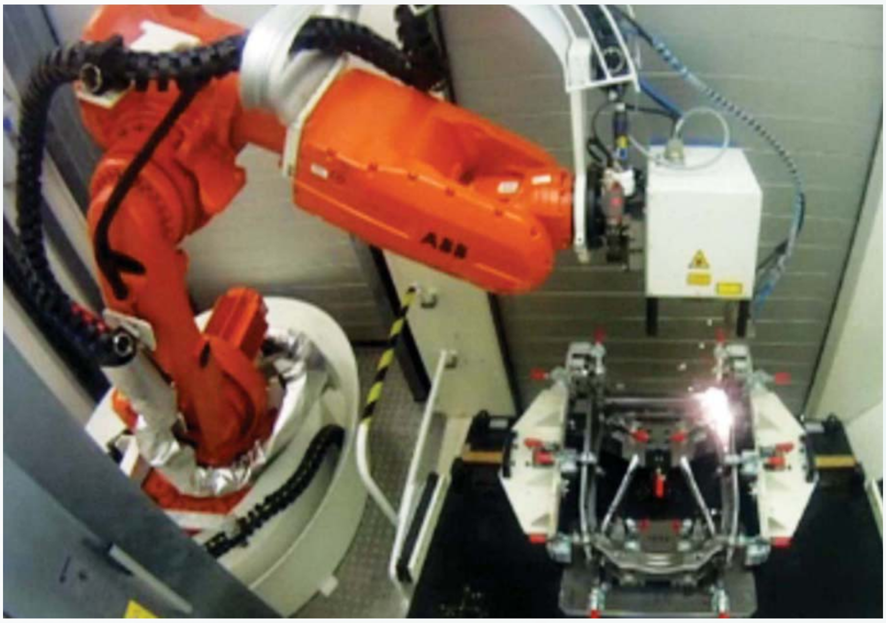


FIGURE 3. Remote laser welding of FSS.

Today, steel is still the preferred material of choice for seat structures — this means from a processing point of view, no shielding gas is needed locally to prevent the weld region from oxidation. However, the use of a high beam quality solid-state laser results in amounts of plume and/or plasma just above the processing point, which creates a thermally affected region extending far above the processing point. As this impedes the efficient transfer of energy into the material, FAS is carrying out extensive studies to create the optimum processing conditions using air suppression mechanisms tailored to its specific seat structures and their clamping arrangement, and thereby to guarantee productivity and a consistent weld quality.

comprised of short stitch welds on two overlapped sheets. However, for joining the recliners (FIGURE 5) to the backrest structure, non-linear welds are the preferred choice, often a full circle, with the precise length and non-linear geometry determined by the service performance. It is noteworthy that this frame-recliner area in particular takes most of the load on impact. For these joints, both overlap and butt joint configurations can be used, with the choice determined by the specific seat design. In the case of a butt joint geometry, the geometrical tolerances of the part design and the laser system positional accuracy need to be perfectly matched to insure the correct beam-to-joint alignment and therefore the weld quality.

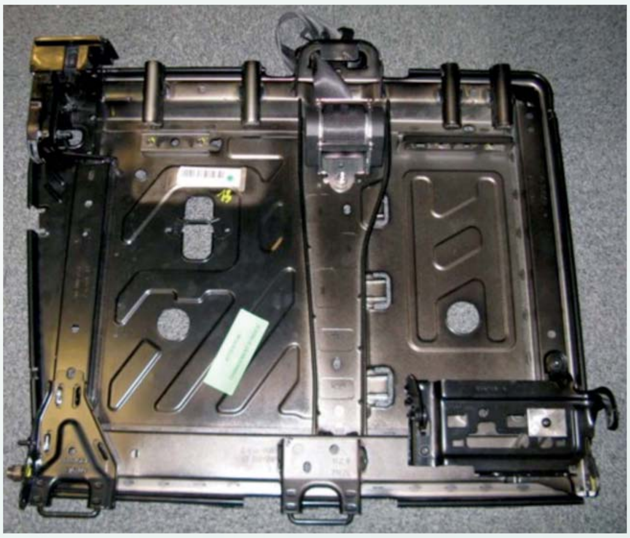


FIGURE 4. Rear seat structure with weld close up.

FIGURE 5. Laser-welded recliner and bracket.

When using remote scanning optics for automotive seat structures, it is important to fully understand the capabilities of the scanning optic, from its positional repeatability to the beam characteristics over the full three-dimensional working range. The latter is especially important to assure a given weld aspect ratio and weld quality over a complete seat structure. In high-volume automotive seat production, with 1000 frames produced per day, the impact of

fume build-up inside the laser processing cell needs attention. This is not something laser system suppliers or system integrators have a great deal of experience with, so in-house investigations are essential to assure, for a given product and clamping arrangement, an adequate cell extraction in combination with the aforementioned air suppression mechanisms.

Faurecia takes prides in delivering quality products to its clients. From a laser welding point of view, this means mastering the process to assure a consistently high laser weld quality. This has led to in-house standardization, not only of the cell configuration and operation, but on many

About Faurecia

Faurecia (www.faurecia.com), an automotive supplier with locations in 33 countries, works in partnership with the world's largest automakers. In 2011, the Group posted sales of €16.2 billion and is listed on the NYSE Euronext Paris stock exchange.

Faurecia holds a leading position in each of its core businesses: automotive seating, emissions control technologies, interior systems (instrument panels, door panels and modules, acoustic solutions, etc.), and automotive exteriors.

With 84,000 employees, 40 research & development centers and 270 production plants, Faurecia supports automakers around the world, helping develop a safer, more comfortable, and more environmentally friendly car of tomorrow.

other levels, including:

Process knowledge: In addition to the training offered by suppliers, Faurecia has developed its own training course to transfer knowledge on laser materials processing from the central advanced manufacturing engineering teams to the application teams and the plants where laser systems are or will be used.

Laser system acceptance: As each scanning optic is unique, Faurecia has developed its own procedure to characterize it and compare it against a Faurecia norm, to assure that the right quality is achieved for every weld in a complete seat structure.

Welding procedure: For each material grade and thickness combination used in its seat structures, Faurecia has developed weldability trials on coupon, substructure, and structure levels to guarantee the product's required performance.

Welding acceptance criteria: Faurecia has developed welding acceptance criteria for frames, tracks, and recliners, defining the level of weld imperfections that can be tolerated for the individual products.

Process assessment procedure: This in-house procedure guides new program applications and plants through the necessary steps that are needed to implement laser welding technology onto the shop floor.

Since 2008, Faurecia's vision in terms of remote laser welding of seat structures has become a reality. The possibilities offered by this process are truly impressive. Nevertheless, further development work is ongoing within Faurecia's seating division to advance this technology to the limits. For example, with the remote processing optics, any weld shape can easily be produced, facilitating fitness-for-purpose welding by tailoring the shape of the weld to the required local mechanical performance. And, for the larger rear seat structures, the use of welding-on-the-fly with remote processing optics can further drive down the cycle time. However, this process, as with any other technology, is not one-size-fits-all, and the advantages and capabilities of remote optics need to be weighed against the restrictions of product design, which calls for a close collaboration between design engineers and process engineers.

And there remains work to be done by the suppliers, too. For instance, there is still variability in the beam characteristics over the optic's full operating envelope. Although considered minimal from an optical point of view, these can affect the weld geometry and quality within the working range. And, to assist in the quality assurance for high-volume seat production, there is a strong need for more and robust solutions in terms of process monitoring.

DR. ING. GEERT VERHAEGHE *(geert.verhaeghe@faurecia.com) is master welding expert at Faurecia, based in Faurecia Autositze GmbH, Stadthagen, Germany.*

application report

A new method of laser surface modification

COMPLEX SURFACE FEATURES IN METALLIC MATERIALS MADE WITH A LOW-POWER BEAM PROCESS

PAUL HILTON AND JONATHAN BLACKBURN

This article relates to a new power beam process that enables controlled surface features to be produced on a range of substrates such as metals, polymers, and ceramics. In application, a rapidly scanned power beam melts material. The molten material subsequently moves, in part, due to the surface tension generated by a temperature gradient created across its surface. Note that no material, for example wire or powder, is added; the process is entirely autogenous in nature. How the material moves, and ultimately the shape of the features produced, can be determined by precisely controlling the beam path and its speed over the surface. The process can manufacture features that may be identical or different. In particular, the scale of surface features available offers performance benefits for a number of applications, including orthopedic implants, composite to metal joining, heat exchangers and aiding in the application of ultra-thick coatings.

A key characteristic of the process is that the beam makes multiple returns to the same point and multiple swipes to sequentially build individual surface features. These characteristics differentiate it from conventional surface texturing processes. Both electron beam and laser beams can be used to produce features by this method, which has been trademark-registered as Surfi-Sculpt. This article will discuss the laser variant, in which optical power is used to melt and displace material, thereby creating the surface feature.

To perform this work, two recent developments in laser materials processing are utilized. High-brightness lasers have the advantage that their beams can be focused to small spots of high power density, while still using a beam focusing lens of long focal length. This large distance between the focusing lens and the focused spot is needed because the rapid manipulation of the laser beam required for the Surfi-Sculpt process is achieved by orthogonally mounted and galvanometer driven beam scanning mirrors. Recent developments in this latter field have produced a new generation of laser beam scanning systems capable of operating with kilowatts of laser beam power. In the work described here, both disc and fiber lasers have been used at relatively modest laser powers of between 200–1000 W, in conjunction with two different laser beam scanning systems. **FIGURE 1** provides an initial indication of the type of features that can be produced using this technique.

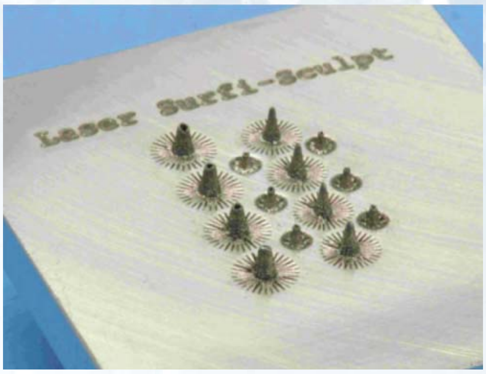


FIGURE 1. A range of conical features produced on titanium. The height of the tallest cone is about 3 mm.

FIGURE 2 shows a simple representation of how a linear feature is developed using this process and shows successive movement of a laser beam focused on the surface of the material. Note the direction of the beam's motion. Material melted by the beam on its first pass flows back along the beam path before it solidifies, producing a slight protrusion at the initial point of contact of the beam and a slight depression at the end of the beam "swipe". Provided the heat input to the process is correctly managed, then successive swipes of the beam magnify this

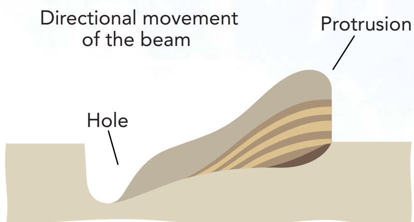


FIGURE 2. Creation of a linear surface feature.

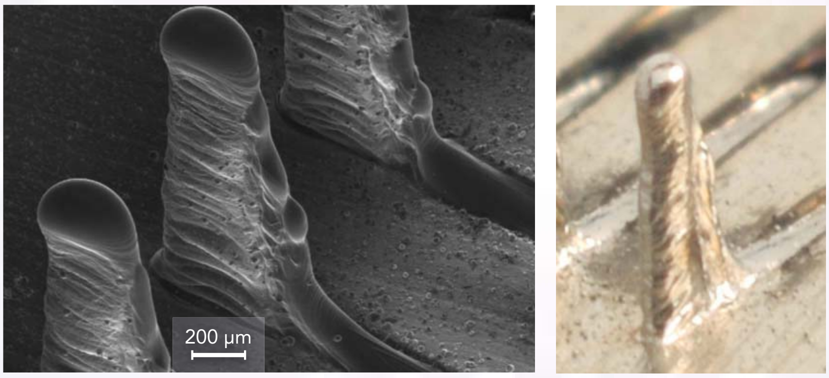


FIGURE 3. Left: SEM image of a series of linear surface features in titanium. Right: Photo of the same feature. Note the level of reproducibility in the features.

effect to the point where protrusions several mm in height can be formed.

FIGURE 3 shows an SEM image and photo of such a linear sculpted feature. Each feature was built up from 400 repetitions, one on top of the other, over a 4 mm swipe length. The laser beam scanning speed was 600 mm/sec. The SEM images, in particular, show clear evidence of cyclic movement and solidification of material. The features shown were made using a 200 W single mode fiber laser and a conventional laser marking scanner and software.

FIGURE 4. Features in 7000 series aluminum.

More complex shapes

Introducing more complexity to the scan pattern enables more complex shapes to be formed. In the initial series of experiments, patterns were limited by the sophistication of the scanning software packages, which were not written with this process in mind. However, several interesting possibilities were still possible, such as the cones shown in **FIGURE 1**. These were made by successively scanning the beam away from a central position, while rotating the swipe angle during the beam-off time. The fine features shown in **FIGURES 1** and **3** were produced with a laser spot size estimated to be about 40 μm in diameter using the single-mode fiber laser. It was also possible to produce similar effects using higher-power multi-mode fiber and disc lasers. All the features shown in **FIGURES 1** and **3** were made on titanium plate using argon shielding gas. The process works in a similar way on Inconel, C-Mn steel, 304 stainless steel and even 7000 series aluminum. However, for the same processing conditions and programmed scan path, each feature is slightly different. These differences are believed to be due to the physical properties of the different materials and how these relate to the physics of the process. Clearly, viscosity of the molten material, its surface tension, thermal conductivity, and reactivity to atmospheric oxygen will all play a part.

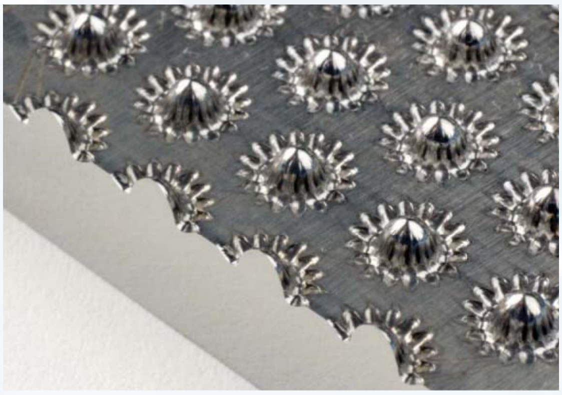


FIGURE 5. Features in titanium.

FIGURE 4 shows a series of protrusions produced on a 7000 series aluminum plate made in air. In this case, the laser power was 1 kW from a disc laser and the sweep speed of the beam was 26 mm/sec. The height of each feature is about 2.5 mm. For comparison, **FIGURE 5** shows features produced using a similar scan pattern on titanium plate (using an argon shield). This time, a laser power of 750 W was used, and 16 legs form the basis of the feature. The domes produced were again about 2.5 mm in height.

FIGURE 6 shows the construction of a "wall" feature in Inconel alloy using the 200 W single-mode fiber laser. In this case, the scan patterns all terminated at the same point. The feature height is about 2 mm. This type of scan pattern and others have been combined to produce the array of features shown in **FIGURE 7**.

The experimental work has shown that the process works best if the intervals between particular swipes in the feature are arranged so that the temperature distribution in the work piece is carefully managed. Without attention to this point, treatments may not produce high-aspect-ratio builds of any kind, or may give features that self-limit in height or even simply melt. Software packages available with current laser scanning systems cannot accommodate this capability easily, for the simple reason that they were never designed to do so. It is thus felt that to fully optimize the capability of this new process, some alterations to the existing software controlling the scanning laser beams will have to be made, if the process is to be implemented simply in an industrial context.

The work described here indicates that a wide variety of surface features can be reliably produced in a range of metallic materials using a relatively low-power laser beam. Furthermore, the cost of such a system, including a small fiber laser and a conventional laser marking scanner, is reasonably cheap.

Emerging applications

There are a number of emerging applications for fine-feature surface manufacture — for example, biomedical devices and implants, where the integration of implants into the body is highly dependent on the surface. Specific small-scale features are required to promote bone growth, for example, and these features are presently difficult and expensive to produce by other methods.

The process described here offers the benefits of being relatively fast, allowing close control of feature shape and ensuring surface features are firmly bonded so that they do not detach from the implant. In addition, from electronic devices to aircraft engines, currently available heat transfer surfaces and structures limit product performance. New and bespoke surface features are needed to provide additional freedom of design that will address the need to reduce size and weight and improve efficiency.

Thus, there is a demand for sophisticated, cost-effective, volume surface manipulation of heat-exchanging surfaces (e.g., fins) to increase the surface area for heat transfer, and introduce vortices into the airflow over the surface, both of which enhance micro-thermal management. More effective heat transfer would allow components to be reduced in size for a given thermal performance requirement, reducing material consumption.

In the area of lubricating surfaces and surface tribology, component design dictates the wear rate and time between servicing

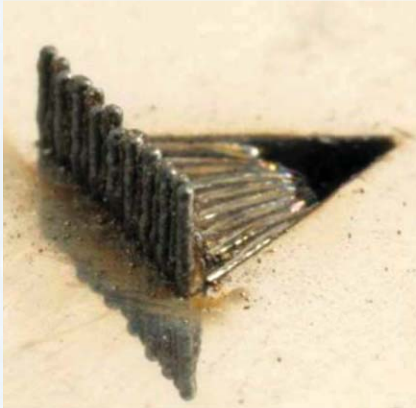


FIGURE 6. Wall feature made in titanium.

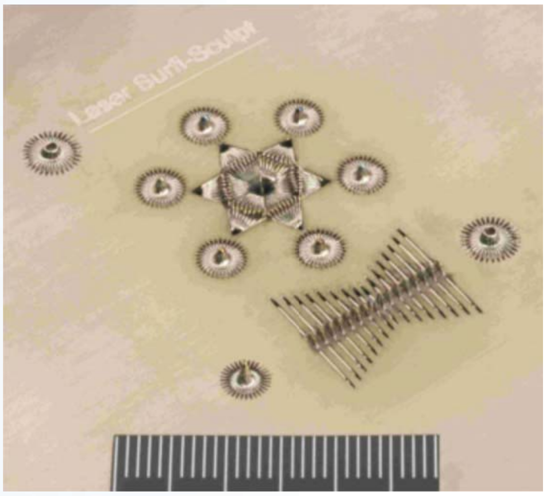


FIGURE 7. Array of features made in titanium.

of many products (e.g., bearings, mechanical seals, and vehicle engine parts). Designers require intelligently tailored bearing surfaces, leading to reduced friction and wear, oil and fuel consumption, and emissions. This is particularly relevant to the automotive and aircraft industries' drive to meet proposed European mandates, e.g. for NO_x, CO_2 and particulate emissions. Bearing performance is also relevant for many other sectors, including process plant, aerospace, and domestic products. Designed surface textures of micro-features are needed to serve as micro-hydrodynamic bearings in cases of full or mixed lubrication, micro-reservoirs for retention of lubricants, or micro-traps for wear debris in lubricated or dry sliding.

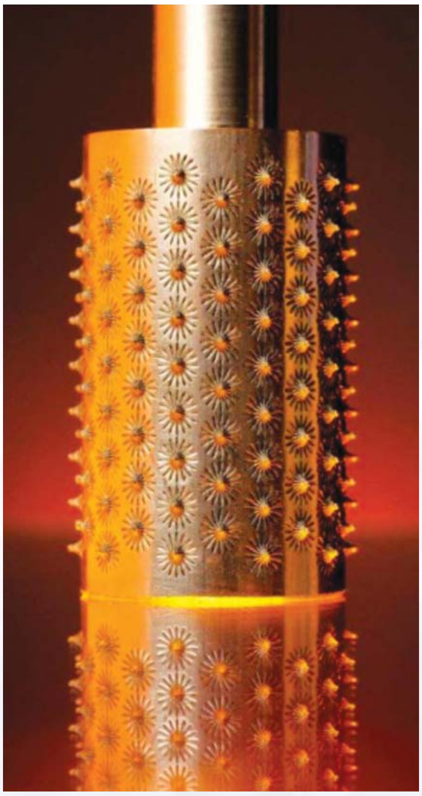


FIGURE 8. Approximately 250 features provide a perforating surface on this stainless steel cylinder.

Finally, the application and performance of thermal barrier coatings for high-temperature devices, deposited by current process technology (e.g., plasma spray or physical vapor deposition) is limited by the relatively low strength of the coating to substrate bond — the impact of thermal expansion mismatch at elevated temperature often causes premature component failure. Enhanced surface structures can be used to both grade coatings and provide enhanced mechanical locking to the surface, which would be beneficial in emerging power generation technologies such as biomass combustion waste incineration, where combustion products are particularly aggressive to structural materials.

The final image (**FIGURE 8**) shows a series of laser induced features on the side of a stainless steel cylinder having a diameter of approximately 30 mm. The cylinder can be rotated across a surface requiring perforation.

PAUL HILTON *and* **JONATHAN BLACKBURN** *are with TWI Ltd Great Abington, Cambridge, UK. For further information, contact paul.hilton@twi.co.uk or jon.blackburn@twi.co.uk.*

technology report

Touchless forge

LASER BENDING RESEARCH NEEDS TO BE ECONOMICAL AND PRECISE

JORGE RAMOS GREZ

The forging of metals has been an ongoing joining technology throughout the history of manufacturing. By 4000 BC, men were able to form and shape spears, knifes, and swords out of brass; later, thin sheets were turned into cooking utensils and similar articles. The application of heat together with pressure over the cast metal allowed it be morphed into the needed geometry — the basis of today's thermo-mechanical based processes.

Later on, iron and its alloys replaced copper-based alloys, becoming a strategic material even up to present times. However, regardless of the metal alloy type, the forging process still is widely used today in the different manufacturing methods that can be applied. Nowadays, most metals alloys can be found in either cast or wrought shape; the latter can be further produced under a cold or hot forge process. However, the wrought alloy, in the form of a sheet or plate, must then be further processed, e.g., severed, joined, or bent. In that regard, laser cutting and welding are well-established processes that add value to the wrought product. On the contrary, laser-based bending or forming processes (sometimes this latter term refers to net shaping as in laser cladding or 3D/additive manufacturing) are still a matter of numerous laboratory research, with little success on introducing them into the shop floor.

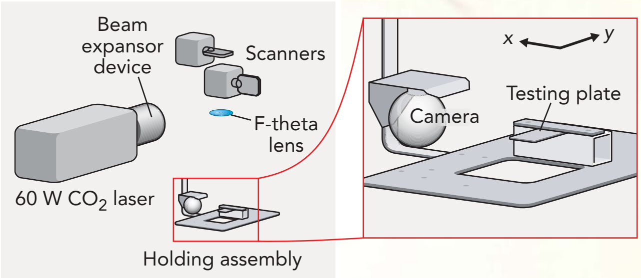


FIGURE 1. Experimental set-up.

Sheet bending is commonly done at cold or ambient temperature; it simply consists of a punch (a hardened metal tool) that is pressed against the wrought sheet, the latter typically resting on a die. However, depending on the thickness of the metal sheet, as for example naval industry parts, where hulls are made out of 3–5 in. thick steel plates, the required curvature is given by pressing on the surface of the latter, but assisted with localized heat to soften the metal and allow it to flow with ease (yield point reduction as well as stiffness decrease). Heat is normally applied in the form of an oxygen-acetylene torch, or in some cases, a plasma torch. The temperature of the flame will dictate how the temperature distributes on the sheet, causing — apart from softening of the material — the generation of permanent thermal stresses which, as expected, introduce strains to comply with the overall sought-out geometry.

In the naval industry application context, perhaps the first effort to seriously research laser bending took place during the late 1970s and early 1980s at Professor Masubuchi's[1] laboratory at the Massachusetts Institute of Technology's (MIT) Department of Ocean Engineering (today called the Department of Mechanical Engineering). The basic principle was to replace the flame or plasma torch by a controllable heat source such as that of an industrial CO_2 laser. The relative motion of the beam with respect to the sheet, as in cutting and welding, should create an intense thermal field on the surface, which under the right control should avoid causing melting of the latter. The thermal field would thus introduce thermal expansion that would in turn be constrained by the cold material away from the laser beam. This would cause the localized thermal expansion to be turned into a compression, and, if of the right magnitude, pass from the elastic into the plastic regime, thus causing a permanent shortening of the layers near the surface of the sheet. The need to comply with a given geometry would cause the sheet to commonly bend toward the laser beam, thus introducing a thermo-mechanical deflection toward an equilibrium angle. This angle was typically a fraction of a degree; therefore, to achieve large bending angles, the processes would need to be repeated several times, on the order of 20 to 40 times. Moreover, in between bend increments, the sheet should be allowed to cool down to room temperature so that the initial thermal conditions (e.g. room temperature) were kept. If this were not the case, then the possibility of reaching melting would be inevitable.

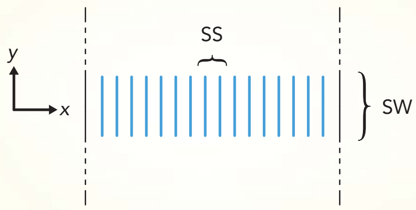


FIGURE 2. Step scanning parameters.

Research at MIT

The MIT research was focused on thick sheets using multi-kilowatt laser units. Concern was then put on the aspects of the CO_2 laser surface interaction, as this conditioned the amount of heat that could enter into the sheet. What was then noticed was the difficulty to achieve the exact same bending angle every time a sheet of the same material was treated using the same process parameters. By then it was known that the bending angle was directly proportional to the laser power and inversely proportional to the laser beam speed. The master thesis of Hsiao[2] considered intensive FEM simulation work on thick sheets. He was able to show that the effect of both power and velocity combined in a given parameter, such as P_{laser}/v_{laser}, would render different angle results for equal parameter values generated from different power and velocity numbers. Simultaneously, interest from Boeing Aircraft Company on superalloys formed this way was also embraced by this research group during the late 1990s.

Research at Erlangen

By the end of the 1980s, research emerged at Erlangen in Germany, where the work of Gieger and Vollersten[3] consolidated the basic theory of the two principal mechanisms, which seemed then to control the process, namely the temperature gradient mechanism (TGM) and the buckling mechanism (BM). Vollersten developed a simple, rather illuminating model of the TGM, which considered the material as a bimetallic sheet on which the laser was heating the upper layer. This upper layer underwent plastic compression according to the temperature increment on the sheet, which in turn was established by the laser's power, its relative speed, and the material's thermal properties. The equation is rather simple, thus convenient for engineering purposes, and it does not depend on the length of the sheet but rather on the inversely proportional thickness (t) of the sheet:

$$\Delta\theta = \frac{\eta P_{laser}\alpha}{\rho C_p v_{laser} t_{sheet}}$$

where $\Delta\theta$ is the bending angle increase after one laser scan (in radians), η is the laser material coupling efficiency, P is the laser power (W), α is the coefficient of thermal expansion (1/°Kelvin), ρ is the density of the material (kg/m^3); C_p is the heat capacity (joules/kg/°Kelvin), and v is the laser's relative speed (m/s). This expression only represents the bending angle increase after one complete laser scan, starting on one edge of the flat sheet and ending on the opposite one, always starting at room temperature.

The buckling mechanism, on the other hand, is more cumbersome. It is based on the fact that the plastic compression can be of such magnitude and cover the whole depth of the sample so that an elasto-plastic instability may occur (unstable permanent bending of the sheet) in either direction, away or toward the laser beam.

FIGURE 3. Bending angle and curvature of the process.

Research at Liverpool

During the mid-1990s, research also moved to the UK at Bill Steen's laboratory in Liverpool. Research was sponsored by British Aerospace in an attempt to introduce the technology into the manufacture of certain aircraft components which needed bending in very difficult to reach areas. This research conducted by Dr. Magee[4] was focused on aerospace material such as Al 2024 T6 Alclad and Ti 64Al4V. The integrity of the sheets was an issue at that time, as the heat treatment commonly done on this aerospace alloy could in certain cases be destroyed, affecting the mechanical properties afterwards. Attempts in this laboratory were also focused on multiple scan passes of the laser beam to produce concave-convex objects.

The future of laser bending

The future of laser bending lies in the capability of modulating the laser energy in space, either with fast-moving galvo mirrors or some form of photomasking technique, to rapidly deploy the required input energy at several locations over the sheet and thus be able to achieve complex curved shapes. **FIGURE 1** shows the setup used by the author's research team: a low-power, 60 W tightly focused CO_2 laser has been used to bend thin SAE 302 SS sheets using a raster scanned (actuated by Cambridge Technologies' galvos) pattern.[5, 6] This laser pattern is characterized by two parameters: the scanning step (SS) and the scanning width (SW), as seen in **FIGURE 2**. This process allowed not only the bending angle, but a curvature as well, as observed in **FIGURE 3**. In **FIGURE 4** it can be seen how the bending angle increased for every scan iteration, as a function of the scan width given by the laser pattern. Currently, control of this process is still a challenge for this research group as is modeling,[7] as it requires intensive numerical simulation based on inverse thermal problems that can estimate what distribution of heat must be applied to obtain specific deformation in space and time. This would certainly have the advantage of replacing in part the hard tooling required today to manufacture complex metal parts. The latter is known to be economical only for large series (in the thousands of parts), but for short series (only hundreds) laser bending could definitely be an alternative.

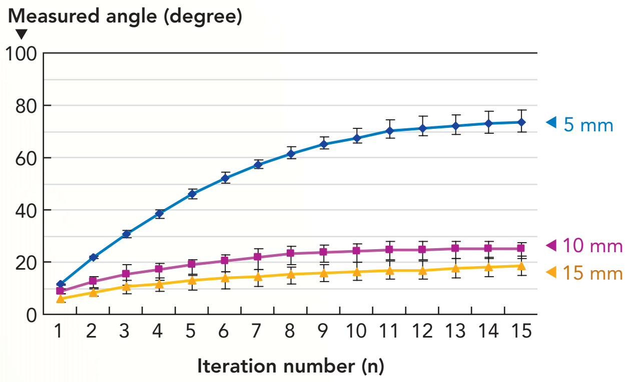


FIGURE 4. Measured angle, SS = 0.5 mm., STS = 7.5 mm/s for three different scan widths.

Conclusion

The challenge offered by laser bending in the years to come is indeed motivating, and will certainly keep several research groups throughout the world busy trying to find economical venues to control the process and achieve sophisticated and precise forging results without physically touching the material.

References

1. Masubuchi et al., "Phase I Report: Laser forming of steel plates for ship construction," submitted from MIT to Todd Pacific Shipyard Corporation, Feb. 1985.
2. Hsiao, "Finite Element Analysis of Laser Forming," MIT Masters thesis, Department of Ocean Engineering and Department of Mechanical Engineering, 1997.
3. M. Gieger, F. Vollertsen,, 1993," The mechanism of laser forming," Ann. CIRP 42 (1), 301–304, 1993.
4. Jorge A. Ramos, J. Magee, K.G. Watkins, "Microstructure and microhardness study of laser bent Al-2024-T3," Journal of Laser Applications, 13(1), 32–40, 2001.
5. Carlos Vásquez-Ojeda, Jorge Ramos-Grez, "Laser bending of thin metal sheet plate using a low output power laser based scanning system," Proc. of the 2nd International Conference of New Forming Technologies, Bremen, Germany, 2007.
6. C. Vásquez-Ojeda, J. Ramos-Grez, "Bending of stainless steel thin sheets by a raster scanned low power CO2 laser," Journal of Materials Processing Technology, March, 2009, 5, 2641–2647.
7. V Stevens, D Celentano, J Ramos-Grez and M Walczak "Experimental and numerical analysis of low output power laser bending of thin steel sheets," ASME Journal of Manufacturing Science and Engineering (2011) DOI: 10.1115/1.4005807

JORGE RAMOS-GREZ *(jramos@ing.puc.cl) is associate professor at the department of mechanical and metallurgical engineering at PUC Chile in Santiago. He is the head of the department, director, and founder of LATIL UC (www.latiluc.blogspot.com).*

Industrial Laser Solutions for Manufacturing | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

application report

FIBER LASERS boost m

MEETING MATERIAL PROCESSING REQUIREMENTS FOR NEXT-GENERATION BIOCOMPATIBLE COMPONENTS

ROLAND MAYERHOFER, DIETER MAIRHOERMANN, AND MICHAEL MUELLER

For decades, lasers have been a well-established tool in the development and production of medical devices. Here, in parallel with other industrial application areas, fiber lasers are now gaining a significantly increased market share. For minimally invasive surgery and miniaturized implants, most of the next-generation products are getting smaller, requiring extremely material-sensitive processing — and laser technology is the ideal solution to meet upcoming requirements.

Most of the welding, cutting, engraving, or marking processes shown in **FIGURE 1** are potential areas for the use of fiber laser concepts. There are three different types of fiber laser concepts applied in the development and production of medical devices: continuous wave (CW) modulated, pulsed/q-switched, and MOPA (master-oscillator-power-amplifier) configurations.

Fine laser welding

Lasers create high-strength and helium-tight welds in metals, glass, and polymers, where the laser welded joints can be used for high-temperature sterilization that exhibit pore-free surfaces without secondary finishing operations processes — crucial requirements for biocompatible components. Excellent laser beam quality, high pulse-to-pulse stability, and flexible pulse shaping are the preconditions for the finest seam and spot welding of biocompatible alloys.

For years, these requirements have been successfully accomplished with flash lamp-pumped Nd:YAG lasers. Now, fiber lasers are beginning to take over specific applications. Until recently, the lower-pulse peak power of fiber lasers has been a drawback in certain welding applications; CW fiber lasers were mainly used when applications required high throughput, narrow seam width, deep penetration, or CW operation due to metallurgical reasons. Pulsed Nd:YAG lasers offered benefits when applications called for low to medium throughput (especially for manual welding systems), spot sizes exceeding 0.1 mm (to bridge larger joint gaps), or when high-reflective materials have to be processed (requiring high peak power).

CW (modulated) fiber lasers must be focused down to very small spot sizes to achieve sufficient power density for generating a deep keyhole-shaped weld. This requires a very tight part fit (almost zero gap tolerance), with beam positioning more precise than is usually necessary in welding operations. To overcome this issue, the weld pool size must be enlarged while maintaining sufficient power density. A flexible way is to oscillate or wobble the laser beam with galvo- or piezo-driven mirrors at a speed of several milliseconds.

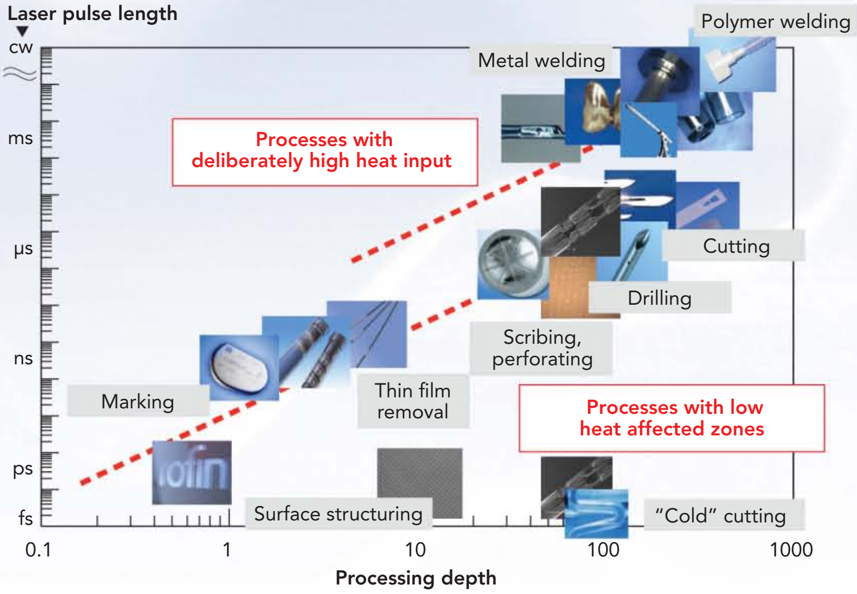


FIGURE 1. Classification of laser applications in medical device manufacturing according to a typical pulse duration used.

With the development of pulsed fiber lasers that produce several hundreds of watts average power and offer millisecond pulses, with a peak power of up to 10 times the average power level, it is now possible to achieve welding results similar to pulsed Nd:YAG lasers. The fiber laser offers

edical device production

higher wall-plug efficiency, easier integration into workstations, and highly flexible pulse shaping. These fiber lasers have the potential to substitute for flash-lamp-pumped solid-state lasers, even if the initial investment costs are currently still higher.

As shown in **FIGURE 2**, the most common laser application areas in manufacturing medical devices and instruments comprise welding operations are:

- Endoscopes
- Surgical instruments (knives and probing devices)
- Pacemaker housings and leads
- Wire stents
- Stent marker
- Vascular clamps
- Dental implants

FIGURE 2. Typical processing results on typical medical devices: pacemaker (top left), welded wire stent (top right), endoscope flange weld (center right), stent marker weld (bottom left), and sealing of glass tracers (bottom right).

Fine laser cutting

Laser fusion cutting, where an inert gas is used to expel molten metal from the cut area, is applied when flat or tubular shaped base materials must be cut into shapes to create medical devices with the least amount of post-processing. For decades, lamp-pumped Nd:YAG lasers with microsecond-pulse durations were used for these material processing operations. Fiber lasers are now taking market share from conventional solid-state lasers, offering the benefits of easier system integration, lower operating consumption costs, and better beam quality.

Most of the cutting applications for medical devices are in the thickness range of 0.2–1.0 mm. Because the cut geometries for medical devices are typically complex, fiber lasers used in medical device manufacturing are operated often in a modulated pulse regime. The peak power level must be significantly above CW level to reduce residual heat affects through more efficient material removal, especially in thicker cross-sections.

Fiber laser fusion-cutting operations are used during the manufacturing process of many different medical products:

- Surgical instruments (scull drills, knives, hip milling devices, bone saws)
- Cartridges (insulin dispensers)
- Needles
- Implants (stents, bone connectors)

The most well-known application is the production of coronary stents (**FIGURE 3**), made from different materials such as stainless steel, CoCr, or NiTi-shape memory alloys, where fiber lasers have been substituted for other solid-state lasers. Using high-peak-power, CW-modulated fiber lasers such as that shown in **FIGURE 4** can cut Nitinol (NiTi50) up to a thickness of 1.0 mm with excellent quality and cutting speeds of up to 20 mm/s.[1]

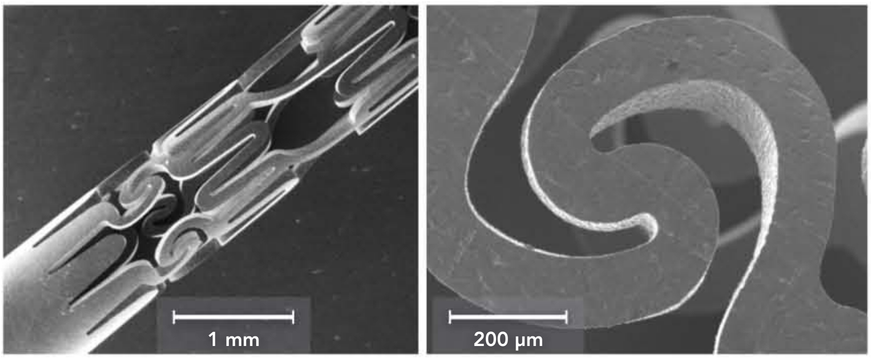


FIGURE 3. SEM pictures of laser-cut stents.

Still, the as-cut quality of fusion laser-cut components is not quite suitable for direct implantation into the human body, so edges have to be rounded off and any melt deposit removed. On stainless steel and CoCr tube materials, the slag and dross removal on the inner tube walls can easily be removed by ultrasonic means. However, it is much more time consuming to remove unwanted melt deposition in medical implants made from NiTi-shape memory alloys where a high degree of manual work is involved, often leading to unacceptably high yield losses. More filigreed parts, for example neuronal stents with outer tube diameter below 200 µm, cannot be mechanically post-processed at all.

FIGURE 4. Laser cutting of stents using ROFIN workstation StarCutTube.

Laser "cold" cutting

The only chance to avoid the generation of large melt pools during the laser cutting process is by the use of ultrashort pulses delivered by a new type of fiber laser concept.[2] Using pulse widths below 10 picoseconds (ps), material processing can be achieved with reduced heat affected zones and melt generation. Because of the low single-pulse removal rates of ultra-short pulses, economic cutting speeds of 1-10 mm/s are only possible when compensated by high pulse repetition rates in the range of 100-1000 kHz, leading to a very high degree of pulse overlap, typically 99.95%. A distribution of the pulse energy by fast scanning cannot be applied with that cutting application. A side effect of high degrees of pulse overlap is that heat can accumulate easily, and even pulses in the picosecond range can lead to unwanted distortion of the medical device. To produce medical micro-implants free of distortion, the pulse duration has to be further reduced by a factor of 10; this is accomplished through decreased thermal penetration depth of shorter pulses, and higher effectivity of the material removal process to minimize heat-affected zones.

Results of tube cutting trials with varied laser pulse durations indicate that cutting speed can be doubled when pulse widths of below 1 ps are applied.[2] This leads to less heat input into the base

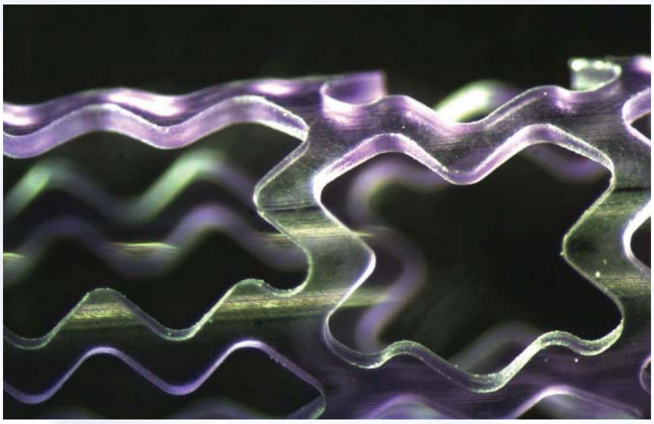


FIGURE 5. PLGA-demonstrator micro part of 250 μm wall thickness, cut by ROFIN StarFemto laser with minimum heat affection.

material and it is obvious that it is more beneficial to use 500-800 femtosecond (fs) pulses for cutting applications with high pulse overlaps instead of typical laser pulses of 6-10 ps.

Even more obvious is the demand for ultrashort-pulsed lasers, when the next generation of medical implants is eventually approved for surgical implantation. Development departments at the large medical device companies are working on bio-absorbable materials, meant to dissolve after implantation within the human body to avoid the risk of re-clogging (stenosis) of vessels. The hot-test candidates for such polymer materials are derivatives of poly-lactic and polyglycolic acids (PLGA), with melting temperatures in the range of 170-230 °C. **FIGURE 5** shows a PLGA demonstrator tube, cut by a fiber laser with extremely high surface quality, showing a negligible heat-affected zone at the cut wall.

Summary

Fiber lasers are continuously substituting other laser concepts in medical device manufacturing. Former expectations, that high-peak-power welding and cutting applications will not be address-able by fiber lasers in the near future, had to be revised quite a while ago. Even femtosecond laser pulses of MW-peak power can be realized through fiber laser MOPA designs, and are a great tool for high-quality "cold" processing. Today, fiber lasers provide an ideal concept for most of the welding, cutting, and engraving applica-tions within the production chain of medical devices. ✷

ROLAND MAYERHOFER *(r.mayerhofer@baasel.de), Dieter Mairhoermann, and Michael Mueller are with ROFIN-BAASEL Lasertech, Starnberg, Germany.*

1. Mayerhofer, R., Mairhoermann, D., Müller, M., Röhner, M., Geiger, S., Holtz, R., Rüttimann, C.: "From CW to FS: Fiber Lasers for Medical Device Manufacturing", Proc. ICALEO, 2012.
2. Mielke, M.: "High Energy Ultra Fast Fiber Laser Systems at 1552 nm for Industrial Applications", FISC Workshop, Dresden, 2010.

Industrial Laser Solutions for Manufacturing
Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page
Qmags THE WORLD'S NEWSSTAND®

technology report

Fiber laser technology

MID-INFRARED LASER WAVELENGTHS OPEN UP NEW PROCESSES

TONY HOULT

The telecom crash in the late 1990s can be seen in hindsight as a pivotal event in the history of industrial lasers; from it emerged industrial fiber laser technology. The existence at that time of in-depth scientific and engineering expertise in active fibers and fiber amplifiers, combined with the availability of an extensive toolkit of components, enabled a brisk scaling-up of laser power into the multi-kilowatt regime.

The industry's shift to fiber laser technology is now challenging well-established lasers in many sectors of the industry. CO_2 and Nd:YAG laser technologies are now almost 50 years old, but the huge success of this new technology comes as no surprise to those who have worked with both the old and the new. The major impacts have been in multi-kilowatt metal processing and in low-power general-purpose laser marking, but there is also rapid progress in other areas. The following presents the emergence of a new process for a new class of mid infrared longer wavelength fiber lasers.

While the differences between a CO_2 gas laser and a fiber laser are obvious and these two technologies cannot be confused, the difference between a fiber laser and a fiber-delivered laser is not always immediately apparent. The technology change comes from generating the beam within the fiber itself, and the inclusion of other optical fiber components within the same continuous hermetically sealed fiber-optic beam path. This contrasts with fiber-delivered lasers, where the beam is generated by an array of solid-state optical crystals and discrete optical components and is delivered to the workpiece via fiber for only the final part of its journey. The fiber laser is produced by constructing continuous beam paths within fibers; these are very familiar techniques for those in the fiber optics industry. This fit-and-forget process is at the heart of the success of the fiber laser, as it removes the need for maintenance issues associated with other types of industrial lasers.

Fiber lasers in the mid infrared

The infrared portion of the electromagnetic spectrum is usually divided into three regions; the near-, mid-, and far-infrared (FIGURE 1).[1] Our concern here is with the higher-energy near-IR regime, approximately 0.8–2.5 μm wavelength. Laser scientists are familiar with CO_2 lasers where electromagnetic bonds between atoms are seen as quantum mechanical springs — for example, the asymmetric vibrational state of the CO_2 molecule is close to the stretching state of the N_2 molecule, so energy exchange between the two molecules occurs and lasing in the far IR occurs.

Mid-IR wavelengths are part of the fiber laser story, and thulium was seen very early on as a candidate rare-earth ion dopant for fiber lasers, because the many Tm 3+ transitions allow a wide range of useful wavelengths to be generated using silica-based fibers in the 2 μm spectral region. Strong absorbance by water occurring around this wavelength led to an early interest in thulium fiber lasers for superficial tissue ablation with minimum coagulation depth, a form of "bloodless surgery." Many other non-materials-processing applications have led to the availability

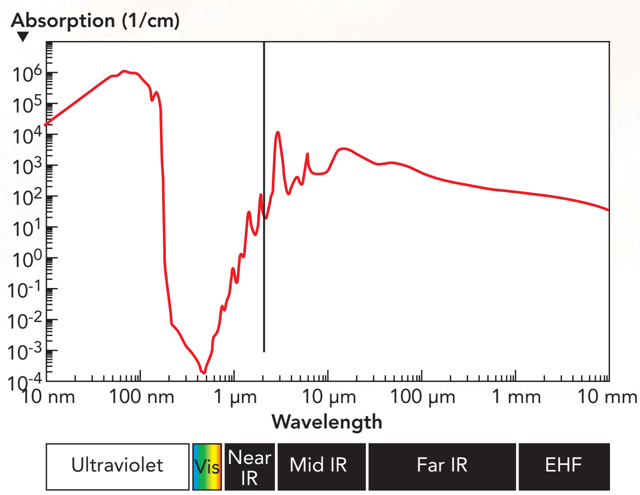


FIGURE 1. IR wavelength ranges and water absorption peak vs. wavelength.[1]

broadens out

of a range of optics for these wavelengths.

It has been known from previous work[2] and from spectroscopic data that many polymer matrices absorb more efficiently at this wavelength, but the reason why is not immediately clear. In this mid-IR range, the spectra from even the simplest polymer materials are complicated by numerous vibrational modes and are not simple symmetrical peaks. The wavelength equivalent for a C-H bond absorption peak is typically 3225 nm, well away from the range of the thulium laser. The energy transitions in the stretch vibrational states of these C-H molecular bonds in high-density polyethylene (HDPE), for example, are therefore small compared to the binding energy of electrons in a carbon atom. It appears, however, that the prominent absorption closest to 1940 nm is the first overtone of the prominent fundamental C-H stretching absorption at 1724 nm. Having said that, mid-IR developments are underway and 3225 nm laser wavelengths are now becoming available. This will be an interesting area for future work.

With the availability of much higher average power at these wavelengths and the high water absorption, please ensure relevant safety standards are followed for guidance. Even the phrase 'less unsafe' perhaps should not be used!

Thulium fiber lasers for polymer welding

Although 50 W average power thulium fiber lasers have been commercially available for several years, recent developments have pushed average power to >100 W while still maintaining a high-brightness single-mode beam, with a power level and $/W cost

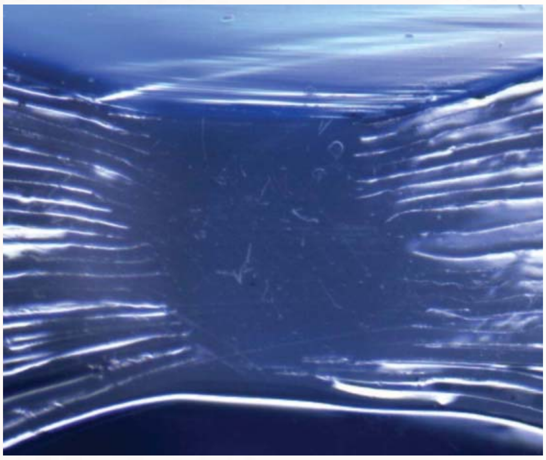


FIGURE 2. Outline of weld volume, 22 layers of 0.1 mm thick virgin LDPE.

TABLE 1. Absorption of Makrolon polycarbonate at 1940 nm.

THICKNESS (MM)	0.5	0.8	1.4	2.0	2.5	5.7
% LOSS	10	14	18	18	25	44

appropriate for high-volume manufacturing processes. The existing through-transmission laser welding (TTLW) technique gaining acceptance within industry only allows lap joints with one absorbing and one transmitting component to be welded. Also, as it employs a near-IR laser, it is unable to weld clear-to-clear polymers unless an additive is used, such as Clearweld infrared dye, and this can make the laser process unacceptable.

Preliminary trials

Trials were conducted to confirm the improved absorption levels of a 1940 nm thulium fiber laser beam on many thermoplastics; results on polycarbonate (PC) are reported below. Using a 4.2 mm diameter collimated beam, power was maintained below 5 W to ensure no significant heating or melting.

This data shows that 10%–45% absorption occurs volumetrically in this clear sheet material depending on sample thickness. These results can be compared with those from a commercially available transmission tester that uses a 0.8 mW diode laser source at 850 nm, which showed >92% transmission on all samples.

As heat input to the sample is increased incrementally and by exercising careful control over the temporal and spatial characteristics of the beam, melting occurs in a highly controllable manner in materials up to 6 mm thick. A simple lap joint with very basic clamping was all that was then required to produce optically clear spot welds between two faying surfaces of like thermoplastics. Relative motion between the laser beam and the melt zone produced linear welds, controlling relative speed and power (line energy) penetration in a manner analogous to welding of metals.

The cross section of the multi-layer joint in low-density polyethylene (LDPE, **FIGURE 2**) was prepared as a simple way of delineating the melt zone. In polymers this is more difficult than for metals, where conventional metallography can be employed. As with

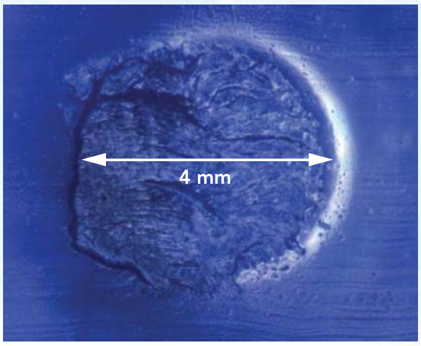


FIGURE 3. Material failure surface at interface of 3 mm diameter PC spot weld.

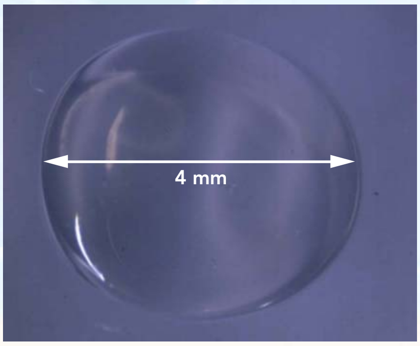


FIGURE 4. 4 mm diameter optically clear spot weld through 2 mm thick unmodified polypropylene.

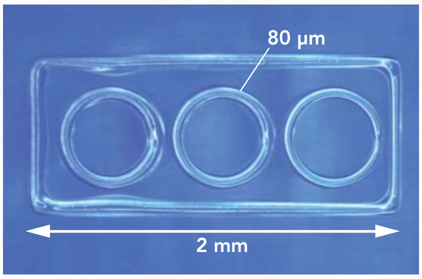


FIGURE 5. < 0.1 mm weld lines in Zeonor cyclic olefin polymer, 2 mm long simulated microfluidic device.

all welds, strength depends largely on the weld area at the interface, and mechanical testing has shown that joint strengths greater than the strength of the parent material can be readily produced. **FIGURE 3** shows a spot weld fracture surface in polycarbonate where cohesive material failure has occurred.

Discussion

FIGURE 2 clearly shows the volumetric absorption of the laser beam in multiple thicknesses of LDPE, which serves two purposes: it shows layers of polyethylene joined together by a high-quality weld, and clearly outlines the melt zone confirming volumetric absorption, as expected from a consideration of Beer's Law. The classic derivation of this law divides the absorbing sample into thin slices perpendicular to the beam, and tells us that light from each subsequent slice is slightly less intense. For a parallel beam of a specific wavelength of monochromatic radiation passing through a homogeneous solid material, the loss of radiant intensity (ΔI) is proportional to the product of the path length through the material Δx and the initial radiant intensity:[3]

$$\Delta I = I \tau \Delta x$$

where τ is the absorption coefficient and represents the relative loss of radiant intensity per unit path length in the material.

An important contrast exists with 4 mm: the longer-wavelength far-infrared regime is where almost 100% absorption occurs, and the polymer welding process is limited to thin films due to the relatively slow conduction processes involved.

With fine-tuning of the welding process, spot or seam welds with no visible charring or degradation were readily achieved. This simple welding technique has since been applied successfully to a wide range of thicknesses of many polymer materials (**FIGURES 4** and **5**). For materials ranging from 0.1–3.0 mm thickness, this absorption appears well-suited at this wavelength for welding many optically clear thermoplastics. The use of high-brightness fiber lasers allows long focal length low f-number lenses or even collimated beams to be employed, as large spots and low power density (typically < 500 W/cm^2) only are required for polymer welding. As many thermoplastic polymers are well-known for their tendency to distort when welding, this enlarges the operating envelope of the process considerably, and removes the need to focus on a particular plane at the joint interface as has been necessary when lower-brightness lasers are used, so access for tooling is also much improved. Although the Gaussian nature of a single-mode beam may at first glance be considered detrimental, optical techniques for producing top-hat beam shapes are now available for this wavelength[4] and may in some circumstances be required. Optically transmissive clamping devices can be used to produce smooth weld surfaces on rigid polymers.

There are many benefits to this process:

- Butt and lap joints are possible
- Light clamping pressure only is required
- Transmissive clamping plate is not always required
- No extra absorbers are required
- Optically clear defect-free welds are readily obtained
- Low-heat-input, sub-0.1 mm wide weld features are achieved
- Long focal length lenses or collimated beams rule out access issues.

What may turn out to be most important of all is that this new laser wavelength allows a far greater temporal and spatial control of heat input into polymers than has previously been possible — this may well have some very interesting consequences!

Summary

Fiber laser technology has broadened out into many sectors of the laser materials processing industry. Multi-kilowatt fiber lasers compete with other laser technologies, fiber laser powered marking systems now dominate general purpose marking, new quasi-continuous wave (QCW) fiber lasers replace flash lamp-pumped solid state lasers, low-nanosecond pulsed lasers are now established and sub-nanosecond lasers are under development, and fiber laser components already are widely employed in the pico and femto-second regime. With mid-infrared laser wavelengths opening up new processes such as that reported here, this trend looks set to continue apace.

References

1. en.wikipedia.org/wiki/Electromagnetic_absorption_by_water
2. Boglea A, Rosner A, Olowinsky A. "New perspectives for the absorber free laser welding of thermoplastics," Proc. ICALEO 2010, Anaheim, CA, USA
3. www.lepla.org/en/modules/Activities/m17/m17-theo.htm
4. Laskin A, "Beam shaping? Easy!" Industrial Laser Solutions, July 2006, p17- 19

DR. TONY HOULT *(thoult@ipgphotonics.com) is general manager of West Coast operations at IPG Photonics (www.ipgphotonics.com), Santa Clara, CA.*

technology report

Laser brazing dissimilar metal medical devices

SEAMLESS JOINING ELIMINATES ADHESIVES

GEN SATOH AND Y. LAWRENCE YAO

The joining of dissimilar materials is a critical issue in the continued development of advanced medical devices due to the unique properties possessed by materials such as nickel titanium (NiTi), platinum (Pt), and stainless steel (SS). Requirements for joining dissimilar biocompatible materials can stem from introducing unique functionalities through the use of shape memory alloys such as NiTi in conjunction with SS, or for decreasing costs while maintaining exceptional corrosion resistance in Pt-to-SS joints. To address these requirements, a new laser joining process is under development to form autogenous (no filler material) joints between dissimilar, biocompatible metal pairs. The autogenous laser joining process would enable seamless joining of these components and eliminate the need for proprietary adhesives and filler materials used in many current designs.

Laser-based joining processes, due to their low thermal input and small spot size, have become the primary joining mechanism of metallic parts in medical devices such as pacemakers. The advantages of lasers in joining processes over conventional heat sources, such as minimal heat-affected zones and controlled energy delivery, are vital to medical device manufacturing processes due to the thermal sensitivity of components as well as their continued miniaturization. Dissimilar metal joints, however, are often complicated by the formation of new phases such as brittle intermetallics within the joint that leads to low strength and premature failure.

Autogenous laser brazing

While the majority of laser-based joining processes use the laser input to directly melt the base or filler materials at the joint, the autogenous laser joining process is designed to form joints that are significantly smaller than the laser beam spot size by taking advantage of heat accumulation at the joint interface. This joining process involves laser irradiation of one of the base materials which is scanned toward the dissimilar metal interface.

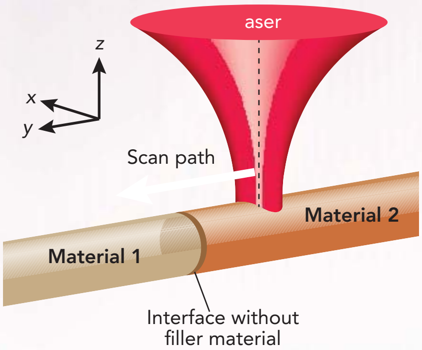


FIGURE 1. Schematic diagram of proposed autogenous laser brazing process for wire-to-wire (~400 µm in diameter). Wire-to-wire process utilizes a Gaussian laser intensity distribution.

Laser parameters such as power and speed are chosen such that the equilibrium temperature of the irradiated piece does not exceed its melting temperature. Heat accumulation due to the thermal resistance of the interface causes the temperature to rise above the melting temperature of one of the base materials as the laser beam approaches, forming a molten layer. The laser beam is turned off as it reaches the interface and the melt layer is quenched when it comes in contact with the adjacent cold work piece, forming an autogenous braze-like joint. A schematic diagram of the joining process is shown in **FIGURE 1**.

The autogenous laser brazing process aims to minimize mixing of the two materials due to the small melt volume, high quench rate, and localized melting of one side of the weld joint to reduce brittle intermetallic formation. Another benefit of the localization of heat is that it allows for joining of material pairs with similar melt temperatures with minimal mixing. **FIGURE 2** shows temperature profiles from a thermal model of a laser beam scanning toward a wire-to-wire interface. An increase in temperature as the laser beam reaches the interface is observed due to heat accumulation.

Experimental setup

NiTi and stainless steel 316L wires, roughly 380 µm and 368 µm in diameter, respectively, were chosen for joining experiments. NiTi and SS have received particular attention for use in medical devices; stainless steel for its low cost and proven biocompatibility, and NiTi for its super elastic and shape memory properties. Prior to joining, one end of each wire was ground flat, perpendicular to the axis of the wire, and assembled in a welding fixture. The ground faces of the samples were held together using an axial force during irradiation by a continuous-wave Nd:YAG laser operating at a wavelength of 1064 nm. The Gaussian laser spot was controlled to be the same size as the diameter of the wires. Laser power was adjusted up to a maximum of 4.75 W while scan speed and scan distance were adjusted between 0.2–1 mm/s and 1–2.5 mm, respectively. Laser joining was performed in an inert environment of ultrahigh-purity argon gas which was flowed into the welding fixture.

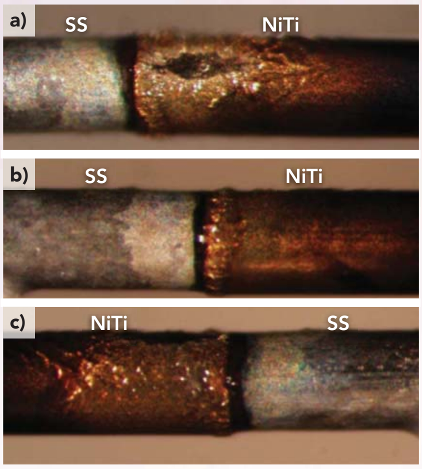


FIGURE 3. Optical micrograph of dissimilar metal joint between NiTi and stainless steel observed from the a) top and sides b), c) of the joint. Sample irradiated on NiTi side of joint.

Weld geometry

FIGURE 3 shows a typical joint created using the autogenous laser brazing process. Overall, the joint shows a clean outward appearance with no obvious signs of porosity or cracking. No large-scale deformation of the wire is observed, indicating that significant melting of the base materials did not occur during processing. **FIGURE 4** is an optical micrograph of the same sample after cross-sectioning along the Y-Z plane. A clean interface is observed with little to no porosity, no cracking, and no signs of incomplete joining at the interface. The joint itself is narrowest toward the center of the wires and wider along the top and bottom surfaces.

Compositional analysis

Quantitative energy-dispersive x-ray spectroscopy (EDS) profiles performed across the NiTi-SS interface at different depths from the irradiated surface are shown in **FIGURES 5A–5C**. Between the two base metal compositions is the joined region showing a mixture between Fe, Cr, Ni, and Ti. The extent of this mixed region indicates the width of the joint. This specific sample shows joint widths ranging from between roughly 5–25 µm. The different shapes of the composition profiles suggest that different joining mechanisms are dominant along different regions of the joint. Toward the laser-irradiated surface the melted layer thickness is greater, which indicates a longer melt duration, allowing greater dilution of the stainless steel into the molten NiTi. Toward the center of the wires, where minimal mixing of the two materials is observed, the melt layer thickness was likely significantly smaller. The composition profile in this region resembles a diffusion-controlled process while the upper layers resemble a fusion-based joining mechanism. **FIGURE 5** also shows that the joint width is significantly smaller than the beam spot size of 400 µm — this confirms that the mechanism of joint formation is not direct melting by the laser beam, but thermal accumulation as desired.

FIGURES 6a and **6b** show compositional maps over the fracture surfaces of a joint created using the autogenous laser brazing process, where red, green, and blue represent Fe, Ni, and Ti, respectively. Both fracture surfaces are dominated by green and blue, which indicates that fracture occurred in the Ni- and Ti-rich regions of the joint. Quantitative measurement of the composition puts the fracture surface within the joint rather than within one of the base materials. Regions with primarily red coloring indicate incomplete joining or fracture in the base SS wire. The existence

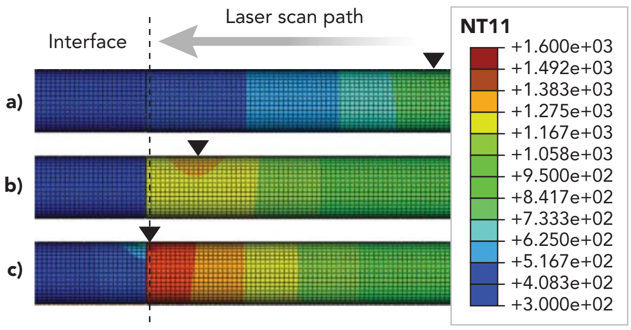


FIGURE 2. Thermal model of autogenous laser brazing process showing thermal accumulation at joint interface as laser beam approaches. The upside-down triangle symbol indicates the position of the laser beam: a) equilibrium temperature distribution far from interface; b) beginning of thermal accumulation at interface; and c) melting of interface.

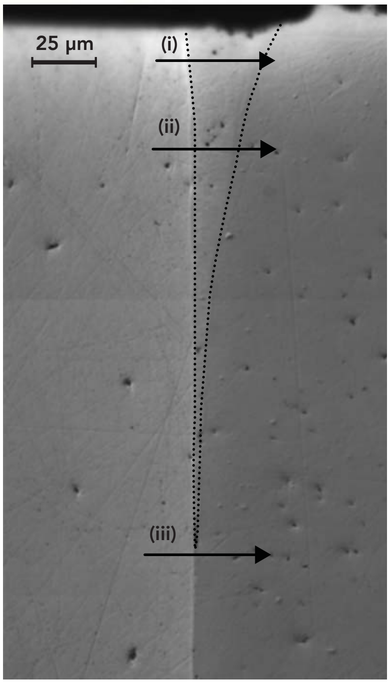


FIGURE 4. Optical micrograph of joint cross-section. Upper mixed region outlined with dotted lines. Note existence of non-zero joint width particularly on top and bottom surfaces of joint.

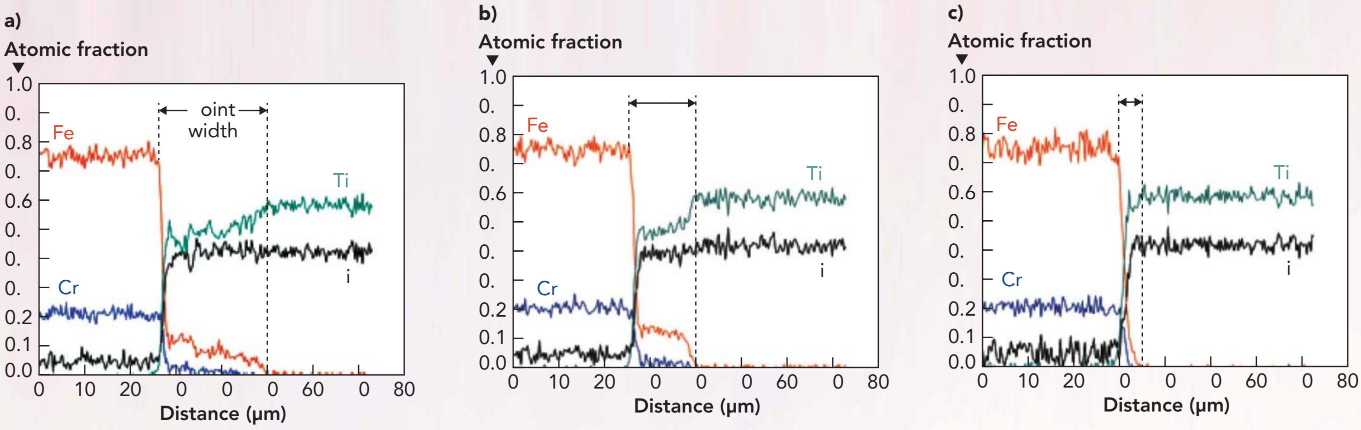


FIGURE 5. EDX line scan composition profiles for scans a) i, b) ii, and c) iii from FIGURE 4. Note change in width of mixed zone (joint width) at different locations along wire thickness.

of incomplete joining at the interface was observed to be a function of scan speed at constant power. As the laser scan speed is increased, the overall energy input into the wire is reduced. This can have the effect of decreasing the melt layer thickness or eliminating the melt layer all together, causing insufficient melting to cover the entire faying surfaces.

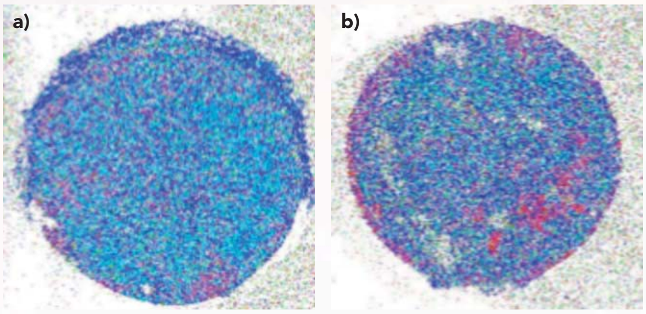


FIGURE 6. Representative EDS maps of fracture surfaces on a) the NiTi and b) SS sides of joint. Red, green, and blue represent Fe, Ni, and Ti.

Joint strength

An ideal joint between dissimilar materials will have a strength that exceeds the weaker of the base materials. The stainless steel wire yields at an applied load of roughly 280 MPa and fractures at a load of nearly 560 MPa after significant plastic deformation. The super elastic NiTi sample initially deforms elastically until the phase transformation from austenite to martensite occurs at a stress level of 470 MPa. After the load plateau, another linear elastic region is observed, and fracture is observed at nearly 1.5 GPa of applied stress.

FIGURE 7 shows a typical fracture surface as seen through electron microscopy for a sample joined using the autogenous laser joining process. The surface has a morphology indicative of quasi-cleavage fracture, and as discussed above, fracture is believe to be occurring within the joint, not in the base material. For experiments at low scan speeds (up to 1 mm/s), the maximum joint strength reaches roughly 275 MPa. While this strength is roughly equal to the yield stress of stainless steel, appreciable plastic deformation within the stainless wire before fracture is not observed. Recent experiments at higher velocities and powers (up to 2 mm/s at 8 W) have shown fracture stresses exceeding 470 MPa. It is believed that the increased scan speed allows for greater heat localization and accumulation to form a smaller melt pool over a shorter time duration, leading to reduced mixing between base materials and reduced intermetallic formation.

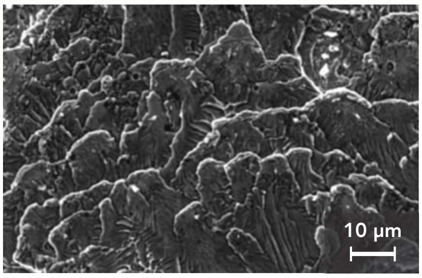


FIGURE 7. SEM of fracture surface for sample irradiated on SS, suggesting quasi-cleavage fracture.

Conclusion

A new joining process, laser autogenous brazing, has been investigated for creating seamless joints between two biocompatible materials, NiTi and stainless steel 316L, for medical device applications. The joints show strengths that approach the yield stress of the stainless steel base material during tensile testing and have fracture surfaces indicative of quasi-cleavage fracture.

Recent experimental results show further increases in fracture strength to levels above the yield stress of the stainless steel. EDS mapping of the cross-sections indicated that joint widths were significantly smaller than the incident laser beam diameter, suggesting melt pool formation due to heat accumulation. The joint strengths achieved suggest that laser autogenous brazing is a viable and promising method for creating robust joints between the NiTi and stainless steel biocompatible dissimilar material pair without filler materials, and is expected to be applicable to a wide variety of other dissimilar metal pairs. ✹

GEN SATOH *and* **Y. LAWRENCE YAO** *are with the Manufacturing Research Lab, Columbia University, New York, NY, gs2358@columbia.edu.*

INDUSTRIAL Laser Solutions FOR MANUFACTURING®

Publisher Christine A. Shaw • (603) 891-9178 • cshaw@pennwell.com
Editor-in-Chief David A. Belforte
(508) 347-9324 • FAX: (508) 347-7737 • belforte@pennwell.com
Associate Editor James Montgomery
(603) 891-9109 • jamesm@pennwell.com
Executive Assistant Susan Edwards
Digital Media Sales Support Tom Markley
Editorial Assistant Virginia E. Belforte
International Editorial Advisory Board Mariana G. Forrest – PhD, MS, Dip.Eng. (automotive applications)
Tony Hoult – PhD, BSc (industrial applications for fiber lasers)
Keng H. Leong – PhD, MS, BA (laser processing applications)
Hua-Chung Man – PhD, MS, BS (laser processing in China)
Stan Ream – MS, BS (laser materials processing)
Ronald D. Schaeffer – PhD, MS, BS (laser micromachining)
Martien H.H. van Dijk – MS, (laser drilling/joining applications in Europe)
Kunihiko Washio – PhD, MS (solid-state laser materials processing in Japan)
Marketing Comm. Manager Adrienne Adler
Art Director Meg Fuschetti
Production Director Mari Rodriguez
Illustrator Christopher Hipp
Audience Development Manager Michelle Blake
Ad Services Coordinator Sarah Pate • sarahp@pennwell.com
(918) 832-9366 • FAX: (918) 831-9153

EDITORIAL OFFICES **PennWell** / Industrial Laser Solutions For Manufacturing
98 Spit Brook Road, LL-1, Nashua, NH 03062-5737
(603) 891-0123 • FAX: (603) 891-0574 • www.industrial-lasers.com

SALES OFFICES

List Rental Kelli Berry • (918) 831-9782 • kellib@pennwell.com
North American Sales Manager Allison O'Connor
(480) 991-9109 FAX: (480) 991-9094 • allison@JAGMediaSales.com
Germany, Austria, Northern Switzerland & Eastern Europe Holger Gerisch
49-8801-302430 FAX: 49-8801-913220 • holgerg@pennwell.com
United Kingdom & Scandinavia Tony Hill
PHONE/FAX: 44 1442 239547 • tonyh@pennwell.com
France, Belgium, Spain, Greece, Portugal, West Switzerland & Netherlands Luis Matutano
33 1-3076 5543 FAX: 33 1-3076 5547 • luism@pennwell.com
Hong Kong/China Lake Shi
86-21-6289-5533 FAX: 86-21-6247-4855 • lake@ringiertrade.com
Israel Dan Aronovic
972-9-899-5813 • aronovic@actcom.co.il
Japan Masaki Mori
81-3-3219-3561 • mori-masaki.@ics-inc.co.jp
Taiwan Diana Wei
886-2-2396-5128 FAX: 886-2-2396-7816 • diana@arco.com.tw

CORPORATE OFFICERS
Chairman Frank T. Lauinger
President and CEO Robert F. Biolchini
Chief Financial Officer Mark C. Wilmoth

TECHNOLOGY GROUP
Senior Vice President and Publishing Director Christine A. Shaw
Senior Vice President, Audience Development Gloria S. Adams

For subscription inquiries: (847) 559-7520 • FAX: (847) 291-4816 • ils@omeda.com
web: ils-subscribe.com • In Europe: Mailfast, JFK/BOS/850858, P.O. Box 66, Hounslow, United Kingdom TW5 9RT • FAX: 44 20 7504 8207

Custom Article Reprints: Increase exposure by including custom reprints of a recent article in your next promotional or marketing project. High quality, custom article reprints are available in both print and electronic format by contacting:

The YGS Group • Toll Free: (800) 290-5460 • (717) 399-1900 x100 • FAX: (717) 399-8900
industrialLaserSolutions@theYGSgroup.com • www.theYGSgroup.com

CALENDAR

MAY

5–10 Manufacturing 4 the Future, Hartford, CT; mfg4event.com

9–11: International Laser Technology Congress (AKL), Aachen, Germany; lasercongress.org

14–16 Montreal Manufacturing Technology Show, Montreal QC; mmts.ca

16-18 Advanced Laser Applications Workshop (ALAW), Livonia, MI; alawlaser.org

JUNE

4–8 North American Manufacturing Research Conference (NAMRC), South Bend, IN; sme.org/namrc

12–15 13th International Symposium on Laser Precision Microfabrication (LPM), Washington DC; engineering.cua.edu/LPM2012

JULY

8–13 18th Ultrafast Phenomena Conference, Lausanne, Switzerland; up2012.org

10-12 7th International Conference on Additive Manufacturing and 3D Printing, Nottingham, UK; am-conference.com

SEPTEMBER

14–16 Laser World of Photonics India, Mumbai, India; photoicsoncia.net

23-27 International Congress on Applications of Lasers & Electro-Optics (ICALEO), Anaheim, CA; lia.org/conferences/icaleo/

OCTOBER

23-24 Lasers for Manufacturing Event (LME), Schaumburg, IL; lia.org/conferences/laserevent

23-24 Laser Welding and Joining Workshop, Schaumburg, IL; lia.org/conferences/laser_welding/conference

23–27 EuroBlech, Hanover, Germany; mackbrooks.co.uk/events/euroblech-2012

24 Medical Manufacturing Innovations, Mississauga, ON, sme.org/canmedical

NOVEMBER

5-9 Laser Safety Officer Training, San Antonio, TX; lia.org/store/education

12–14 FABTECH, Las Vegas, NV; fabtechexpo.com

12-15 International Conference on Photonic Technologies (LANE), Furth, Germany; lane-conference.org

27 Laser Safety Officer Training Course, Phoenix, AZ; rli.com/training

28-29 Espace Laser 2012, Mulhouse, France; espace-laser.biz

INDEX OF ADVERTISERS

Industrial Laser Solutions © 2012 (ISSN 1523-4266) is published 6 times a year by PennWell Corporation, 1421 S. Sheridan, Tulsa, OK 74112. Subscriptions: $158.00 USA, $210.00 Canada, $262.00 International Air, $79.00 Digital. Reproduction in any form is forbidden without permission. Subscription inquiries: Tel: (847) 559-7520; Fax: (847) 291-4816; Email: ils@omeda.com. We make portions of our subscriber list available to carefully screened companies that offer products and services that may be important for your work. If you do not want to receive those offers and/or information, please let us know by contacting us at List Services, Industrial Laser Solutions, 98 Spit Brook Road, Nashua, NH 03062. Back issues of Industrial Laser Solutions may be purchased at a cost of $16.00 each in the US and $21.00 Canada, $26.00 International.

POSTMASTER: Send address changes to *Industrial Laser Solutions* P.O. Box 3425 Northbrook, Il 60065-9542. Return undeliverable Canadian addresses to: P.O. Box 122, Niagara Falls, ON L2E 6S4. GST No. 126813153. Printed in the USA. Publications Mail Agreement No. 40052420.

my view

Will the auto industry drive the next laser growth spurt?

STILL MANEUVERING INTO A KEY MARKET

Making it in the automotive industry has always been seen by industrial laser suppliers as an endorsement of their products' use in difficult manufacturing operations. From the 1979-80 Nissan, Toyota, and Honda installations of three-axis laser trim line die cutters and the 1979 GMC truck and bus welding of bus roof panels, every victory was hard-won, and notable setbacks like the now infamous 1973 Ford purchase of an underbody welding system were devastating to a nascent industry.

Then successes, spectacular at the time — such as the 1986 Volkswagen installation of a laser/robot system for online cutting of air conditioning ports, and the 1980s replacement of electron beam systems with high-power lasers at Ford Transmission — buoyed the industry as the increasing usage of then-called "unconventional" process gained acceptance by a tough-to-please industry.

I presented a first-time view of lasers in the automotive industry at a 1988 meeting in Stuttgart, and since then I have tracked their penetration into the auto industry, reporting on this periodically in *ILS* and at many international conferences. Over the years, the number of new annual installations increased to a peak in 2006 when about 75 significant installations of high-power lasers for welding were made in OEM plants. Since then, annual installation locations are around 30-40 per year.

Counting only installations at OEM automakers and their Tier One suppliers, I estimate at least 3000 industrial lasers are being used for welding and cutting operations in global auto plants. Considering that in 2011 more than 60 million cars were made by 37 companies, with 24 of these making more than 500,000 and the top eight making more than three million each, the number of laser installations is not that large — leaving room for lots of expansion.

China took the top spot in 2011 with more than 14 million cars built last year, in a low-growth year for auto sales in that country. We don't have a good handle on the use of high-power lasers in the Chinese auto plants, but we speculate that it may be at a lower level than in Western countries. With the cost of labor increasing in China, one could expect a move to more automated — and laser-oriented — manufacturing. Europe, on the other hand, seems to be in a bit of a muddle right now as reports of slipping sales are appearing due to the dismal economic situation. North America had a good year as the economy brightened and the US automakers returned to profitability.

Volkswagen, a well-documented laser processing innovator, has moved up to number two as a carmaker, just 900,000 cars behind GM which regained the number one slot. VW has a policy of standardizing auto production in all its global plants, so a laser installation in Germany would be replicated in South Africa, etc., which is great for laser sales.

The top eight automakers operate about 500 plants worldwide, so recent laser applications spreading throughout the industry, such as the spurt of roof-to-side wall joining operations, can ratchet laser sales up quickly.

The pot of gold that attracts laser suppliers is the potential for laser spot welding to replace the current resistance spot welding process. Replacing thousands of resistance spot welders with lasers could be a marketer's dream. Hand- or robot-held, lightweight, fiber-delivered laser energy sources have been introduced and may be the forerunner of laser replacement of the resistance welding process.

David A. Belforte
belforte@pennwell.com