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Welding for brass instruments

Cladding goes 'green'

Welding zinc alloys

Cutting RV parts

Solar cell applications

Women in laser manufacturing

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INDUSTRIAL LASER SOLUTIONS FOR MANUFACTURING®

VOL 33 | NO.2

MARCH/APRIL 2018

P.9

An example of a saxophone produced at Amati-Denak is shown. (Courtesy: Amati-Denak)

Features

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DABbling

A blog by DAVID A. BELFORTE

David shares his insights and opinions on current activities affecting industrial laser materials processing.

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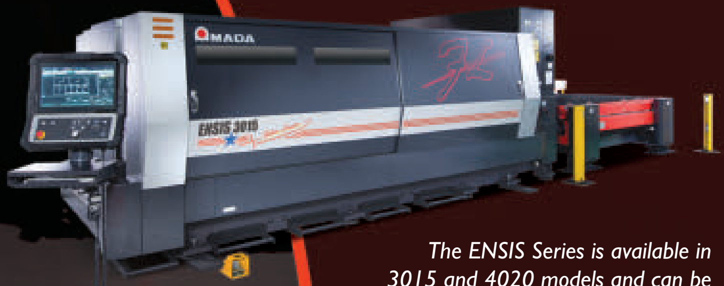
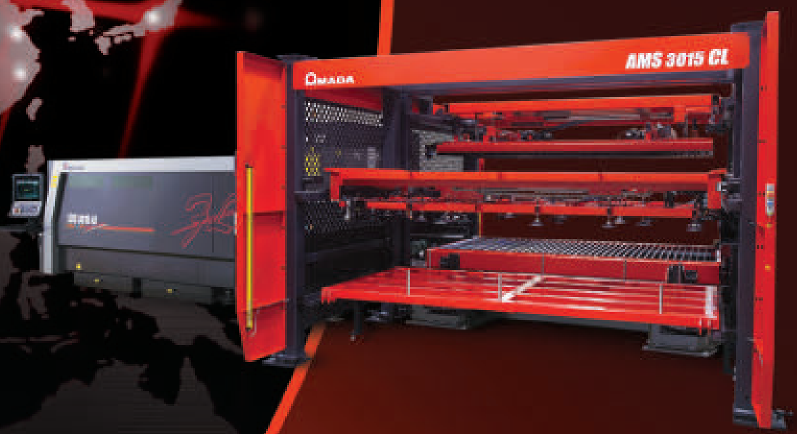


The ENSIS Series is available in 3015 and 4020 models and can be configured with CL automation options to best suit your specific manufacturing needs.



The LCG Series is also available in 3015 and 4020 models and can be configured with CL automation options to best suit your specific manufacturing needs. (Shown with AMS 3015 CL Cycle Loader)

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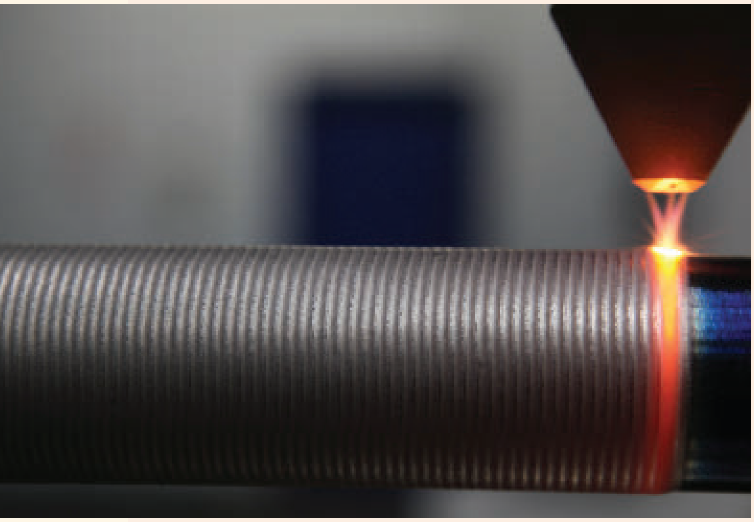
Laser cladding method extends boiler tube life

EAST GRANBY, CT – American Cladding Technologies was recently confronted with the challenge of laser cladding the endcap of a 14-ft.-long, laser-clad carbon steel soot blower tube. These soot blower lances are used in a boiler system for a waste-to-energy power producer, where tubes are subjected to highly corrosive conditions. This lance was too long to clad in the typical horizontal position, so the company developed a program and process to clad the endcap in the vertical configuration. The cladding material is a multi-blend of different alloys, essentially nickel-based, and the build-up is 0.040 in. The entire lance takes approximately 1 hour (**FIGURE**).



American Cladding Technologies' laser cladding process for soot blower lances takes about 1 hour to complete.

The customer was replacing one lance per month—now, they're replacing it every six months. Alternative processes are tungsten inert gas (TIG) and metal inert gas (MIG) welding with Inconel overlay, but advantages in using laser cladding are low dilution, thinner coatings (because dilution is controlled), lower heat input, higher-quality metallurgical bond, less stress, and shorter process times.

American Cladding Technologies' laser cladding processes have extended the life of boiler tubes for the waste-to-energy industry up to five years without failure. The company specializes in innovative laser cladding solutions for the power generation, aerospace, and chemical processing industries, as well as for valves, pumps, and industrial gas turbines.

For more information, please visit www.americancladding.com.

CRP Group is Energica's technology partner for developing electric sportbike

MODENA, ITALY – Ego Corsa, the Energica Motor Company's electric sportbike for the FIM Enel MotoE World Cup (**FIGURE**), will be developed through CRP Group's laser additive manufacturing experience. Livia Cevolini, CEO of Energica and marketing director of the CRP Group, has introduced the Ego Corsa, which is the tuned version of the Ego.

Energica Motor Company has partnered with CRP Group in developing the Ego Corsa electric sportbike using laser additive manufacturing.

The relationship between Energica and the CRP Group will be continued at full capacity, even in this new era of two-wheeled motorsports. CRP's


II-VI HIGHYAG
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subtractive and additive manufacturing will be supporting the development of the Ego Corsa.

The Energica project was born between 2008 and 2009 when the company created an all-electric racing bike called eCRP. The company required technical expertise, and the experience and technologies inherited from parent company CRP Group allowed it to create a new concept of motorcycle racing. CRP Group's experience in the Formula 1 and aerospace industries supported Energica into further developing electric technology and creating a line of premium street-legal electric motorcycles. The team raced for two years and then started working on the first high-performance electric motorcycle.

Energica's motorcycle range includes three models, among them the tuned Ego Corsa sportbike. This model, which will have many similarities with the production bike from which it is derived, will be used by teams that will race the FIM Enel MotoE World Cup. The CRP Group team will be involved in many phases of Ego Corsa development.

The Energica R&D team is already committed to this bike, working on drivability on the track and then on track specifications. A testing demo program will be held during the 2018 MotoGP World Championship.

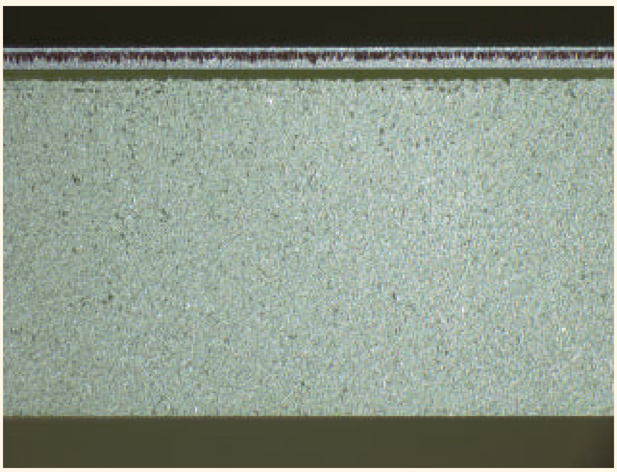
For more information, please visit www.crp-group.com and www.energicamotor.com.

Femtosecond lasers extend glass cleaving to mixed materials

SANTA CLARA, CA – Filamentation cutting is a relatively new process that uses ultrashort-pulse (USP) lasers to cut a wide range of glass substrates, from soft borosilicates to chemically hardened glass used in smartphone displays. Among the advantages of filamentation cutting are the ability to produce curved shapes and cut-outs, cutting speeds up to 2000 mm/s, and superior stress-free edge quality, which eliminates the need for post-processing.

The high peak intensity created by a focused USP laser produces self-focusing of the beam because of the nonlinear optical Kerr effect, further increasing power density until, at a certain threshold, a low-density plasma is created in the material. This plasma lowers the material refractive index in the center of the beam path and causes the beam to defocus. If the beam focusing optics are properly configured, this focusing/defocusing effect can be balanced to periodically repeat and form a stable filament, which extends over several millimeters in depth through an optically transparent material. To achieve a continuous cut, these laser-generated filaments are produced close to each other by a relative movement of the workpiece with respect to the laser beam. The typical filament diameter is in the range of 0.5 to 1 µm, enabling very high-precision cutting.

Until recently, all commercial versions of this cutting technique, such as SmartCleave from Coherent | Rofin, have used picosecond lasers. Several display manufacturers now make extensive use of these systems, which can cost-effectively cleave glass up to 10 mm in thickness.



An edge view of 20 µm of polyimide on 0.5 mm glass, cut with a femtosecond laser with 40 W of average power and a pulsewidth ~350 fs produced a surface roughness of <350 nm.

However, one limitation in some applications is that these picosecond systems are not material neutral. Cutting mixed layer substrates, such as polyimide on glass and metal on glass, usually requires an additional laser process to cut the non-glass layer with the requisite high-quality edge.

Femtosecond lasers have a much higher peak-power-to-average-power ratio than picosecond lasers, and are known to be able to process nearly any material by conventional ablation—that is, cutting by material vaporization. However, femtosecond lasers have not been employed in filamentation applications because of their higher cost and lower power as compared to picosecond lasers.

But the increasing demand in industry to cut multi-layer substrates has led laser manufacturers to develop more cost-effective femtosecond lasers which also offer high average power. This has been accomplished by switching to ytterbium-doped fiber, rather than the traditional titanium:sapphire, as the gain medium.

The Coherent Monaco is one example of a new generation of industrial femtosecond lasers that already offer average power as high as 60 W. Moreover, its pulse width can be software-tuned by the operator from <350 fs to >10 ps, enabling the output to be optimized for different filamentation conditions, as well as other material cutting and texturing processes.

In Coherent's applications laboratory, tests were performed using this laser for glass filamentation. Monaco can cut glass up to several

millimeters in thickness by using a so-called "burst mode," where the laser output is grouped into a series of fast bursts. The brief spacing (20 ns) between individual pulses creates a material interaction proportional to the entire burst energy rather than the energy of a single pulse.

Most importantly, they have demonstrated that by careful process optimization, layered substrates with two or more dissimilar materials can be completely cut in a single pass, with superior edge quality, virtually no residual edge stress, and no heat-affected zone in the "delicate" layers. In the example shown, an edge view of 20 µm of polyimide on 0.5 mm glass, cut with a femtosecond laser with 40 W of average power and a pulsewidth ~350 fs produced a surface roughness of <350 nm, as measured with an atomic force microscope (**FIGURE, P. 6**).

"SmartCleave has proved a very popular process for manufacturers of FPDs and smart devices using our picosecond lasers," explains Michael Laha, director of product marketing at Coherent. "But, there's a demand from manufacturers to extend this technique to mixed layer substrates without adding any extra steps. The work we've performed proves we can satisfy this need with a femtosecond laser having a similar cost per watt as market-established picosecond lasers."

For more information, please contact Michael Laha at michael.laha@coherent.com, or visit www.coherent.com.

ES Precision offers laser marking services for several industries

The exterior of ES Precision's building is shown.

KINGSTON BAGPUIZE, ENGLAND – ES Precision opened in 2017 to offer laser processing to industries such as medical device, Formula 1, aerospace, electronics, and general engineering (**FIGURE**). The company's six-person staff runs laser marking jobs on eight workstations.

"Turnover for the first quarter was well ahead of expectations, so we've entered the new year with a very solid start," says Tim Millard, managing director. "We've taken on some part-time staff locally in addition to our six permanent staff to meet the demand peaks. We've met delivery expectations 100% so far as a result, which is crucial when a new company is building a reputation."

The company's lasers include a 200 W CO_2 galvo-delivered source that can drill and cut organic materials at very high speed, and a lower-power CO_2 laser with automatic reel-to-reel feeding to mark label data onto any shape of label—the laser also cuts the label profile, so no kiss-cutting dies are required. Labels are tamper-evident and high temperature- and weather-resistant, so customers use them for tracking and traceability as well as outside use. They can have incrementing barcodes, ID matrices, or human-readable characters, and cannot be removed without destroying. Most people will have seen the material on their cars—such laser-marked black labels are ubiquitous showing fuel type by the gas fill-up cap and tire pressure on the door interior.

"We've also got UV, fiber, and vanadate lasers with galvo delivery so that we can optimize marks on virtually all materials—all metals, most plastics, as well as coated materials," Millard explains. "We have a tool room to fabricate fixtures so that repeat customers are guaranteed consistent results. The business model needs customers who have a regular permanent identification or decorative need for their products, so ensuring every customer is happy with our service is of course essential."

For more information, please visit www.esprecision.co.uk.

Laser welding yields high-quality brass instruments

PROCESS CREATES RELIABLE JOINTS IN BRASS INSTRUMENT PRODUCTION

TOMÁŠ MUŽÍK AND VLADIMÍR HAVRÁNEK

FIGURE 1. An example of a saxophone produced at Amati-Denak.

Amati-Denak produces all kinds of woodwind and brasswind instruments, from medium- to luxury-quality level. While the company has a rich history dating back to the 17th century, progress has not stopped. Recently, they made a dramatic technology change in the production of trumpets and saxophones (**FIGURE 1**). What were manually soldered joints on brass parts has been replaced by laser welding, specifically for their top-class instruments.

Amati-Denak, with 200 employees, ranks as the leader in the market regarding assortment range and quality. As a result, it is one of the largest manufacturers of musical instruments in Europe. All of the company's products are made in its main factory in Kraslice, Czech Republic, where there is a rich tradition in making woodwind and brasswind musical instruments. A second factory is situated in Hradec Králové, where all rotary valve instruments of VF Červený are manufactured. In 2016, the British Geneva company acquired a majority of Amati-Denak, which started another chapter in the company history. There are now more premium brands being added to the Amati-Denak and VF Červený portfolio—Geneva, Oldroyd Cardinal, and Lineage.

Company history

Despite the current economic situation in central Europe, the company managed to ensure sufficient production and sales mainly because of modern handicraft production, which builds on years of experience and passion for making musical instruments.

Amati-Denak is currently collaborating with musicians dedicated to producing high-quality musical wind instruments with a unique full sound, which is in demand in the current music world. The combination of modern handicraft, together with the understanding of musicians and their requirements, provides the company with a basis for making wind instruments of the highest quality on the market.

The company can satisfy the tastes and requirements of all musicians. Primarily, however, they aim to satisfy advanced players and professionals. This diversity of product range with unique variations gives customers the ability to choose the instrument consistent with the personality and style of each individual musician. The main goal of the company is to supply customers with high-quality instruments that bring not only the perfect sound, but also the joy of music.

Amati-Denak's musical instruments are manufactured in the cities of Kraslice and Hradec Králové. Musical instrument-making had become a tradition in both cities hundreds of years ago, and each city underwent a completely different historical evolution. Kraslice can be considered a cradle of musical instrument production in the country, as stringed instruments were first produced there at the beginning of the 17th century.

Melchior Lorenz was the first legally confirmed musical instrument maker. In the 18th century, the instrument makers of Kraslice adapted to the boom of orchestral music and aside from violin-making, they engaged in the production of wind instruments.

Technical improvements of wind instruments at the beginning of the 19th century, in which the Kraslice musical instrument makers participated, made it easier to play, enabling better virtuosity of the players. That, in turn, resulted in increased interest in playing these instruments.

Instrument makers wanted to meet and satisfy most players' demands, thus making Austrian and French system instruments in Kraslice and, from the beginning of the 19th century, musical toys as well. The first factory had been established in Kraslice in 1840 and shortly afterwards, others followed. By the end of the 19th century, there were already 11 factories in operation, employing around 300 workers. About 500 additional people were involved in domestic production. In the city, there were 16 merchants trading musical instruments.

Production quickly recovered after World War I. Between the two World Wars, there were 59 musical instrument manufacturers—among the biggest of these firms were Bohland & Fuchs, Hüller & Co., A. K. Hüttl, Julius Keilwerth, Karl Püchner, Adolf Rölz, and Ant.Kohlert. However, during WWII, many plants ceased to exist, while others served military purposes.

In September 1945, a cooperative of musical instrument manufacturers was established in Kraslice. And because the production of both wind and stringed instruments was anticipated, the cooperative was given the name Amati.

In 1948, the entire production was nationalized. Kraslice gradually became a center of wind and percussion instrument manufacture. At present, the assortment of wind instruments produced in Kraslice is unusually wide and made up of practically all common instruments. In Kraslice, cases are also produced for instruments, cymbals, and the whole range of Orff musical instruments that are simple and easy to play, even for first-time musicians. Students of the Orff Approach, learning by doing, play instruments alone as well as in groups.

All instruments are manufactured from quality materials, with a high level of handcraftsmanship combined with modern technology. Amati-Denak instruments are sought after for their award-winning features, such as beautiful and mellow sound quality, good intonation, functional reliability, perfect workmanship, and very reasonable prices.

Laser technology for brass welding

Although Amati-Denak is a very traditional company, it has always been looking for innovations and best-available technologies to bring design and sound of their instruments to the absolute top level. They identified one technological issue in joining technology in the production of trumpets and saxophones. For several reasons, they must be produced as an assembly

welded from several parts, sometimes made from different brass grades. These joints have been done by means of soldering using lead-based solder or by plasma-transferred arc (PTA) welding. This is a proven and easy technology—however, there is always a small notch remaining on the inner surface of the instrument, causing small sound disturbance. PTA welding has other technological challenges, too, including changing the joining technology to avoid grooves.

After conventional-technology welding trials failed to create reliable joints, Amati-Denak asked the company MATEX PM for assistance. Welding technologists at MATEX, working with technical people from Amati-Denak, managed to prepare a reliable clamping device and after several trials, they found proper parameters

for reliable laser welding process and presented laser-welded samples (**FIGURE 2**).

MATEX used one of their robotic laser cells to produce welded joints for Amati-Denak. It is based on a KUKA robot and Laserline's fiber-guided diode laser, with available 5 kW laser power as well as continuous-wave and pulsed modes. Also tested were many protecting gas mixtures. In brass instrument construction, several brass grades and slightly different sheet thicknesses may be used. This caused concern because of the very high reflectivity of laser light from copper alloys. However, this effect turned out to be manageable. The most demanding challenge was construction of a precise clamping device, which can keep complex-shaped instruments in precise position during the welding process.

Amati-Denak's processing needs were readily accomplished with laser welding, as several brass grades can be used, the metal surface can be in the shiny polished condition, and no additive material is needed. Only the best quality joints are allowed, with no wavy surface, no porosity, and no post-weld steps on both surfaces. There is no other surface treatment done before welding and no preheating is allowed. Weld seams are done as

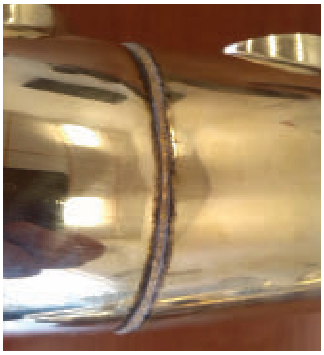


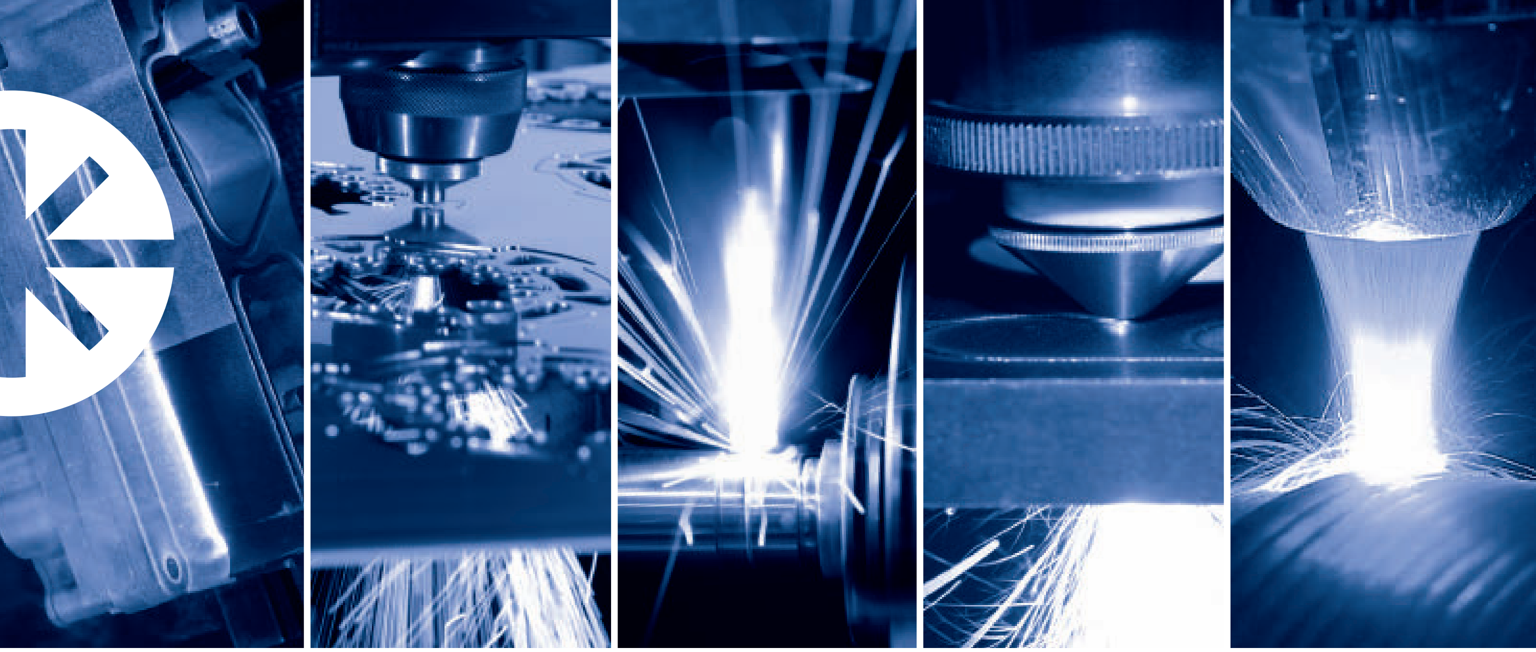
FIGURE 2. Examples of laser-welded sample pieces for saxophones are shown.

butt joints, without filler wire, and the joints are only mechanically polished after welding to make them virtually invisible. Welding speed and price-per-meter of weld seam are taken as unimportant parameters because it is obviously very fast and affordable compared to other production steps. Most important is visual quality of the instrument. The success in welding lies not in laser wavelength—the diode laser is similar to neodymium-doped yttrium aluminum garnet (Nd:YAG), but combines proper pulse length related to metal sheet thickness, welding speed, and appropriate shielding gas.

MATEX used to concentrate on laser hardening for the automotive and heavy machinery industries, so its laser operators and welding engineers were quite surprised and skeptical about this job. Later, it was taken as a new opportunity and a chance to prove their mastery. It was necessary to make many trials, lab analyses, and changes in clamping, and it took quite a long time to set the proper parameters. However, after the first parts were successfully welded, their pride and satisfaction with the breakthrough were clearly visible. It wouldn't have been possible to solve the technology issues without their enthusiasm and skills.

Today, laser welding is used for production of some types of top-class instruments. It is something different than mass production for automotive, which is a typical application for laser welding. This application is more like prototype production, but Amati-Denak and MATEX are sure that laser technology helps to create masterpieces with very unique design and sound. Laser robotic welding instead of conventional soldering and welding is now the main process for making brass instruments, as it meets Amati-Denak's goal of getting a perfect connection of parts made from brass material.

TOMÁŠ MUŽÍK *(muzik@matexpm.com) is with MATEX PM, Plzeň, Czech Republic; www.matexpm.com/en, while* **VLADIMÍR HAVRÁNEK** *is with Amati-Denak, Kraslice, Czech Republic; www.amati.cz/en.*



Laser cladding technology helps manufacturers 'go green'

TECHNOLOGY ENABLES LOW-COST REFURBISHMENT OF HIGH-VALUE COMPONENTS

ROGER KAUFOLD

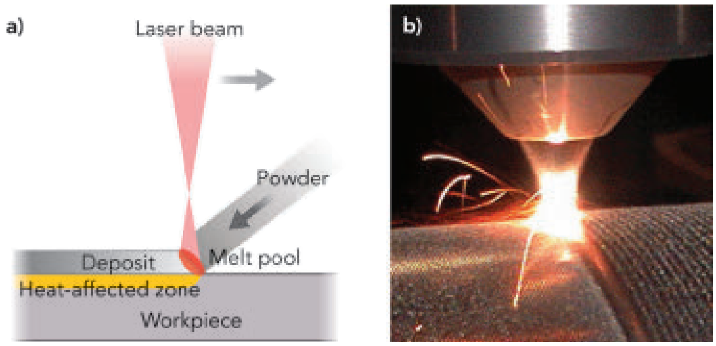


FIGURE 1. A schematic of the laser cladding process (a) and a steel roll being resurfaced with high-strength steel (b) are shown.

Society in general is becoming "greener," and we are witnessing fundamental changes in our attitude and usage of various technologies. Everyone appreciates the benefits of recycling and reusing resources, tools, and gadgets, as long as there is no loss of quality in the end products. From past experience with industrially developed parts of the world and with the ongoing economic difficulties around the globe, we know that we no longer have the luxury of being able to throw away everything that is slightly damaged. Yet the world over, commercial advertisements and marketing tools are pressuring society to buy the latest products. This is how the consumer society was created and is sustained, to the detriment of our natural resources.

Fortunately, cooler heads in society and manufacturing industry understand that we must reduce costs by repairing, regenerating, and renovating. Industry does not have excess money to buy new machines—instead, it needs and really depends on recovery. Even if the resources are available, nobody is now prepared to throw their money to the winds. Thanks to these social changes, new attitudes, and economic pressure, the repair and refurbishment sector of mechanical and manufacturing engineering is currently booming.

The size and potential of this repair and renovation market is enormous in virtually every manufacturing sector, from heavy equipment to welding. The industrial services market is expected to grow at a compound annual growth rate (CAGR) of 5.4% between 2017 and 2023, and would be worth $35.41 billion by 2023.

How laser cladding works

In these industrial processes, an arc is established to melt the surface of the base material to a shallow depth. The clad material is then introduced in either wire or powder form and is also melted by the arc, thereby forming the clad layer. Typically, arc welding techniques deliver a fully welded, metallurgical bond having high strength, good impact properties, and low porosity. However, the high heat input into the part usually melts enough of the substrate to produce a significant amount of mixing of the base material into the clad layer. Such dilution is undesirable because it alters the very properties for which the clad material was selected. Also, the high heat input can cause mechanical distortion, creating the need for further processing after cladding to restore the part's dimensional accuracy. This thermal stress leads to inferior mechanical quality, surface quality problems such as cracks and porosity, as well as shortening the lifetime of the repaired part. Microelectronics is pursuing the same overarching goal of reducing production costs while simultaneously improving yield and final product quality.

Lasers are powering this trend in many industries because of their ability to perform highly precise, non-contact processing. Cladding, in particular, is a process that achieves these ends. With shifting economic pressure to keep machinery in operation, thereby diminishing the size of our carbon footprint in landfills, the repair and refurbishment sector of production engineering is experiencing a positive surge. With the rapid growth of laser applications and the reduced cost of laser systems, laser material processing is being successfully implemented in automotive, aerospace, shipbuilding and ship repair, oil and gas drilling, and many other industries.

By definition, laser cladding is a method of depositing material by which a powdered or wire feedstock material is melted and consolidated by use of a laser to resurface or fabricate a near-net shape part, such as in additive manufacturing. In many cases, laser cladding technology is being used in the repair and reconditioning of all types of mechanical equipment (**FIGURE 1**). The most common traditional methods for metal cladding are all variations on the arc process.

Using the laser as the heat source offers an attractive alternative to arc welding because the laser can produce the required heating in a highly localized and controlled manner (see "Laser cladding advantages," page 18). By melting very little of the bulk material, laser cladding dramatically reduces dilution in the clad layer, while still producing a true metallurgical bond. Also, the lower heat input avoids part distortion, largely eliminating the need for post-processing. High-power diode lasers are a particularly good match for the needs of high-speed, large-area cladding applications.

FIGURE 2. A laser-cladding process at work on a truck axle is shown; the process can also be used to repair wind-turbine components, such as damaged or worn shafts.

System developments

Substantive research is now being concentrated on developing automatic laser cladding machines (**FIGURE 2**). Many of the process parameters must be manually set, such as laser power, laser focal point, substrate velocity, and powder injection rate, and thus require the attention of a specialized technician to ensure proper results. However, many groups are focusing their attention on developing sensors to measure the process online. Such sensors monitor the clad's geometry height and width of deposited track, metallurgical properties such as the rate of solidification, the final microstructure, and temperature information of both the immediate melt pool and its surrounding areas. With such sensors, control strategies are being designed such that constant observation from a technician is no longer required to produce a final product. Further research has been directed to forward processing, where system parameters are developed around specific metallurgical properties for user-defined applications such as microstructures, internal stresses, dilution-zone gradients, and clad contact angles.

The clad layer improves performance, as well as lowers cost and the choice of substrate material for a part. This invariably represents a compromise between its bulk and surface properties, as well as its cost. For example, it might be desirable to fabricate an engine crankshaft from a material that is sufficiently flexible so that it doesn't fracture when exposed to high torsional stress. However, it would also be advantageous if, for example, the bearing surfaces of this crankshaft were very hard so that the part would not wear quickly in use. Cladding is a process that enables independent choice of the bulk and surface properties of a material, therefore avoiding this type of compromise. Specifically, cladding involves the creation of a new surface layer on a substrate having a different composition than the base material. For example, it enables a fabricator to utilize a low-cost material for the bulk of a part, yet still selectively achieve the wear, corrosion, or heat resistance properties of a more expensive alloy. Furthermore, cladding cuts costs in many industries by enabling economical refurbishment of high-value parts, rather than expensive replacement.

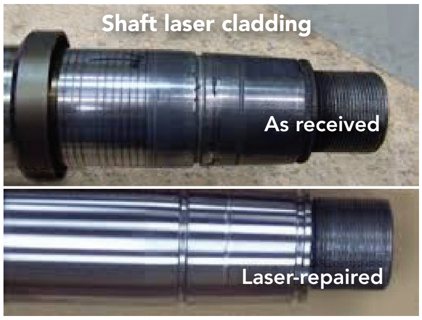


FIGURE 3. Wear and corrosion processes need environmentally sustainable engineering practices that reduce energy consumption, dangerous emissions to meet government standards, and material waste.

The powder used in laser cladding is normally of a metallic nature, and is injected into the system by either coaxial or lateral nozzles. The interaction of the metallic powder stream and the laser causes melting to occur, and is known as the melt pool. This is deposited onto a substrate—moving the substrate allows the melt pool to solidify and thus produces a track of solid metal. This is the most common technique, but some processes involve moving the laser/nozzle assembly over a stationary substrate to produce solidified tracks. The motion of the substrate is guided by a computer-aided design (CAD) system that interpolates solid objects into a set of tracks, therefore producing the desired part at the end of the trajectory.

Research is now being concentrated on developing automatic laser cladding machines. Many of the process parameters must be manually set, such as laser power, laser focal point, substrate velocity, powder injection rate, etc., and thus require the attention of a specialized technician to ensure proper results. However, many groups are focusing their attention on developing sensors to measure the process online. Such sensors monitor the clad's geometry (height and width of deposited track), metallurgical properties (such as the rate of solidification and, hence, the final microstructure), and temperature information of both the immediate melt pool and its surrounding areas. With such sensors, control strategies are being designed such that constant observation from a technician is no longer required to produce a final product. Further research has been directed to forward-processing, where system parameters are developed around specific metallurgical properties for user-defined applications (such as microstructure, internal stresses, dilution zone gradients, and clad contact angles).

Laser cladding advantages

- Best technique for coating any shape to increase lifetime of wearing parts
- Particular dispositions for repairing parts, which is ideal if the mold of the part no longer exists or too long of time is needed for a new fabrication
- Most suited technique for graded material application
- Well adapted for near-net-shape manufacturing
- Low dilution between track and substrate (unlike other welding processes) and strong metallurgical bond
- Low deformation of the substrate and small heat-affected zone (HAZ)
- High cooling rate is greater than or equal to fine microstructure
- Wide material flexibility (metal, ceramic, and even polymer)
- A built part is free of crack and porosity
- Compact technology
- Reduced production time
- Highly satisfactory repair of parts
- Production of a functionally graded part
- Production of smart structures

Industry usage examples

There are a wide range of successful applications, including offshore rig shafts and drive components for the energy industry, such as boiler tubes and water wall and wind turbine components (**FIGURE 3**). Other uses include cutting blades and knives for the agriculture industry; logging equipment for the forestry equipment industry; guides, rollers, and drawing dies for the steel industry; hydraulic shaft treatment, buckets, and augers for the heavy equipment industry; and specialized drilling and extraction component repair for the mining industry. The process is also used in the digital printing machine industry, paper mills, and the plastic film and textile sectors.

Laser cladding is deployed in manufacturing and repair industries, basically in three different sectors: surface cladding, repair welding, and generative manufacturing. These technologies have been closely associated with the commercial success of laser build-up welding over the past 15 years. The availability of ever-newer generations of laser beam sources have provided the decisive impetus for this successful development. Components in manufacturing/production equipment are often subject to extreme operating conditions that may include oxidation, high temperature corrosion, thermal fatigue, high compressive stresses, and abrasive wear. These conditions result in accelerated deterioration of the functional surfaces and consequentially a reduction in the service life of the component.

It is therefore part of everyday life that when operating any type of mechanical equipment with moving parts, worn metal components need to be repaired or rebuilt. Repairing the component at a fraction of the cost of a new component will save the user a substantial amount of money. In addition, repair of components to original specification will also reduce to need to keep spares, and can significantly reduce downtime if repairs can be implemented rapidly and *in situ*.

When a worn part is rebuilt, the potential also exists to repair that component in such a manner that its performance is enhanced, resulting in a longer wear life than a new part. Because of the unique capabilities of laser-based refurbishment, this process will be suitable for the refurbishment of the vast majority of components and, in some cases, even the enhancement of these components. However, components that will benefit the most from the laser cladding refurbishment process are generally high-value components where refurbishment and servicing occurs on a regular basis. Although refurbishment applications using lasers and donor materials for component repair, surface patterning, and strengthening have been under development for decades, laser-based refurbishment is just now gaining widespread industrial and commercial adoption. The reasons for increased adoption are similar to those for the growth in laser welding: the advent of higher-power laser systems with tailored beam profiles, improved parts quality, and longevity.

For example, **FIGURE 4** shows a slurry pump that experiences excessive wear, colored in blue and outlined by yellow boundary marks. There are 54 tons of production loss each time a pump is taken out of service for replacement, which equates to a $5400 loss based on $100 per ton. The rebuild cost average is $20,000 per pump performed after 4000 hours, or approximately one year of service. Target improvement for a clad liner is 16,000 hrs., or about two years.

The potential of this technology is massive for improving the reliability for new and used components, with research and government groups around the world continuing to contribute to its growth through research programs, industrial applications, and training students in laser cladding techniques.

One of the most important manufacturing considerations today is life-cycle engineering, where the designer must consider both the implications of the part through its service life and the end-of-life disposal of the part. This means that we must now consider the life-cycle implication of a component in terms of its carbon footprint and the long-term impact of the part on the environment.

With refurbishment, by optimizing the design of a product and manufacturing it with absolute minimum material, it is possible to significantly decrease the weight of parts. However, if that part happens to be an aircraft or automotive components, then the life-cycle carbon footprint of the vehicle will be significantly reduced, as the component part made using laser-assist machining will weigh less, generating a lower fuel burden.

Summary

Laser cladding offers numerous advantages as a repair process, providing complete restoration of a part's initial quality as well as its overall enhancement, resulting in improved and longer service life. It thus demonstrates sufficient suitability for the refurbishment of a high-value components. Further research must be undertaken in terms of establishing input, process and output parameter coherence, and necessary empirical adjustments that will lead to development of a knowledge-based controller, which is of crucial importance for the *in situ* refurbishment laser cladding process. ✷

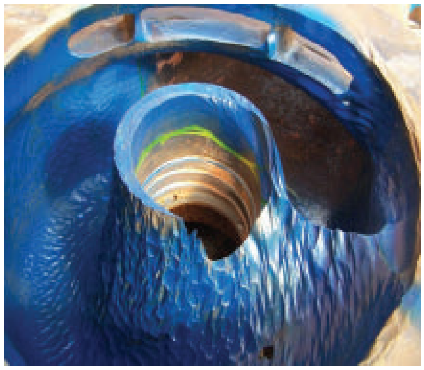


FIGURE 4. A worn refinery slurry pump is shown.

REFERENCES

1. E. Toyserkani, A. Khajepour, and S. F. Corbin, *Laser Cladding*, CRC Press (Aug. 12, 2004).
2. J. A. Folkes, *Surf. Coat. Technol.*, 63, 65–71(1994).
3. W. M. Steen, "Laser surface treatment—an overview," *Laser Processing: Surface Treatment and Film Deposition*, Kluwer Academic Publishers (1996).
4. C. Bremer, "Automated repair and overhaul of aero-engine and industrial gas turbine components," *Proc. ASME*, 4725X, GT2005-6819, 841–846 (Jan. 1, 2005).
5. J. Wang, S. Prakash, Y. Joshi, and F. Liou, "Laser aided part repair – a review," Department of Mechanical Aerospace & Engineering Mechanics University of Missouri – Rolla, Rolla, MO (2002).
6. "Market Analysis & Industry Outlook: Repair & Maintenance," AnythingResearch (Feb. 2018); see https://goo.gl/sSVxLP.

ROGER KAUFOLD *(trotters1@verizon.net) is a surface/coating engineering consultant with his own company, R. W. Kaufold, LLC, in Pittsburgh, PA.*

Solar manufacturing

TECHNOLOGY UPGRADES BECOME ESSENTIAL

FINLAY COLVILLE

Installations of solar photovoltaic (PV) panels are forecast to reach 120 gigawatts (GW) during 2018, compared to 100 GW installed during 2017. This double-digit growth epitomizes an industry that is going through a seemingly unstoppable phase of unopposed end-market acceptance, stimulating upstream technology innovation change at unprecedented rates (**FIGURE 1**).

Growth metrics in the solar PV industry are not simply measured by way of end-market panel deployment. They are also measured at the component manufacturing stages, with cell and module producers being forced to increase investments into research and development (R&D) and technology upgrade processes just to remain competitive.

Capital expenditure (capex) for the midstream segment of the value chain (covering ingot, wafer, cell, and module manufacturing) reached $8 billion in 2017—more than double the investments seen back in 2014, with 2018 expected to be a fifth consecutive year of capex growth (**FIGURE 2**).

Alongside these growth metrics, however, the PV industry is constantly having to adjust its upstream (manufacturing) and downstream (module shipment and installation) tactics and strategies to adapt to a rapidly changing and uncertain global trade landscape that constantly seeks to impose import barriers based on manufacturing country of origin.

This article reviews recent developments in PV manufacturing and technology, discusses the impact on cell and module manufacturers, and highlights the key issues for capital equipment suppliers seeking to benefit from the current round of capacity expansions and technology upgrades.

Specific attention is afforded to laser-based equipment, which remains one of the major beneficiaries of an industry-wide upgrade cycle that is well underway, arising from the necessary addition of passivation layers deposited on the rear side of solar cells. Indeed, this process flow change has even morphed into module product-line nomenclature, simply abbreviated to PERC (passivated emitter rear cell). The PERC revolution in solar cell manufacturing has created the most dynamic and meaningful application for lasers yet seen within the industry.

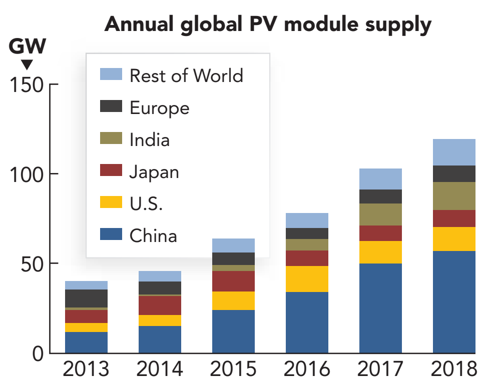


FIGURE 1. Annual solar PV installations reached 100 GW in 2017, with China consuming half of the global demand; growth at the 20% level is forecast for 2018.

China drives solar growth

The growth in solar PV deployment since 2012 has greatly exceeded forecasts. The general consensus a few years ago was that annual deployment of solar PV would hit the 100 GW level during the 2020-2025 period. In reality, this occurred in 2017, providing the first key indicator that solar was finally emerging from a policy-subsidized market to a supply-driven solution to meet the growing global appetite for renewable energy contributions within the overall energy supply mix.

Underpinning this transformation has been the changing role of China, for both component manufacturing and end-market system deployment. This is most evident when reviewing market activity during 2017, when Chinese-owned companies produced more than 80% of the polysilicon, wafers, cells, and modules that served the 100 GW of systems installed during the year.

The signs have been abundantly clear over the past decade that PV manufacturing dominance was a key motivation for Chinese banks being given the go-ahead to release funds to its domestic sector. However, what was not foreseen was the explosive growth in module deployment within the country, moving from 12 GW in 2013 to a projected 60 GW in 2018, and accounting for about half of all end-market solar installations during 2017-2018. **FIGURE 1** confirms the role of China in global market growth since 2013.

Currently, there are no signs that China plans to slow down solar industry investments. Indeed, the government is now seeking to stimulate the domestic manufacturing segment even further, in an attempt to become not simply a low-cost producer of high-volume components, but to match this with technology leadership by having the highest-efficiency solar cells being produced.

While commentary on this Chinese ecosystem provides much of the impetus today for component manufacturing, capex, and equipment supply, solar PV is rapidly gaining widespread acceptance from institutional investors whose due

moves into the 100 GW-plus era

diligence is based purely on return-on-investment at minimal risk. This is driving record levels of investments to install new solar parks globally and, within the burgeoning secondary market, by companies that are mandated to add renewable energy assets to diversified long-term portfolios.

Silicon continues to dominate manufacturing

The use of crystalline silicon (c-Si) wafers for solar cell production continues to meet more than 95% of global end-market supply, with only two prominent companies left pursuing thin-film based technologies—First Solar (Tempe, AZ) using cadmium telluride (CdTe) and Solar Frontier (Tokyo, Japan) with copper indium gallium selenide (CIGS). **FIGURE 3** shows market share contributions from c-Si variants and thin-film production.

Indeed, as the solar industry has moved from a 50 GW market in 2014 to 100 GW in 2017, the scale of c-Si production in China, from its collective base of manufacturers, has firmly set the benchmarks for production cost and selling prices. The only obstacle for the Chinese companies has been to address import barriers arising from trade cases imposed by the European Union and the U.S. Department of Commerce. Until the end of 2017, this was dealt with easily through use of capacity located in Southeast Asia (particularly Vietnam, Malaysia, and Thailand), either as direct company operations or by using a third-party supply of modules.

The dominance of Chinese c-Si producers can be seen clearly in **FIGURE 4**, looking at the top 10 module suppliers to the PV industry during 2017. Nine of the companies are Chinese-headquartered, with Hanwha Q-CELLS the only non-Chinese company. Hanwha Q-CELLS has its main operations now in South Korea, with multi-gigawatt cell and module facilities also in China and Malaysia.

Just a few years ago, having module shipments at the gigawatt level was sufficient to be an industry leader. Now, however, the top module suppliers (in particular, JinkoSolar and Trina Solar) are shipping up to 10 GW annually, with cell and module capacity levels well above 5 GW located across China and Southeast Asia.

In the near-term, it is highly likely this domination will continue. As long as China is accounting for about half of module supply to the PV industry, Chinese-based producers (that exclusively supply the domestic China market) will have a baseline of supply that is not available to non-Chinese companies. This is allowing Chinese companies to have an economy-of-scale that sustains acceptable double-digit gross margins in production, almost regardless of the rate of decline of module pricing.

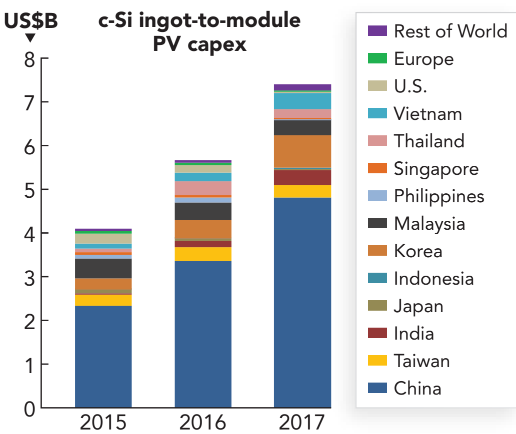


FIGURE 2. Capital expenditure (capex) by PV ingot, wafer, cell, and module producers has nearly doubled in the past few years, driven by new capacity and technology upgrades in China.

China wants to be a technology leader

With Chinese companies now dominating production metrics across the entire value chain, from polysilicon to module stages, the next target for the country is to show technology excellence. This drive started a few years ago, when minimum module efficiency levels were imposed as constraints for deployment to qualify for the Top Runner program implemented by the government.

This had an immediate effect on cell manufacturing that has seen most of the domestic cell producers implement process flow changes to increase cell efficiencies. It has also created a thriving opportunity for PV equipment suppliers to upgrade existing lines, in addition to the healthy order intake for the tool makers coming from new factories built in China and Southeast Asia.

Until the end of 2016, the PV industry—particularly China—was focused on *p*-type c-Si wafer use, as opposed to higher-specification *n*-type substrates that are the cornerstone of the semiconductor industry. The PV industry consumes about 95% of all silicon production.

Indeed, the technology focus in China, which led to the country's dominance in production, was largely from using multi c-Si wafers produced by using slurry-based wire saws to slice silicon bricks grown in casting furnaces. This low barrier-to-entry route was a perfect fit for the Chinese companies, and led to *p*-type multi c-Si cell production having about 75% market share as the industry moved beyond the 50 GW annual deployment mark.

However, in the past couple of years, this has all changed. While the driver was in part coming from the domestic competition within China to have higher performance modules, the industry as a whole is now moving quickly to using *p*-type mono wafers, where the ingots are produced using Czochralski-based pullers and sawed into wafers using diamond wires.

The use of mono c-Si wafers had always been a motivation for solar cell producers to push average efficiency levels of cells above 20%. However, the lack of any major supplier for mono wafers had previously hindered any market-share gains against *p*-type multi wafers.

The catalyst for change has come from the highly ambitious and successful strategy of just one company based in China—Xi'an LONGi Silicon Materials (branded as LONGi Solar; Shanghai, China). This company set out a clear plan years ago to become a multi-gigawatt, low-cost supplier of mono c-Si wafers—something that had never been done before. By the end of 2017, LONGi Solar had accumulated 15 GW of mono ingot pulling and diamond-wire wafering in China, and now plans to add about 10 GW per year for the next three years, to reach 45 GW of mono wafer capacity at the end of 2020.

More recently, another Chinese-based company—Tianjin Zhonghuan Semiconductor (or Zhonghuan) — has joined LONGi Solar in having mono capacity levels measured in the tens of gigawatts. Collectively, these two companies have created the supply channel for *p*-type mono that has allowed cell manufacturers to make the shift from multi to mono, in the knowledge that wafer supply is available at cost-per-watt prices competitive with *p*-type multi wafer supply.

Consequently, the PV industry technology landscape is now going through a radical transition to mono c-Si, resulting in increases in module efficiencies (and panel powers) that are forcing every company to have high-efficiency cell lines in place. This shift from multi to mono is also accelerating the change in rear-side cell processing, where passivation layers are now being deposited as standard, replacing the legacy aluminum-based back-surface field approach that was the norm with screen-printing tools. This new cell architecture (simply known as PERC) has created the first major application for lasers in the PV industry.

Investments flow into *n*-type technologies

Going back 20 years in the PV industry, every roadmap was based upon technology finally moving from *p*- to *n*-type mono cell production. However, the economics did not stack up, and the challenges in producing 23–25% cells in mass production were beyond the capability of the entrants that currently dominate cell production with *p*-type capacity.

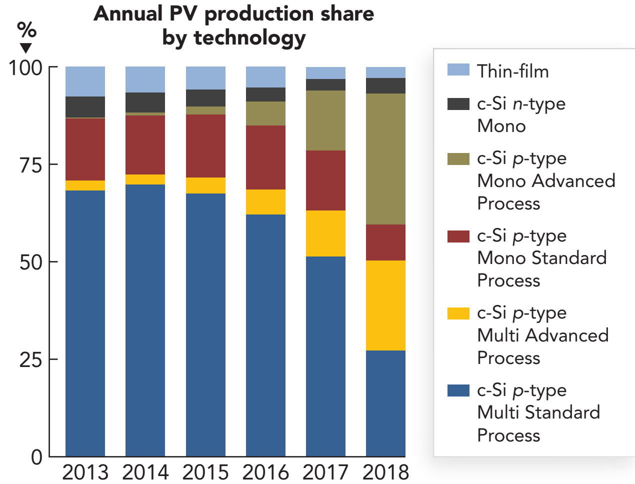


FIGURE 3. Until 2016, standard processed c-Si *p*-type solar cells dominated PV production; during 2017, *p*-type mono cells have increased market-share contributions in addition to advanced process flows including PERC cells.

The use of *n*-type wafers allows performance levels above the best-in-class *p*-type variants, a fact demonstrated by the first two companies that succeeded in scaling gigawatt-level operations with *n*-type: SunPower (San Jose, CA) and Panasonic (Osaka, Japan; through inheriting the former Sanyo PV business in Japan).

The rapid price erosion of module average selling prices (ASPs) since 2012, resulting in module prices in the $0.30–0.40/watt range, has left SunPower and Panasonic with marginally profitable operations, and has somewhat consigned *n*-type to niche-offering status.

However, in its drive to show technology leadership, the Chinese government is now seeking to create a manufacturing base within China to push *n*-type capacity. The vehicle for this is coming from the creation of the Super Top Runner program with 1.5 GW of domestic module demand on offer to higher-performing modules that necessitate the use of *n*-type production.

With state backing in China, investments are now flowing into new capacity for *n*-type production and, in particular, heterojunction-based solar cells that had been the exclusive domain of Panasonic to date. The plan within China is to match the performance levels of Panasonic, but with much lower capex and operating costs, and using deposition equipment manufactured within China by Chinese-owned tool suppliers.

This new initiative remains highly ambitious and not without considerable risk, as most of the process know-how for *n*-type heterojunction resides with equipment suppliers outside China (and Panasonic), and almost all of the Chinese companies seeking to disrupt the industry have little, if any, previous experience producing solar cells.

However, the threat to *p*-type producers cannot be dismissed, even if just one of the new entrants manages to scale to the gigawatt level with *n*-type production. If this does happen in the next 2–3 years, and the technology is shown to be cost-effective in high volume, then it could be expected that many companies showing in the top-10 ranking list for 2017 will make the necessary adjustments to in-house cell capacity and add *n*-type production lines.

PERC: the first major application for lasers in PV

For laser-based equipment supporters following the PV industry in the past, there was no shortage of false alarms in terms of applications that could create strong revenue streams. The lack of success, however, left the laser industry somewhat disillusioned with the PV sector, with applications such as thin-film patterning, laser edge isolation, through-hole via drilling, and laser doping offering nothing but lumpy new-order-intake blips.

By the end of 2018, however, virtually every solar manufacturing line will have laser tools operating at key process flow stages. The major driver is coming from one application: PERC. However, it is also noteworthy to discuss briefly what is happening with thin-film solar manufacturing, as there is a mini-boom happening here as well.

Thin-film PV manufacturing that demands multiple laser tools being used in production lines can broadly be split into three categories: First Solar with its expansion plans; Solar Frontier fighting to retain profitable operations and seeing declines in production output; and another phase of Chinese optimism that has the hallmarks of one-off R&D spending to bolster the balance sheets of a handful of European equipment suppliers.

First Solar (as the only CdTe provider) is currently investing $1 billion over a 2- to 3-year period to replace its legacy 2–3 GW of Series 4 panels (600 × 1200 mm) with Series 6 panels (1230 × 2003 mm). Furthermore, the company is setting up additional capacity in Vietnam, complementing the main production site in Malaysia. Loyal to its equipment suppliers that have been instrumental to the success of Series 4, most of the original suppliers are contracted now to deliver the equipment for Series 6. This includes LPKF Laser & Electronics (Garbsen, Germany) for the laser-based patterning equipment, making the company the only laser-based tool supplier to truly benefit from the thin-film euphoria that engulfed the sector until 2012.

The major opportunity for laser tools, however, is coming from PERC cell production, both with new capacity being installed (both *p*-type mono and multi), and upgrades to existing *p*-type lines. Currently, most of the legacy *p*-type mono cell capacity has been upgraded to PERC, and the focus during 2018 and 2019 is moving *p*-type multi to be 100% PERC-compliant. This represents a massive driver for laser-based tools, in ablating contact openings in the passivated layers on the rear side of cells.

Laser tool supply has been met until now by system integrators InnoLas (Krailling, Germany) and 3D-Micromac, with lower volumes supplied by the former Rofin-Sinar Technologies systems business based in China (now absorbed within Coherent). The majority of supply though is coming from laser tool supplier Wuhan DR Laser Technology (Wuhan, China), with a further 5–6 Chinese tool suppliers also selling into the China PERC upgrade space.

What's next for PV technology and laser tooling?

The solar PV industry has now moved firmly into a new phase of strong global growth that will propel annual deployment from 100 GW in 2017 to terawatt levels by 2030. Industry-leading manufacturers are now counting in-house capacities in the tens of gigawatts, with plans to continue growing production to match industry supply levels.

Top-10 PV module suppliers in 2017

RANKING	PRODUCER
1	JinkoSolar
2	Trina Solar
3	Canadian Solar
4	JA Solar
5	Hanwha Q-CELLS
6	GCL-SI
7	LONGi Solar
8	Risen Energy
9	Shunfeng (incl. Suntech)
10	Yingli Green

FIGURE 4. The top-10 module suppliers (by shipment volume) to the PV industry in 2017 included nine companies headquartered in China, with Hanwha Q-CELLS being the exception (Korea operations); the top-10 companies supplied almost 60% of PV modules in 2017.

Solar cell efficiency is moving into the 20%-plus bracket as a standard offering, with advanced *p*-type structures and *n*-type architectures set to dominate production. Over the next couple of years, however, the PERC upgrade phase will dominate much of the process flow changes for mainstream *p*-type cell producers in China, sustaining healthy order intake levels for laser tool suppliers.

During 2019, it is expected that the next phase of technology upgrades will gain traction, either based upon full industry migration to bifacial *p*-type offerings, or seeing a stronger contribution from *n*-type production, including heterojunction-based solutions.

FINLAY COLVILLE *(fcolvlle@pv-tech.org) is head of research at PV-Tech & Solar Media, London, England; www.solarmedia.com.*

Fiber laser enables successful weldi

TECHNOLOGY YIELDS HIGH-SPEED, SPATTER-FREE PROCESSING OF METALS

JARNO KANGASTUPA

While fiber lasers are widely used for metal welding and cutting, there are some applications in which they still deliver less-than-ideal results. Welding of zinc-coated steel and aluminum are two important examples. This article presents a new embodiment of fiber laser technology that overcomes the prior limitations of fiber lasers in these applications.

Welding zinc-coated steel

Various types of zinc-coated steel are used extensively in automobiles as well as other applications where corrosion is an issue, such as in agricultural equipment and construction. However, in the past, zero-gap lap welding zinc-coated steel has presented a challenge for laser welding, as zinc has a substantially lower boiling temperature than steel. As a result, it evaporates first when the laser energy is applied to the material, and this creates gas pressure that can blow out the molten steel, resulting in an inconsistent weld seam as well as spatter that needs to be subsequently cleaned. There's no easy way to control these dynamics with a single focused spot, because the laser power required to open and maintain the welding keyhole also produces a turbulent, unstable melt pool.

This problem is mitigated by either dimpling the material to create gaps, or adding spacers between the metal sheets, so that there is sufficient space (~0.1–0.5 mm) for the vaporized zinc to vent in a controlled manner to the side, rather than the top, of the keyhole. One major challenge with this approach is that it's difficult to maintain a consistent small gap between the sheets for parts with complex, three-dimensional shapes, such as car doors. It's far easier to create fixtures that clamp parts tightly together.

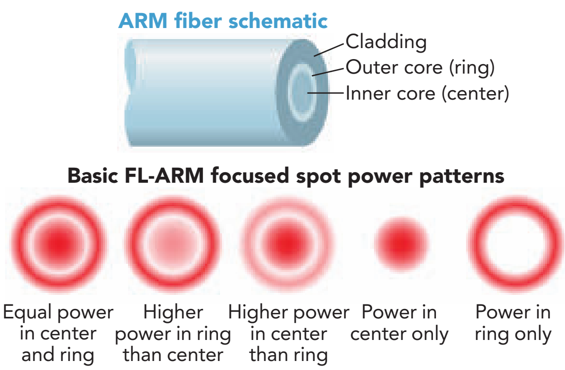


FIGURE 1. The simplified ARM fiber schematic and the five basic power patterns possible in the focused laser spot are shown.

Aluminum welding

Electric cars are becoming increasingly popular with consumers, creating a growing need to weld the aluminum cases of the lithium batteries used in these vehicles. Specifically, the battery manufacturer must weld the top onto this case to obtain a hermetic seal over the lifetime of the component. It's critical that this seal prevent moisture infiltration because water reacts strongly with lithium, creating gas and pressure that could destroy the device. Furthermore, it's important that the welding process produce no spatter, as metal particles (as well as moisture) can create internal leakage currents that would short-circuit the battery. Finally, the weld must be mechanically strong enough to withstand rough treatment, or even the shock of a collision.

Sealing the aluminum battery case has traditionally been performed using laser conduction welding because the battery walls are thin (<1 mm). However, using conduction welding, it's difficult to achieve sufficient penetration to produce a strong-enough weld with sufficiently low porosity to prevent the intrusion of moisture. But, using higher laser powers to achieve a deeper penetration (keyhole) weld runs the risk of deforming the casing, and virtually always causes some spattering.

FL-ARM technology

Past methods to eliminate the spatter problem experienced when processing certain materials with a fiber laser have included performing the laser process in a chamber at far below atmospheric pressure (in the millibar range), or drastically reducing the feed rate. But, these ultimately reduce throughput or create practical difficulties that negate the inherent advantages of the fiber laser. Until recently, there was no technique that could deliver fiber laser power in a manner that enables very precise control over the dynamics of the melt pool, supports market-enabling throughput, and is simple to implement.

Extensive development work at the Coherent applications laboratory in Tampere, Finland, has proven a new solution for high-speed, spatter-free processing of metals. This is achieved by modifying the intensity profile of the focused laser spot on the workpiece so that it departs significantly from the traditional, single-peaked Gaussian distribution. This research has shown that a beam consisting of a central Gaussian distribution spot, surrounded by another concentric ring of laser light, can often provide an effective approach.

Achieving this unusual configuration in the focused fiber laser spot is accomplished using Coherent's FL-ARM specialized ring

ng of difficult materials

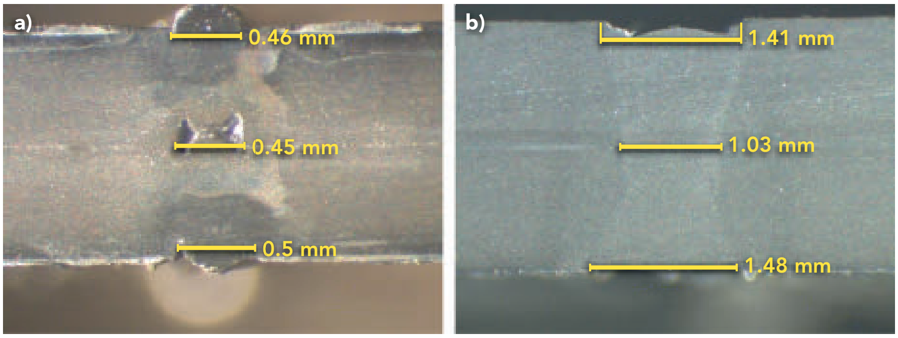


FIGURE 2. **Cross-sections show the weld seam for 1.25-mm-thick zinc-coated steel processed using a fiber laser without a gap between the sheet and at a feed rate of 3.3 m/min, where conventional laser focusing creates a seam with voids (a) and the FL-ARM creates a weld seam with excellent uniformity and no porosity (b).**

laser combiner and delivery fiber, developed by the company's site in Finland (formerly Corelase). This fiber has a traditional circular core surrounded by another annular cross-section fiber core.

These systems can be built incorporating output from one to four separate fiber lasers, thus providing total maximum output powers from 2.5 to 10 kW. No matter what the exact configuration, in all cases the total beam profile (that is, the power in the center and the ring) can be independently adjusted on demand. Separate closed-loop power control systems for the center and ring beams also ensure excellent stability over the entire power adjustment range, which is from 1% to 100% of the nominal output maximum output. The core and ring beams can even be independently modulated, at repetition rates up to 5 kHz.

In this arrangement (**FIGURE 1**), there are virtually an unlimited number of possible combinations in terms of the power ratio of the inner to the outer beam. However, all these can be broadly grouped into the configurations shown in the figure. These basic patterns can then be varied to deliver a wide range of processing characteristics to optimally service a diverse set of applications.

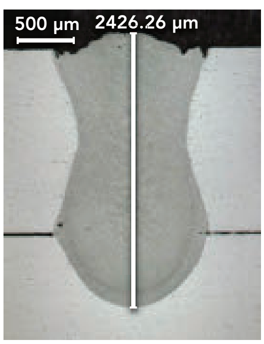


FIGURE 3. **This cross-section of a weld in stack of two 1.6-mm-thick 5000 Series aluminum parts shows deep penetration with no pores or spatter.**

Applications results

Testing of this technology on zinc-coated steel sheets has proven the ability to perform welding without the need for a gap between the parts. In this case, the beam is configured to have power in both the center and the ring, as opposed to the traditional single laser spot. The ring is primarily responsible for performing the welding, although it divides the process into two steps. First, the leading edge of the outside ring pre-heats the workpiece, while the additional energy required to perform welding is delivered by the trailing side of the ring. Dividing the supplied laser energy in two and spreading it out over a larger area produces a larger melt pool and reduces the temperature gradient in the material, all of which reduces spatter (**FIGURE 2**).

At the same time, the center spot maintains the keyhole (at a lower temperature than at the edges), which pushes molten material to the sides. This allows the zinc gas to vent out easily through the center without producing any spatter, even when the parts are clamped together with zero gap.

Also, because the ring beam is rotationally symmetric, the orientation of the beam doesn't have to be changed to follow the direction of the weld seam, which might vary substantially on a contoured or shaped part. This greatly simplifies its implementation.

Keyhole welding can be performed successfully in this application with the FL-ARM laser. The result is a strong weld absent of deformation. Again, the beam is configured with power in both the center and in the ring.

This approach works because the leading edge of the ring beam raises the aluminum temperature sufficiently to increase its absorption at the laser wavelength. Then, the center of the beam creates the keyhole, which is now very stable because of the pre-heating. The trailing edge of the ring beam sustains the melt pool sufficiently to allow gas to escape. Because the keyhole is stable and the material doesn't resolidify as fast, the entire process is more consistent and the process window is larger. The ultimate result (**FIGURE 3**) is uniform, consistent material penetration and higher-quality, porosity-free welds without spatter.

Fiber lasers are used in many industrial processes, but no single product embodiment is optimum for every use. This is the reason that laser manufacturers, such as Coherent | Rofin, have developed a broad range of different fiber laser implementations. The company then pairs these products with extensive process knowledge to extend their utility, delivering better results such as reduced spatter, improving throughput, and reducing production costs for the user. ✺

JARNO KANGASTUPA *(jarno.kangastupa@corelase.fi) is business director & product line manager of custom fiber lasers at Coherent, Tampere, Finland; www.coherent.com.*

RV industry supplier

FIBER LASER CUTTING TECHNOLOGY INCREASES PRODUCTIVITY LEVELS

ROBERT KOLCZ

In 2017, North American RV shipments hit their highest level ever, according to the Recreation Vehicle Industry Association, marking the industry's ninth consecutive year of gains. Those shipments are accelerating and should grow even more in 2018, the group said.

Through hard work, great timing, smart fabrication equipment procurement, and a strong employee base, sheet metal fabricator Rock Run Industries (Millersburg, IN) has been able to ride this strong RV wave to register some very impressive growth. Located near Elkhart, IN, known as the RV Capital of the World, the company was founded by Fritz Schlabach in 2007. Schlabach quit his full-time job in the mobile home industry, and purchased an old punch press and other used equipment. Today, the company has grown to 45 employees housed in a 37,000-sq-ft. building for offices and fabrication, and a small powder coating facility that will soon be relocated to a 36,000-sq-ft. building. Since 2013, the company has doubled its sales.

"The RV industry is very demanding," Schlabach explains. "We are a high-mix, low-volume industry with short lead times—less than two weeks most of the time. To meet the JIT [just-in-time] demands of our customers, we began searching for new equipment. We made our first new equipment purchase in January 2015—a Prima Power E6x turret punch press with modern servo-electric punching productivity [**FIGURE 1**]. We found we liked their servo-electric technology. And a year later, we were looking for a laser and a press brake. We looked at other brands, but because of the excellent service on the turret punch press, we selected them for the fiber laser and servo-electric press brake."

Fiber laser cutting

Rock Run Industries purchased the Prima Power Platino 2.0 fiber laser with a 10-station tower, which was installed in March 2016 (**FIGURE 2**). This machine is the right choice for sheet metal manufacturers looking for a production tool that is efficient, providing energy and maintenance savings; productive, particularly on thin- and medium-gauge sheets; flexible and suitable for a wide range of materials, including highly reflective metals; reliable and capable of meeting any production need, with a variety of automation modules; and user-friendly, easy to install, and maintain.

The fiber laser can be used to cut a wide range of materials. Fiber lasers are more effective than other laser sources for cutting highly reflective materials such as aluminum alloys, copper, and brass. The Platino 2.0 fiber laser cuts various thicknesses, up to 20 mm of mild steel, with efficiency and quality. Productivity increases particularly with thin- and medium-gauge sheet metal.

Outdoor kitchen cabinetry is a relatively new product for Rock Run Industries that utilizes galvannealed steel for the countertops and doors. "We are cutting a large amount of 16-gauge galvannealed steel every week," Schlabach explains. "We had a CO_2 laser, but it didn't do that good of a job on coated materials like galvannealed. As a result, we were outsourcing all of this work. When we bought the Platino fiber laser, we brought that work back in-house."

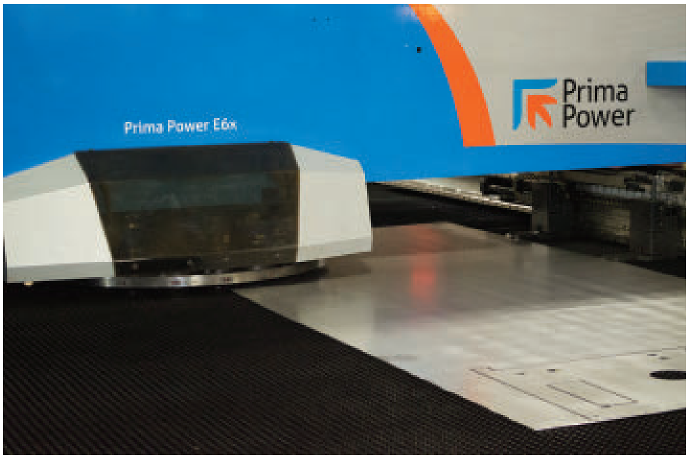


FIGURE 1. The E6x turret punch press features modern servo-electric punching productivity.

wins with laser cutting

FIGURE 2. The Platino 2.0 fiber laser, with a 10-station tower, cuts a wide range of materials.

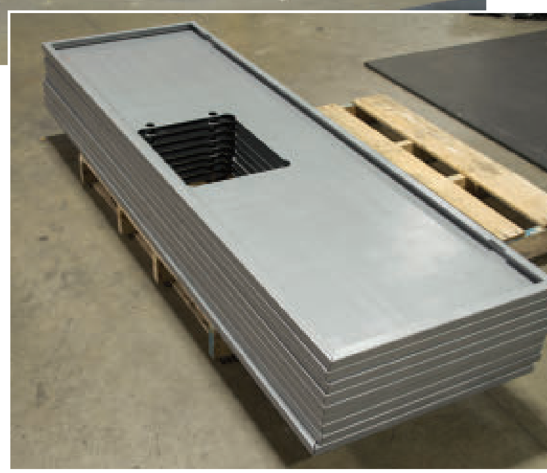


FIGURE 3. The TowerServer allows easy loading/unloading for blanks and processed sheets (inset).

Flexible automation

The compact TowerServer allows easy loading/unloading for blanks and processed sheets (**FIGURE 3**). It has an elevator for loading and unloading the pallets on and off the tower, and features single-sheet separating, control systems, and sheet reference.

It is particularly suitable for lights-out operation, often performed in unattended mode. It is a fully independent machine, with no need for manual intervention during machine operation. Once the production schedule is programmed, this laser system takes care of the necessary settings, tip replacement, and sheet change and storage, among other tasks.

"We bought a 10-shelf compact tower because we don't have a lot of room in our shop and also wanted to do lights-out production," Schlabach says. "The Platino fiber laser and tower has a small footprint that fits our shop. It has allowed us to bid jobs and be confident that we have the capacity to complete the job on time. If needed, we can run the unmanned extra shift on the laser without adding people."

Servo-electric press brake

A Prima Power eP servo-electric press brake was also installed at Rock Run Industries in 2016 (**FIGURE 4**). The design of this high-precision brake is based on the company's extensive experience in press brakes and servo-electric machine tools in the metalworking industry. The eP servo-electric brake reduces the costs to form metal components by lowering operating costs, increasing productivity, and reducing setup time.

"The eP-1030 servo-electric press brake is very accurate," Schlabach says. "In fact, the repeatability is so great that the welders request any jobs in lighter gauges to run on the ep-1030. We keep the Prima Power machines quite full of production...we don't have the luxury of being down a day or two."

FIGURE 4. The eP servo-electric brake reduces the costs to form metal components by lowering operating costs, increasing productivity, and reducing setup time.

FIGURE 5. The BCe panel bender is ergonomic, and can produce radius bends and hems that press brakes cannot.

Panel bender

Rock Run Industries' latest addition, a Prima Power BCe panel bender, was installed at the company late in 2017 (**FIGURE 5**). "We purchased the BCe Smart to run the galvannealed product," Schlabach says. "There are many 6-ft.-long panels that are 2.5 ft. wide and weigh approximately 40 lbs. When we make these on the press brake and put a flange on a 6-ft.-long part, the operator is lifting the part up past his head, and then flips the part. You can't do this type of work year after year and not create some type of physical problem. So instead of buying another press brake, we decided to go with the panel bender. It is faster, a lot more ergonomic, and it can do bends that press brakes can't, such as radius bends, hems, etc. It will allow us to offer more options and versatility to our customers."

Customer satisfaction

Rock Run Industries currently offers sub-contract work for over 150 different RV OEM plants. "Our customers will check on us from time to time," Schlabach explains. "They want to make sure that we have the modern equipment that will run every day. They will come to our plant and inspect. They are knowledgeable customers, and they have to be comfortable working with us on a just-in time [JIT] basis."

"The addition of the Prima Power equipment has been a big part of our success," Schlabach continues. "It has allowed us to supply a high-quality part at a very competitive price that we can deliver to our customer on a JIT basis."

"We made the decision to purchase the BCe Smart based on the service we have received from Prima Power," Schlabach concludes. "It's the people at Prima Power that make the difference."

ROBERT J. KOLCZ *(bob.kolcz@primapower.com) is director of marketing and corporate communication for Prima Power North America, Arlington Heights, IL; www.primapower.com.*

Women make strides in laser manufacturing leadership

OPPORTUNITIES FOR WOMEN, FROM THE SHOP FLOOR TO UPPER MANAGEMENT, ARE GROWING

RYAN FORSELL

FIGURE 1. Teresa Beach-Shelow, president and co-founder of Superior Joining Technologies (SJTI).

Teresa Beach-Shelow (**FIGURE 1**) founded Superior Joining Technologies (SJTI; Machesney Park, IL) with her husband Thom Shelow in 1992. The business started in their garage and after four relocations because of continuous growth, it now occupies a 55,000-sq-ft. facility in Machesney Park.

While growing their business, Teresa noticed lasers being used as the next big advancement in manufacturing and knew her business needed these advanced processing tools. The company purchased its first laser for micro-welding applications and as this business grew, demand produced the need for a second micro laser. The company's focus has always been towards precision joining of metals, which led to the slogan "Joining with You." It now has five lasers in-house, ranging from a micro-yttrium aluminum garnet (micro-YAG) laser for welding to a multi-axis CO_2 5 kW laser for cutting and welding (**FIGURE 2**).

Welding and cutting capabilities

In 2010, Teresa purchased a large Trumpf TruLaser 7040 laser cutting system to assist their own production schedule and bring outsourced laser cutting processes back in-house. This purchase opened the door for both multi-axis laser welding and cutting of parts. SJTI now has a precision welding laboratory with unique capabilities to assist its existing customers and new customers. Why use lasers for welding, some may ask? Lasers reduce the heat-affected zone, as well as post or any secondary operation to the welded area. There is generally no need for grinding or weld recovery needed when using a laser to weld materials.

SJTI uses its lasers daily to manufacture parts for the aerospace, dairy, and medical industries (**FIGURE 3**). Laser welding is continuously improving and reinventing its uses in manufacturing. Laser welding is already in the next big phase of lasers now hitting the market with laser additive welding. This type of process is being used in all industries, including the aerospace market, which is moving closer to implementing this type of process. The company is preparing for its next laser purchase to stay competitive in the marketplace, and its welding and cutting capabilities achieve consistent results.

Examples of such precision are obvious with the welding of intricate assemblies for aerospace and medical applications. Micro laser welding gives SJTI the ability to join components smaller than the human hair for customers across North America. The company has been able to serve customer needs by applying micro laser welding to join gear assemblies that are not much larger than the head of a pin. This is accomplished without compromising the hardened condition of the critical features of the gear.

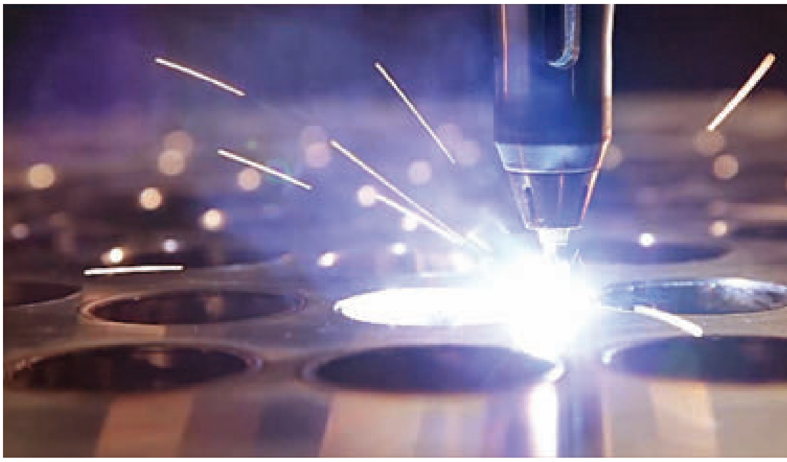


FIGURE 2. High-power laser beam welding is shown in action.

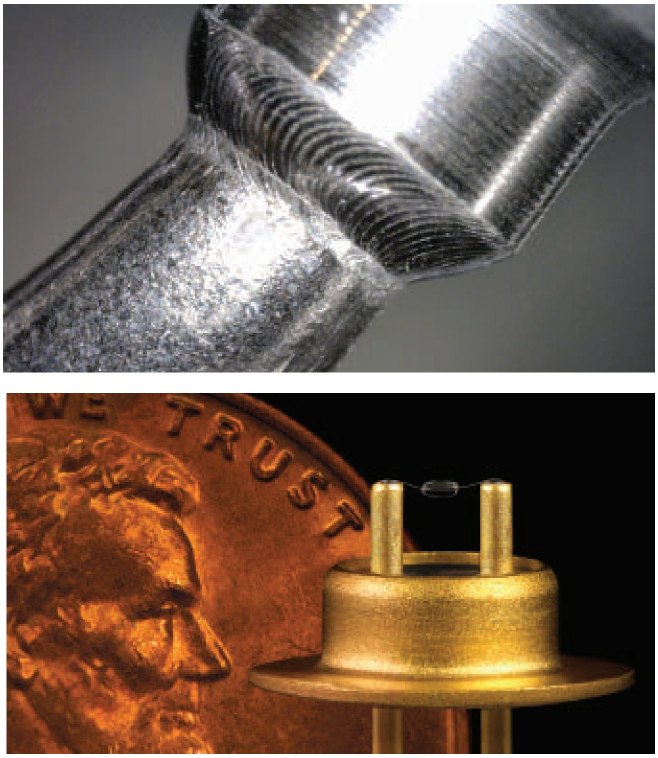


FIGURE 3. Examples of micro-welded components are shown.

Manufacturing association and community support

Teresa's role as president stemmed from her background in finance and business. With her husband's welding and laser expertise, they started taking orders and networking their capabilities. With her dedication to the community and the future of the business, SJTI joined several manufacturing associations and started supporting local science, technology, engineering, and mathematics (STEM) events. She co-founded Women of Today's Manufacturing, an organization that raises scholarship funds for students to further their education in STEM-related fields. She continues to be involved with several manufacturing associations, held a board chair for the Fabricators & Manufacturing Association (FMA) in 2015, and is now being elected to the board for the Tooling Manufacturing Association (TMA) for 2018.

As president of SJTI, Teresa oversees the Quality Department, and has been involved with every ISO 9001, AS9100, and National Aerospace and Defense Contractors Accreditation Program (Nadcap) accreditation that the company has achieved. In 2017, Teresa and her team gained their second Nadcap accreditation for laser welding and fusion welding (**FIGURE 4**). This Nadcap laser welding accreditation has been issued to less than 20 companies in the U.S. They also achieved AS9100 Rev D later in 2017. SJTI continuously works to maintain and keep its high quality of accreditations for their customers. It was the first laser-approved supplier to the United Technologies Aerospace System (UTAS) for laser welding. Teresa assisted UTAS with writing the certifying documents during this approval process.

Despite her many recognitions as a co-founder and board member of numerous manufacturing organizations, as well as 20+

FIGURE 4. The SJTI team gained its second Nadcap accreditation for laser welding and fusion welding in 2017.

successful years of supplying the aerospace industry, Teresa is proudest of her volunteer work with young people and displaced workers, encouraging them to choose manufacturing as a career. As co-founder of Women of Today's Manufacturing, a northern Illinois-southern Wisconsin group, she created Manufacturing Camp, a one-week camp for teens, as well as camp scholarships. Her effort reached more than 100 regional students.

It grew into a nationwide project with nearly a dozen camps every summer when the Foundation of the FMA brought the effort under its wings. Now called "Nuts, Bolts and Thingamajigs," it has influenced nearly 4000 youths in 27 states.

Teresa and Thom now support several area robotic teams, Lego teams, and The Quiz Bowl (a high-school TV show), and Teresa dedicates her time to local Manufacturing Days, Engineering Days, and Career Days throughout the year. With such a large amount of manufacturing employees nearing retirement, SJTI feels that by involving the kids early on in STEM-related events sparks their interest in manufacturing and will hopefully enter the manufacturing industry to help offset some of the open positions manufacturing will have soon. By dedicating their time and open space to students of all ages who are interested in manufacturing, it gives them a type of assurance that they and all manufacturing companies will continue to have great employees with amazing capabilities for our future generation of manufacturing.

Women in manufacturing

Teresa was recently interviewed and had this to say about the future of women in manufacturing: "I encourage women to enter the manufacturing industry for the opportunities that are available, from the shop floor to upper management. Wage gaps are shrinking, and women are becoming more visible within the industry in higher management roles and ownership positions. Manufacturing is a career that gives immediate gratification of being part of a team that creates something and does not always require the traditional four-year degree, as training offerings can vary. The stigmas of manufacturing are going away with more programming and robotics being used throughout the shops."

RYAN FORSELL *(ryan@superiorjt.com) is a sales representative at Superior Joining Technologies (SJTI), Machesney Park, IL; www.superiorjt.com.*

CALENDAR

MARCH

27-28 Laser Additive Manufacturing (LAM) Conference, Schaumburg, IL; www.lia.org/conferences/lam

28-29 Lasers for Manufacturing Event (LME) 2018, Schaumburg, IL; www.lia.org/conferences/lme

APRIL

8-12 Additive Manufacturing Users Group (AMUG) Conference, St. Louis, MO; www.amug.com/amug-conference

23-26 RAPID 2018, Fort Worth, TX; www.rapid3devent.com

MAY

2-4 AKL - International Laser Technology Congress (AKL'18), Aachen, Germany; www.lasercongress.org/en/home

2-4 FABTECH Mexico 2018, Mexico City, Mexico; http://mexico.fabtechexpo.com

16-18 Industrial Laser Safety Officer Training, Novi, MI; www.lia.org/training/non-medical/classroom-courses/industrial-laser-safety-officer-training/2018-05-16

JUNE

5-7 LASYS 2018, Stuttgart, Germany; www.messe-stuttgart.de/en/lasys

11-15 Laser Safety Officer with Hazard Analysis Training, Niagara Falls, NY; www.lia.org/training/non-medical/classroom-courses/laser-safety-officer-hazard-analysis-training/2018-06-11

12-14 Laser Safety Officer Training, Indianapolis, IN; www.lia.org/training/non-medical/classroom-courses/laser-safety-officer-training/2018-06-12

12-14 FABTECH Canada 2018, Toronto, ON, Canada; http://fabtechcanada.com

24-26 The 3rd Smart Laser Processing Conference 2018 (SLPC2018), Yokohama, Japan; www.jlps.gr.jp/slpc2018

25-28 19th International Symposium on Laser Precision Microfabrication, Edinburgh, Scotland; www.jlps.gr.jp/lpm/lpm2017

26-28 Additive Manufacturing Europe 2018, Amsterdam, Netherlands; www.amshow-europe.com/welcome-additive-manufacturing-europe

JULY

10-12 SEMICON West 2018, San Francisco, CA; www.semiconwest.org

10-12 The International Conference on Additive Manufacturing and 3D Printing, Nottingham, England; www.am-conference.com

15-20 21st Ultrafast Phenomena Conference, Hamburg, Germany; www.up2018.org

AUGUST

15-16 Industrial Laser Safety Officer Training, Novi, MI; www.lia.org/training/non-medical/classroom-courses/industrial-laser-safety-officer-training/2018-08-15

INDEX OF ADVERTISERS

Laser welding is a hot application

OPPORTUNITIES ARE GROWING FOR SEVERAL APPLICATIONS

Several decades ago, I entered the industrial laser business with an interest in lasers' possibilities as a welding process. This was the early days for lasers as an economic alternative to similar processes like electron beam and tungsten inert gas (TIG). My background in welding included these two, plus resistance-spot and flash-butt welding—so I knew a little about joining metals in an industrial environment. Then, the workplace environment was one of the key factors for a cool reception from welding engineers.

In the 1970s, the nascent industrial laser industry was trying to convince the market that laser technology was suitable as a factory floor process. The products were transitioning scientific devices, not even dressed up to compare to a conventional welder. Then, I had the hutzpah to walk the floor in a plant with a welding engineer pointing out the joining operations that could be replaced with a laser.

Looking back, I know why the few applications that made it then were accomplished with the unwavering support of a few laser welding industry pioneers—called 'risk takers'—ready to defend this new technology within their companies. I'd like to construct an honor roll of these prescient engineers. If any of you are reading this, consider this as a big pat on the back.

Today, laser welding is an accepted industrial process in plants around the world, in the auto, energy, aerospace, medical devices, agriculture, and heavy equipment industries, to name a few. In this issue, with its Hot Applications and Welding Advances themes, we will be featuring joining opportunities for a new crop of industrial lasers, led by fiber lasers.

Starting our series on laser welding is the cover feature of this issue contributed by Tomáš Mužík, who describes the laser welding of brass musical instruments at venerable Amati-Denak in the Czech Republic (see page 9). Formerly soldered by craftsmen, the formed blanks are now laser-welded. Jarno Kangastupa from Coherent-Finland shows how a new fiber laser technology overcomes the prior limitations of fiber lasers in welding zinc-coated steel and aluminum, both of which are susceptible to spatter from fusion joining processes (see page 24). And Ryan Forsell (Superior Joining Technologies) profiles Teresa Beach-Shelow, who established Superior Joining Technologies 25 years ago in Machesney Park, IL, with her husband Thom Shelow. She noticed lasers as the next big thing in manufacturing and knew her business, of which she is president, needed these advanced processing tools. Their first laser was purchased for micro-welding applications and soon demand produced the need for a second micro laser. Today, the company has four laser welders and is about to add another (see page 29).

On other topics, solar photovoltaic cell expert Finlay Colville is back with us, who presents his view on the key drivers behind end-market deployment within this sector and the uptick in the use of laser-based tools for rear-side contact openings as part of passivated emitter rear contact cells (see page 20).

Laser cladding consultant Roger Kaufold describes how laser cladding technology is being used in the repair and reconditioning of all types of mechanical components in a great primer and update on the process (see page 15). And finally, as Bob Kolcz (Prima Power) writes, the RV industry is showing impressive growth, so one supplier, Rock Run Industries (Millersburg, IN), purchased a fiber laser with a 10-station tower that cuts up to 20 mm of mild steel, with efficiency and quality (see page 26).

David A. Belforte
belforte@pennwell.com

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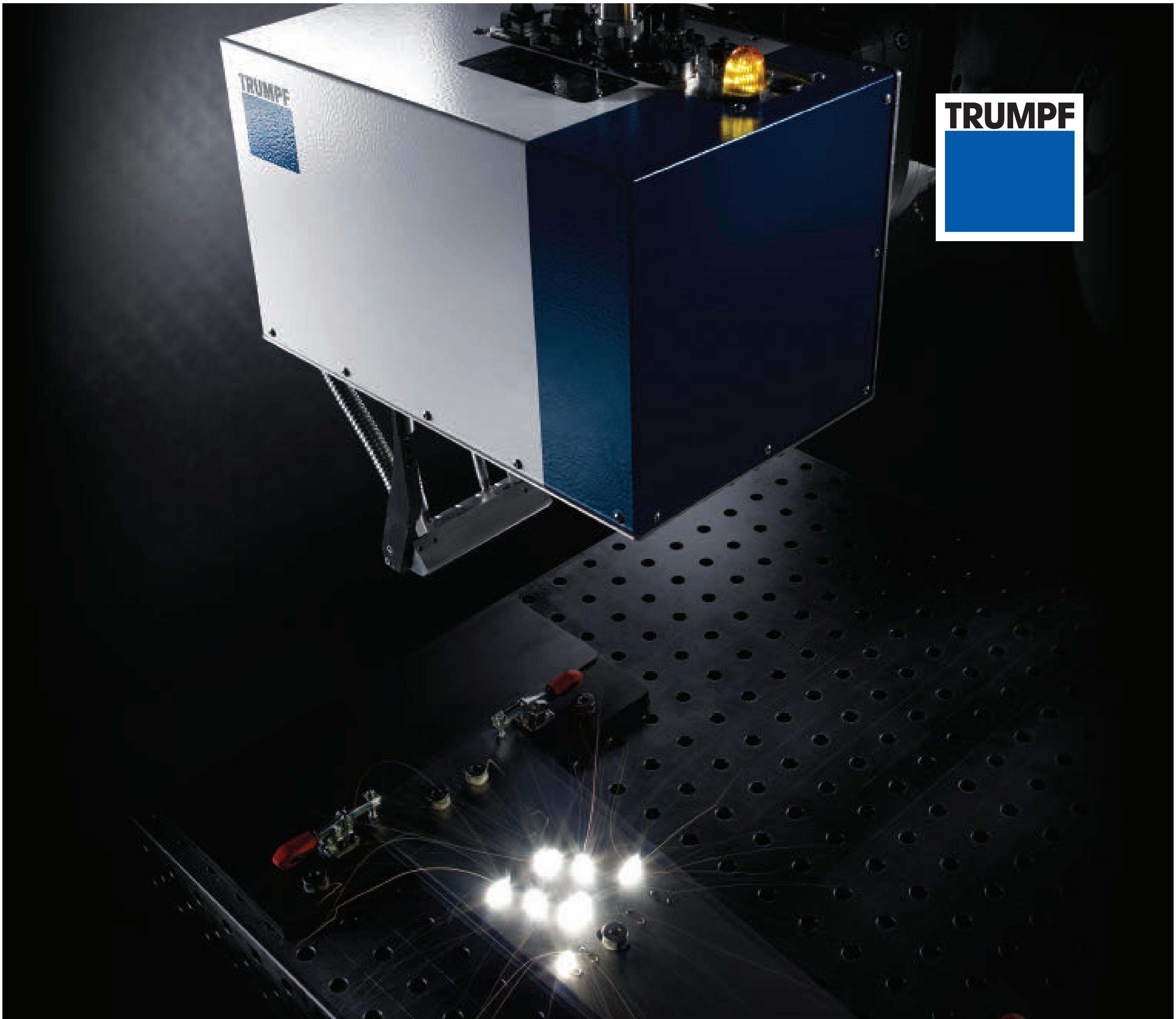
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