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P.2

In less than 25 years, AWL has grown from a small local player to a global partner with its customers. The company continues to expand and maintain a leadership position in laser welding with special machines. Courtesy: AWL Techniek

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.
www.industrial-lasers.com/blogs/dabbling/index.html

update

COVER STORY

Laser systems for automotive applications

HARDERWIJK, THE NETHERLANDS – The headquarters of one of today's important system integrators for the automotive industry, AWL-Techniek B.V., is located here in this former Hansa city. In the Late Middle Ages, Harderwijk and other cities dominated trade along the shores of Northern Europe.

The company itself has roots dating back to 1965, when it started out as a small business serving local industry with system solutions primarily based on resistance and arc welding. Today, AWL builds systems for all major European suppliers to car manufacturers and has a strong lead in the automotive seating market.

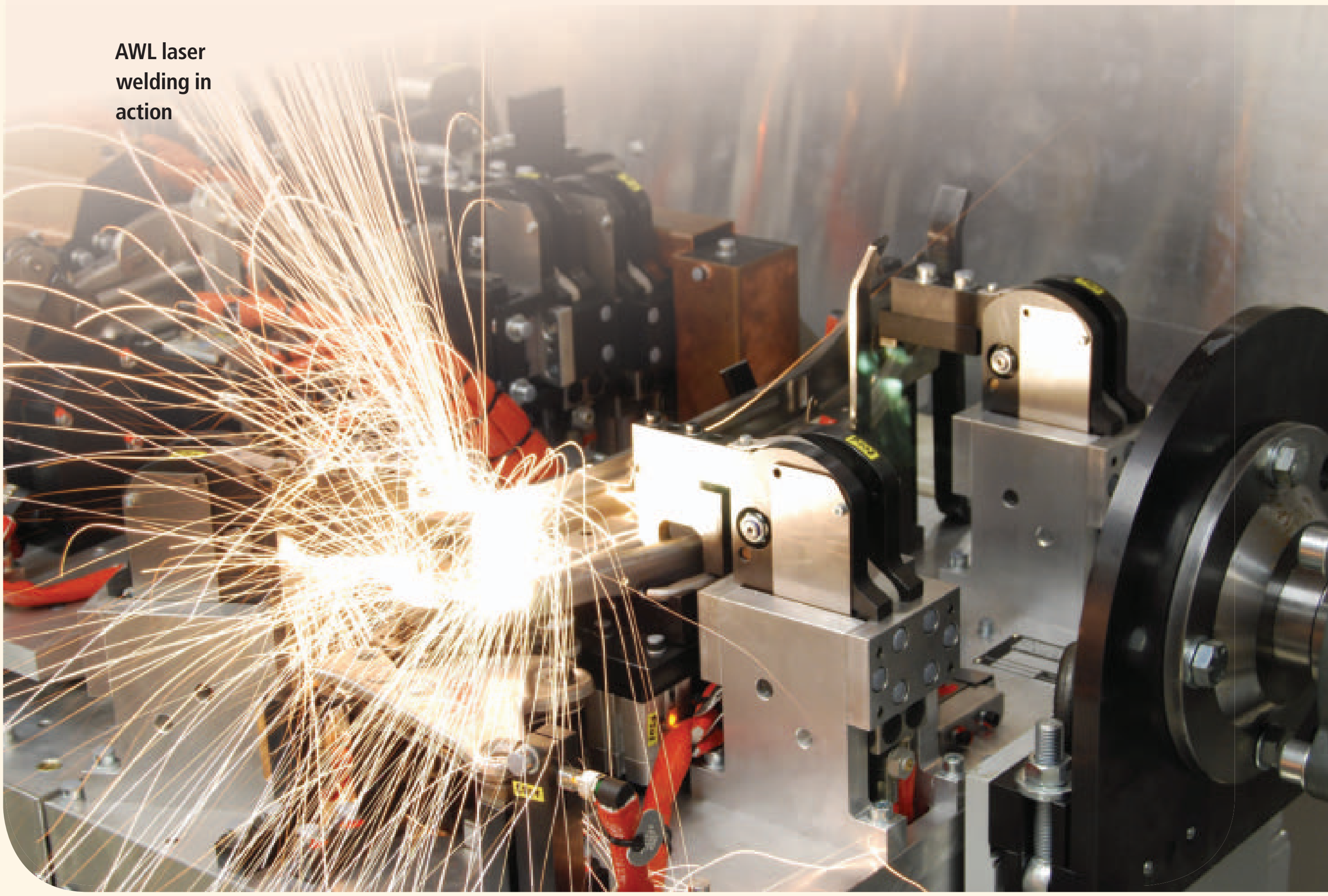
In 2003, AWL introduced laser welding, which today accounts for 60% of the integrated technologies in its projects. Although there is a strong focus on the automotive industry, AWL still values projects in general industry.

China facility

To ensure good global coverage, AWL has a production facility in the Czech Republic, and in 2013 opened a new facility in Wuxi, China. Additionally, the company recently formed a strategic partnership with JR Automation Technologies in Holland, MI.

The reason for opening a facility in China, says Marlous van de Wiel, communication professional at AWL, was that many of the company's customers have fully fledged branches in China, where they are very interested in AWL know-how and expertise. In addition, the platform strategy of modern-day car manufacturers is becoming more global, meaning multiple models of an OEM are built on the same platform and are usually manufactured locally.

AWL customers must be able to supply and locally



AWL laser welding in action

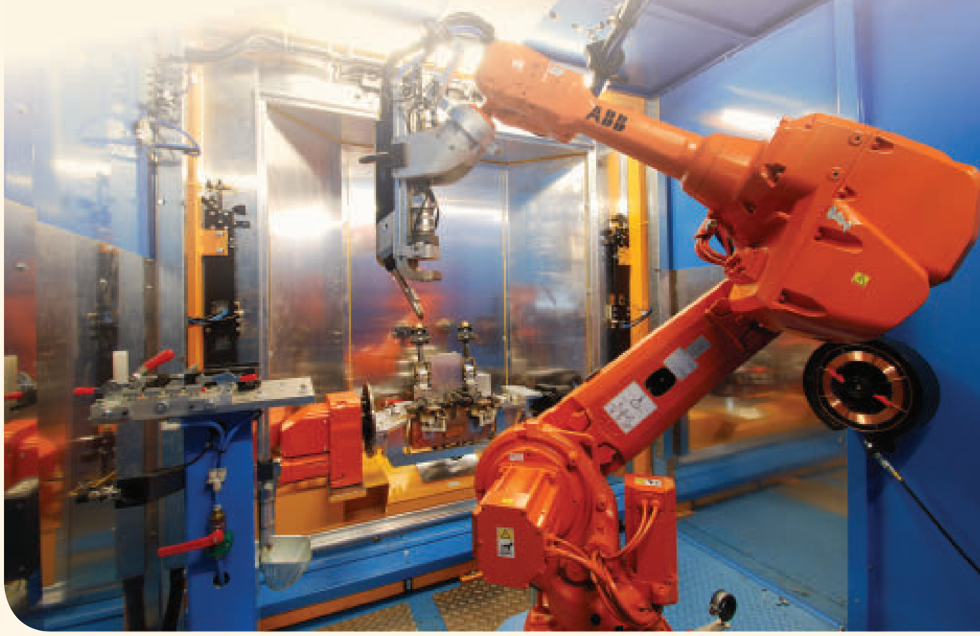
manufacture uniform components across the globe, without compromising the quality of their products. With a facility in China, AWL is able to supply multiple and, in terms of quality, identical machines backed by local service and support. To ensure one global standard, all facilities use the same procedures, processes, software, and hardware, and all employees are trained at the head office in Harderwijk.

Continuous improvement

At AWL, in the recently dedicated R&D department, technology manager Wouter Zweers explains that R&D at AWL is about crossing borders using open innovation and striving to enable its customers to use state-of-the-art technologies in reliable machines. This department cooperates closely with customers, institutes, universities, and suppliers, allowing them to develop and implement high-end technologies, application expertise, and machine integration knowledge. This expertise, together with the results of the company's own research projects, is rolled out in AWL as a continuous improvement process.

The equipment available to the R&D department consists of the full range of joining technologies that may be integrated into production machines. Beside laser-welding-based systems, AWL is experienced in developing systems for resistance welding, arc welding, plasma welding, and adhesive joining. Other important areas are machine design, advanced robotics, and control systems.

Currently, systems are built for production of automotive items such as seats, seat tracks, and body components. For the



AWL laser hybrid welding

general industry, systems are built for production of a broad range of products ranging from industrial fencing to racking to ice skates.

Welding automotive parts

One of the special competencies at AWL is the design and manufacturing of fixtures for welding automotive parts, where quality is crucial for high-volume production. AWL's fixtures ensure end-product quality and ease of adjustment when configuring the welding process. In addition, good spatter protection, unloading assistance, and nest intelligence are some advantages of these high-end fixtures. The fixture portfolio ranges from manual welding to laser welding fixtures. According to AWL, when it comes to fixtures, integrated design is the decisive factor for success.

Tolerances achieved by proper clamping and fine tuning of the fixtures to compensate for deformation due to the thermal process are smaller than 0.3 mm. If needed, the tolerance can be as small as 0.1 mm. All this enables robust and reliable production for customers.

In many of AWL's projects, the company has developed and integrated a laser beam switch management system, where two robots share one laser source, and the beam switches from one optic to the other such that the laser source is fully utilized.

Another popular welding cell configuration involves robot-guided remote laser welding that incorporates laser beam manipulation by a large industrial robot and a laser scanner head. The large reach of the robot is combined with the high dynamics of scanner mirrors in the welding head, resulting in improved process efficiency and productivity for the customer. In-process monitoring using vision systems and special sensors control the welding process and guarantee the quality of the laser-welded product. This can also be combined with product traceability.

Recently, AWL finished the development of a special laser welding cell for car seat tracks. This cell enables the reliable production of non-overlap joints, resulting in an improved joint design and a weight reduction of the assembled component by a choice of material and optimized part design.

Design

In the engineering department, a group of more than 90 degreed engineers uses 3D CAD systems to design all components for building production systems. This involves the structure of the production cell, including electric and pneumatic design as well as welding fixtures and logistic systems. At the same time, a robot simulation is performed to ensure smooth and quick installation and commissioning of the machine.

Suppliers of lasers, robots, and hardware are selected depending on customer preferences and AWL's extensive experience. The closed-loop communication link between engineering and assembly ensures a short lead time and high quality machines.

In less than 25 years, AWL has grown from a small local player to a global partner. The organization continues to expand its activities and maintains a leadership position in laser welding.

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Fiber laser revenues

MODEST GROWTH IN GLOBAL MANUFACTURING SETS THE TONE FOR INDUSTRIAL LASER REVENUES

DAVID A. BELFORTE

The year 2013 started out on a high note as fiber laser industry leader IPG Photonics booked and shipped volume orders. This company's performance in the first half, combined with improved performance of leaders in other sectors of the market, caused investment analysts to rush to their phones to check with their experts on possible stronger growth than had been forecast. Many industry veterans, the cooler heads of those who have experienced economic cycle swings before, cautioned that like sporting events the game is never over until the final whistle sounds. And true to form, a mid-summer slow-down in key market sectors (read this as China) slowed bookings and, even with strong fiber laser sales, the economy self-corrected and the year finished up just about where the experts had predicted at about a 4% total growth. Considering that *ILS* had projected a 2% increase last January and corrected this mid-year to 6%, as a result of strong fiber laser sales, we didn't do too badly.

I am pausing here because longtime followers of these annual reports will have noticed a not-so-minor change this year, which is explained in the accompanying sidebar "Changes to market data collection and processing" on p. 8. My colleague Allen Nogee, senior analyst at *ILS* sister PennWell organization, Strategies Unlimited, is contributing his expertise as an analyst to this report, and by so doing the market categories are being realigned to bring this report in-line with international industrial laser market reports.

The global marketplace

It was a mixed year in the global manufacturing markets for industrial lasers: the US held a strong position buoyed by export sales; Europe, supported by growth from major exporter Germany, managed to just about break even; the Asian markets, with encouraging increases from the Asean nations, helped to offset an unplanned slowdown in China and zero growth in Japan; and the failure of the BRIC (Brazil, Russia, India, China) nations to spark global sales all contributed to a so-so year for laser revenues, as shown in **TABLE 1**.

In and of itself, this would normally be discouraging, but as we said in January 2013 http://www.industrial-lasers.com/articles/print/volume-28/issue-1/features/2012-annual-economic-review-and-forecast.html: "… projections from laser suppliers … were for a mixed year in manufacturing ranging from flat to low single-digit growth."

Table 1. All industrial laser material processing revenues

INDUSTRIAL REVENUE (US$M)	2012	2013	2014 (F)
MARKING	$320.8	$342.3	$367.6
y-to-y		7%	7%
MICRO MATERIALS PROC.	$564.2	$576.7	$594.5
y-to-y		2%	3%
MACRO MATERIALS PROC.	$1,425.8	$1,474.4	$1,541.0
y-to-y		3%	5%
TOTAL	$2,310.8	$2,393.4	$2,503.1
y-to-y		3.6%	4.6%

Lo and behold, regardless of 2013's strong first half led by fiber and ultra-fast pulse lasers, laser revenues ended up about where we had reforecast at mid-year. Note in **TABLE 1** we have revised the reporting categories to mirror widespread market formats; succeeding tables will detail the major market divisions.

For the year, laser sales were up in the seven market sectors *ILS* had identified as key to continuing revenue growth — markets that to one degree or another seem to be resilient to regional economic downswings and markets with processes that are judged to have long-term growth prospects. These are: transportation (165,000 new cars produced every day), energy (global wind power

boost the 2013 laser market

capacity in 2013 was in excess of 35.5 GW), medical devices (the annual global market for stents exceeds $5 billion), agricultural (world demand for agricultural equipment is expected to increase 6.8 percent per year through 2016), aerospace (airlines will buy more than 36,000 planes over the next two decades), communications (laser annealing is the process of choice for flat panel displays used to produce high-definition images), and fabricated metal products (a manufacturing industry that generates nearly $2 trillion in annual revenue).

These markets are all in demand for planned annual production that will be supported by industrial laser material processing operations. As shown in **TABLE 1**, these operations can include one or more of the revenue categories — marking, micro, and macro — that define the industrial laser market.

For 2013, revenues grew about 3.6%, in line with industry and analyst predictions of a flat to low growth year. On a percentage basis, Marking showed the largest increase, around 7%, due no doubt to the increased regulatory requirements set forth by government mandates. Macro experienced a slow growth as markets vacillated throughout the year, led mainly by a slowdown in capital equipment investment spending in China in the first 6 months of the year. Looking ahead to 2014, anticipation is that normalcy will return to the market by the midyear and that a modest increase in global revenues will boost totals by 4.6%.

Marking

Marking (including engraving) generated about 14% of total laser revenues in 2013, and as shown in **TABLE 2**, is dominated by fiber lasers which, growing at 13% per year, produced 66% of 2013 category revenues. Marking revenues grew 6.7% in 2013 and are expected to grow 7.4% in 2014, leading other categories in growth as new government and company regulations for permanent marks for traceability are being put in place, for example, mandated US government requirements for 2D bar code marking of all contractor manufactured parts.

In the marking category, fiber laser revenues increased as CO_2 (-3%) and solid state (-5%) lost share, as most of the more than 225 system integrators opted for the fiber as the power source of their systems.

Micro

Micro Materials Processing (**TABLE 3**), led by Fine Metal Processing, produced 24% of total laser revenues in 2013. This category is still led by solid-state laser sales at 32% (**TABLE 4**), did not show much growth in 2013 (2.2%). Fiber lasers are challenging for leadership, growing at 76% in 2013. In this table, we now include diode, fiber, and solid-state lasers that are used as the power source in additive manufacturing applications, one of the fastest growing (76%) markets for lasers, led by 3D printing technology.

New to the Micro category this year are lasers used in Fine Metal Processing, which is defined as lasers using

Table 2. All lasers used for Marking/engraving

REVENUE (US$M)	2012	2013	2014 (F)
CO_2	$47.5	$46.1	$44.7
y-to-y		-3%	-3%
SOLID STATE	$72.3	$69.0	$66.3
y-to-y		-5%	-4%
FIBER	$201.0	$227.1	$256.7
y-to-y		13%	13%
TOTAL	$320.8	$342.2	$367.6
y-to-y		6.7%	7.4%

Table 3. All lasers <1 kW used for Micro Materials Processing

REVENUE (US$M)	2012	2013	2014 (F)
SEMI/PC BOARD	$184.2	$167.2	$166.7
y-to-y		-9%	0%
FINE METAL PROCESSING	$311.5	$323.6	$327.2
y-to-y		4%	1%
ADDITIVE MANUFACTURING	$11.5	$20.3	$22.8
y-to-y		76%	13%
OTHER	$57.3	$65.7	$77.8
y-to-y		15%	18%
TOTAL	$564.2	$576.7	$594.5
y-to-y		2.2%	3.0%

less than 1 kW of power that are popular in any application using metal material such as stent cutting and fuel injector nozzle drilling. The Other category includes those lasers less than 1 kW used in processing glass, plastics, and other non-metals.

In **TABLE 4**, the decline of the solid-state laser is evident, as it is replaced by fiber lasers; 2013 revenues did not grow, while fiber lasers gained 14% over 2012 numbers.

Macro

By far, the largest revenue producing category is Macro Material Processing (**TABLE 1**), where higher power lasers, with higher selling prices, are used to process mostly metals in the thickness range greater than 10 mm. In this category, as seen in **TABLE 6**, CO_2 lasers represent about 47% of revenues and overall 36% of total laser revenues. It is in this category where the clout of fiber lasers on processing revenues is felt most, with CO_2 and solid-state lasers experiencing negative growth in 2013, while fiber lasers grew an impressive 24%. Estimates are that high-power fiber lasers, up to 6 kW in power, have penetrated into the fabricated metal processing market for sheet metal cutting to as much as 35%, resulting in CO_2 lasers experiencing a 7% decline in revenues. The same holds for solid-state laser revenues, which declined 5% in 2013. The bright light was a significant 26% increase in direct diode revenues attributable to sales of kilowatt-level units for auto body cladding and lower power units for joining of polymer materials.

Table 4. All lasers <1 kW used for Micro Materials Processing by laser type

REVENUE (US$M)	2012	2013	2014 (F)
SOLID STATE	$184.6	$183.9	$185.8
y-to-y		0%	1%
FIBER	$111.7	$127.2	$154.3
y-to-y		14%	21%
CO_2	$126.7	$119.4	$117.3
y-to-y		-6%	-2%
OTHER	$141.6	$146.3	$137.1
y-to-y		3%	-6%
	$564.6	$576.8	$594.5
y-to-y		2.2%	3.0%

Projections

Overall, the revenue picture for 2014 looks a lot like 2013, with slight increases in all three of the categories: Marking (7.0%), Micro (3%), and Macro (5.0%). Macro

Changes to market data collection and processing

Some 30 years ago, the publisher of *Laser Focus World (LFW)* challenged me to produce an annual report on the nascent industrial laser market. This was to complement the market report his magazine was publishing. The first of these was presented at a 1985 meeting in Chicago, where laser industry companies were convened. Out of this came agreement by these companies to support annual reports by commenting on industry numbers that I generated. From 1986 onward, with industry's support and in conjunction with *LFW*'s annual survey of the entire commercial laser market, the industrial sector numbers were presented in this publication and at photonics industry meetings.

Thanks to industry support and contributions, the *ILS* annual market report became the most verifiable published data available at no cost publically. With the passage of strict regulatory financial reporting rules on public companies by the US Congress, *ILS* no longer had access to a flow of forward-projection information so collection of verifiable data became more difficult. Tactics changed and *ILS* began tracking published data by leading industry suppliers. These crimped our style a bit, because of varying fiscal year reporting, but once we settled into a pattern and could generate trend lines, *ILS* reports again were verifiable.

Over the past few years, *ILS* has cooperated with colleagues at Strategies Unlimited (SU), who themselves were publishing market data on the entire laser market. As changes in the publishing industry brought about by the impact of web-based reporting necessitated a tightening of editorial budgets, it was decided to concentrate market data collection and reporting with SU analysts.

This year, for the first time, the annual market report in *ILS* will use SU data. However, the analysis of this data, much of which is generated by *ILS*, will be ours. Readers may notice some disconnect in the numbers brought about by category changes that SU uses to conform to generally accepted definitions. For example, the revenues for the new category, Fine Metal Processing, were reported by *ILS* last year as part of Metal Processing.

Generally speaking, the numbers reported are within the error band of those reported by *ILS* in January 2013, with some differences reflected in the very active revenue numbers generated by fiber and diode laser suppliers in 2013. Inquiries about the market numbers should be directed to Allen Nogee, allenn@pennwell.com.

More details on the laser markets is available from Strategies Unlimited in its new report, *Worldwide Market for Lasers 2014* (www.strategies-u.com). — **D.A.B.**

Table 5. All lasers used for Macro Materials Processing (1 kW or higher) by application

REVENUE (US$M)	2012	2013	2014 (F)
METAL CUTTING	$1,083.6	$1,110.2	$1,157.3
y-to-y		2%	4%
METAL WELDING	$299.4	$317.0	$331.3
y-to-y		6%	5%
OTHER	$42.8	$47.2	$52.4
y-to-y		10%	11%
TOTAL	$1,425.8	$1,474.4	$1,541.0
y-to-y		3.4%	4.5%

Table 6. All lasers used for Macro Materials Processing (1 kW or higher) by laser type

REVENUE (US$M)	2012	2013	2014 (F)
CO_2	$750.9	$696.1	$647.3
y-to-y		-7%	-7%
FIBER	$348.7	$432.4	$536.2
y-to-y		24%	24%
SOLID STATE	$210.0	$199.5	$190.5
y-to-y		-5%	-5%
DIRECT DIODE/OTHER	$116.2	$146.5	$167.0
y-to-y		26%	14%
TOTAL	$1,425.8	$1,474.4	$1,541.0
y-to-y		3.4%	4.5%

will show the largest dollar increase, growing $67 million as more high-power welding applications, particularly in the automotive industry, evolve.

Within the Marking category, fiber lasers are expected to show double digit growth while CO_2 and solid-state lasers continue to experience market share erosion primarily through the growth of fiber laser sales.

Additive manufacturing is the hot technology in manufacturing today, and this is reflected in the double-digit projection for Micro laser revenues in 2014 (**TABLE 3**), where fiber lasers are expected to be the main beneficiary (21%) of system integrator interest (**TABLE 4**).

Metal Cutting and Welding (**TABLE 5**) make up 96% of revenues in the Macro sector as the Macro market is poised for modest growth in 2014. Continued uncertainty about progress in the important European markets and ongoing US congressional dithering, leading to anxiety in the capital investment plans of major industries, will hold this market sector to a 4.5% growth rate. ✺

Laser welding in comm

EXPANDING INTO NEW METAL MARKETS WITH R&D

LUIS ÁNGEL VOCES REBORDINOS AND ÁLVARO PRADA FERNÁNDEZ

Over the past few years, the aesthetic appeal of display furniture design for retail stores has increased exponentially as a consequence of visual merchandising strategies. The quality requirements of metallic components for display furniture, decorative elements, racks or store counters have also increased at the same rate. Today, these elements are considered a key factor in the brand image of trading companies. The increasing competitiveness in commercial furniture manufacturing involves the implementation of new processes with enhanced productivity in order to reduce the manufacturing costs without detriment to the quality requirements.

To fulfill these objectives, Hydracorte, a company with years of expertise in laser cutting of sheet metal, has focused its efforts on implementing and pioneering disk laser welding technology in this industry field as a flexible and productive solution for welding metallic components intended for this commercial sector, an application which, until now, has been served by arc welding processes.

To develop this new business line, Hydracorte is conducting R&D activities in collaboration with the AIMEN Technology Centre to increase the know-how about the laser welding process, improve the technological level of its facilities, and access new industrial markets that require this kind of technology. AIMEN, located in A Coruna, Spain, has dedicated its efforts over the past 40 years toward the development and strengthening of the competitive capacities of companies through R&D activities and technological services.

Hydracorte, founded in 2000, focused its activity on industrial cutting of all kinds of metallic materials using abrasive waterjet technology. After continuous technological evolution, the company has diversified and enhanced its capabilities and assets, both technical and human, mainly with the implementation of other kinds of manufacturing methods like welding, metal forming, punching, milling, or marking. With these methods, Hydracorte can develop the entire fabrication process of commercial metallic furniture, decorative elements, or window display components for worldwide textile stores.

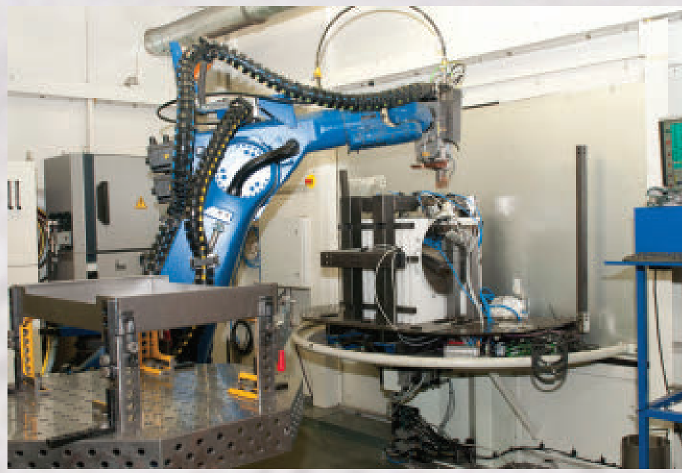

FIGURE 1. CO_2 **laser sources for cutting process in Hydracorte.**

In regard to this technology evolution, laser technology has produced a push in Hydracorte's manufacturing process, giving it a flexible manufacturing system to reduce delivery times and to offer a quicker and more efficient service for all clients in cutting, welding, and metal forming. To develop these activities, Hydracorte has a 6,000 m^2 facility, which includes a wide range of high technology machinery for laser cutting,

ercial furniture manufacturing

FIGURE 2. TruLaser Robot 5020 cell.

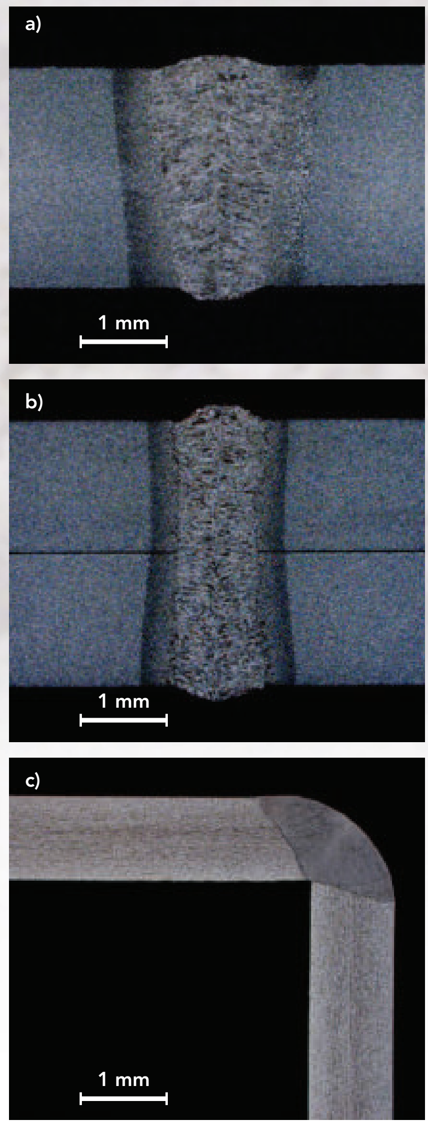

FIGURE 3. Examples of transverse sections of laser welds: a) butt joint, b) overlap joint, and c) corner joint.

welding, and marking that makes it possible to manufacture parts in the most flexible and economical way, while offering a comprehensive service.

Hydracorte is reportedly the first company in Spain to focus laser technology on the welding of metal components for the commercial sector. This differentiating factor makes the company a pioneer in the implementation of this technology and positions it at the forefront of the global industry in this field.

CO_2 laser cutting

Hydracorte currently has three Trumpf CO_2 laser cutting systems for sheet metal (mainly carbon steel, stainless steel, and aluminum alloys): a 3 kW TC L3030S model, a TC L3050 model with 5 kW output power, and a TL 5040 model with 7 kW laser output power and a maximum working area of 4000 mm × 2000 mm (**FIGURE 1**). These allow cutting from 0.5 mm up to 25 mm in noncoated and galvanized steels, 30 mm in stainless steels, and 20 mm in aluminum alloys, as well as other materials such as brass and titanium. The machinery's high degree of automation, including options like a single laser cutting head for processing all the possible thicknesses, an automatic nozzle changer, an automated sheet loading and unloading system connected with the robotized storage system, increases the productivity in such a way that large batches are not a problem.

In addition, two Trumpf CO_2 tube laser cutting machines have recently been installed for processing any profile section (round, square, rectangular, oval, etc.): a TruLaser Tube 5000 model with 2.7 kW output power and a TruLaser Tube 7000 with 3.6 kW laser output power, which allow any type of laser cutting on tubes with up to 10 mm thickness. Profiles with diameters ranging from 10 mm to 250 mm can be machined with this kind of equipment. These machines include an automatic loading system to process 6 m length profiles in a single part and tube seam welding detectors to place the machined contours in the right position.

FIGURE 4. A demonstrator component welded with disk laser technology.

Disk laser welding

Placing Hydracorte at the forefront in its industry, the company has installed a Trumpf TruLaser Robot 5020 cell (**FIGURE 2**), equipped with a TruDisk 4002 4 kW laser disk source with two outputs for optical fibers. Minimum spot diameter on the workpiece and minimum spot size of the beam are 0.2 mm and 0.6 mm, respectively, with a beam quality of 8 mm x mrad and a BEO D70 laser head (with a 200 mm focal length), which offers the possibility of a productive welding service adapted to the highest quality standards for different applications. This cell is equipped with a 6-axis Kuka KR30HA robot, a swivel tilting table, a two station rotary table, and a horizontal rotary axis.

These components make it possible to obtain maximum accuracy, reliability, repeatability, and easy access to the workpiece and maximizes the quality and accuracy advantages already offered by the laser cutting process.

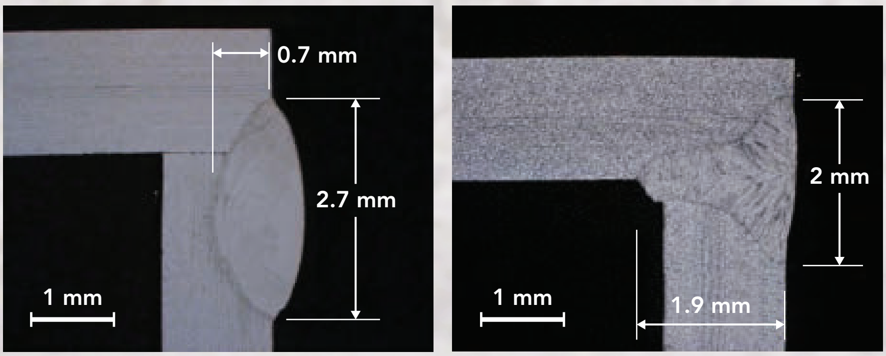

FIGURE 5. Thermal effect comparison between (left) GTAW and (right) laser welding processes.

Laser marking

Hydracorte also has a compact Trumpf VectorMark station for laser marking of pieces. This station is capable of marking with high quality onto a wide variety of parts in different sizes, shapes, materials, and all kinds of graphic contents (serial numbers, barcodes, logos, etc.).

Laser influences the manufacturing process

To evaluate the influence (technical and production) of laser welding on the manufacturing process and typical applications, the company initiated the MONACO project to "develop new concepts of auxiliary

Table 1. Summary of joint configurations, materials, and thicknesses evaluated in MONACO project

METALLIC MATERIAL													
	CARBON STEEL							AUSTENITIC STAINLESS STEEL			ALUMINIUM		
Quality	DC01 noncoated		S235JR noncoated			DC01 galvanized		AISI304L		AISI316L	AW-1050		AW-5754
Thickness (mm)	1	1.5	2	3	5	1.5	3	1	3	1.5	1	2	1.5
JOINT CONFIGURATION													
Butt joint		X		X	X	X	X		X	X			X
L Butt joint		X								X			
Overlap joint	X	X	X					X		X	X	X	
Corner joint	X	X	X					X		X			X

furniture and decorative components for the sewing industry using laser technology" in collaboration with AIMEN Technology Centre. This project is co-funded by the government of the territory of Galicia, Spain — the Xunta de Galicia — where Hydracorte and AIMEN are located, and its Consellería de Economía e Industria. It is also funded by the Fondo Europeo de Desarrollo Regional (FEDER, the European Regional Development Fund) and called "Fomento de la Investigación y de la Innovación Empresarial 2010."

In this project, disk laser welding was evaluated for several joint configurations (butt joint, overlap joint, or corner joint) (**FIGURE 3**) and several combinations of metallic materials and thicknesses (the most common combinations in the current manufacturing system), and the results were compared with the previous gas tungsten arc welding (GTAW) (see **TABLE 1**).

These tests defined the parameter window of laser processing (laser power, welding speed, focal position, and shielding gas type and flow) in order to obtain good geometric quality, and microstructural, functional, and aesthetically acceptable welds for a wide range of constructive possibilities.

In metallic furniture manufacturing, laser welded butt joints are generally used for profile closure and subcomponent assembly after the previous processes of laser cutting and bending. In this joint configuration, the requirements for joint positioning and adjustment are particularly critical for laser weld quality. For this reason, the gap between sheet edges should be less than 0.15 mm.

Overlap joints also allow the assembly of furniture subcomponents, and this joint configuration is a constructive solution to facilitate the laser welding process and to allow the development of new piece designs that maximize the productive capabilities of laser welding technology. This is because its implementation permits the elimination of butt joints, which facilitates the positioning of the components.

Finally, corner joints are widely used in the manufacture of components for commercial furniture, office or home, for aesthetic and hermetic edges, with the objective of replacing adhesives or mechanical joints that are often subject to corrosion attack. To provide a good aesthetic and surface finish of the joints, laser welding generally uses the conduction mode. With this information, several demonstration furniture components have been developed, such as stock closet hangers and different types of racks or window dressing decorative pieces.

To demonstrate and quantify the potential benefits of laser welding versus conventional arc welding processes, a wide number of samples of both laser and GTAW were produced and were tested by Hydracorte and the AIMEN Technology Centre, first on laser weld specimens and then on demonstrator components (Figure 4). Metallurgical tests and visual observations were carried out.

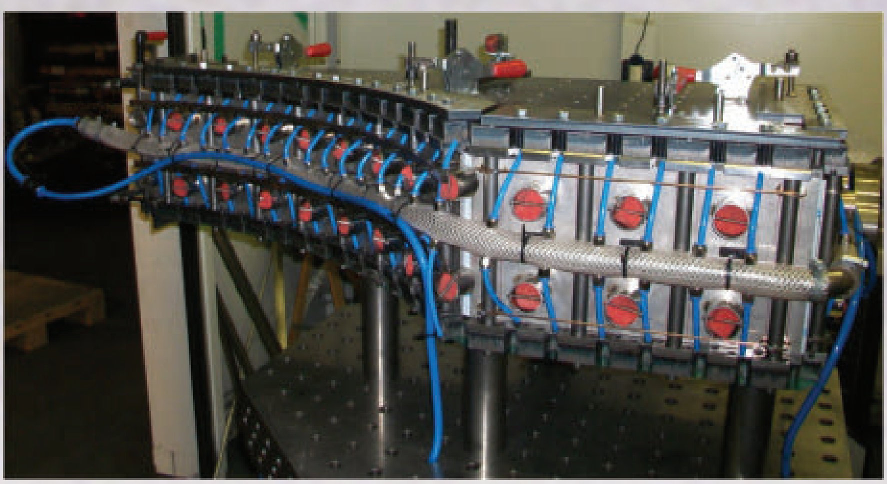

FIGURE 6. Laser welding tool.

Laser welding benefits

The main benefits of the laser technology versus the previous welding processes are:

- Higher productivity. Welding speed has increased between 4 to 8 times depending on the application.
- Precise working with exact placing of the energy spot. High repeatability.
- Small focus spot diameter and higher power density on the workpiece with deep penetration welding.
- High weld depth ratio through deep penetration welding.
- Possibility of welding of complicated joint geometries and very different geometrically components.
- Low total heat application (**FIGURE 5**) resulting in minor microstructure changes and narrow heat affected zone.
- Generation of high aesthetic quality welds.
- Minimal thermal distortion of the workpiece.
- Low post-weld operation times and costs.
- Higher process flexibility due to large working distance with good accessibility.
- The resistant capacity of storage closet hangers has been increased 5% compared to the previous components welded with conventional welding processes. This is possible while reducing the welding cycle four times.

Laser welding compared to arc welding with filler material

- Need to adjust the previous processes (laser cutting and bending) tolerances.
- Need to make specific welding tools to adapt the manufacturing process of components to the new laser welding process.
- Need more complex and more precise welding tools (**FIGURE 6**).
- Ability to develop new innovative piece designs, adapted to higher constructive flexibility that allow laser technology. In this case, cost-effective laser welding demands workpieces designed in a manner that is compatible with laser technology. Proper

design and laser weld positioning results in high quality welds that require little or no finishing operations.

With this laser technology, manufacturing small batches and prototypes, which previously represented a great cost, is made possible by the high degree of flexibility provided by laser welding. With this flexible manufacturing system, it is also possible to introduce or adapt new piece designs.

In order to develop this new business line, Hydracorte is currently carrying out different R&D activities in collaboration with the AIMEN Technology Centre related to different laser processes:

- ETNA Project: "Laser Additive Manufacturing of High Added Value Components" led by Hydracorte, which aims to develop an additive manufacturing system by selective laser deposition, which makes viable the industrial production of parts, using and developing technologies and procedures in order to manufacture and/or reconstruct high value-added parts.
- AUTOLAS Project: "Laser robot cell, flexible and easy to use, with an implemented expert system." The main goal of this project is to give a feasible solution to small- and medium-sized enterprises (SMEs), to implement a robotized laser system in their shop floor, with the minimum requirements in terms of money and qualified staff, which are the main barriers to tackling these kinds of installations by these enterprises. The project scope includes the development of an offline system to get the robot program from a 3D CAD file and also develop an expert system to set the laser parameters in an automatic way from the data introduced by an operator through an easy-to-use interface.

Both of them are funded by the Centre for Industrial Technological Development (CTDI) and the Fondo Tecnológico, and also supported by the Ministry of Science and Innovation and the Consellería of Economy and Industry of the Xunta de Galicia through the Galician Innovation Agency (GAIN).

These R&D activities allow the company to increase its know-how about laser technologies, improve the technological level of its facilities, and access new industrial markets that require this kind of technology. In the same way, the activities increase the technological level of Hydracorte's manufacturing system, consolidate its position in the custom metal fabrication equipment industry, mainly for the commercial sector, and increase the portfolio company diversification of products and industries for the coming years.

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Laser cleaning composites optimize adhesive bonding

EXCIMER LASER SURFACE PREP IS BEST CHOICE

FRANK GÄBLER AND RALPH DELMDAHL

Carbon fiber reinforced plastics (CFRPs) are composite materials that offer a highly desirable combination of physical strength and light weight. Originally developed primarily for aerospace applications, they can now be found in products ranging from automobiles, sailboats, and racing bicycles to golf clubs.

Adhesives are often used to join individual CFRP pieces in an assembly because bonding offers several advantages over mechanical fastening methods. However, achieving a high strength adhesive bond can be frustrated by the presence of surface contaminants. A variety of techniques have been employed to clean CFRPs prior to bonding, but each of these methods has limitations in terms of either speed, complexity, or the need for subsequent cleaning. Excimer laser-based surface cleaning and ablation now offers a practical alternative that yields a pristine surface with the requisite characteristics for adhesive bonding. This article reviews how excimer laser cleaning is implemented and discusses the results of bond strength testing performed using this technology.

CFRP background

A CFRP consists of a so-called reinforcement and a matrix. The reinforcement, which provides load-bearing strength and rigidity, is carbon fiber, usually woven like a fabric. Other fibers such as Kevlar, aluminum, or glass are also often added. The matrix, which surrounds the reinforcement and binds it together, is most commonly epoxy or some other polymer resin.

CFRP components are manufactured in all shapes and sizes with various technologies like tape laying, molding, resin transfer molding (RTM), or braiding. Building up larger composite structures, such as airplane parts, requires joining individually fabricated CFRP components. This joining can be accomplished using conventional mechanical fasteners (screws, rivets, etc.); but this approach has several drawbacks. First, the drilled through-holes required to employ traditional fasteners can damage the load-carrying fibers. Furthermore, internal stress levels can be high around these fasteners since they concentrate the load-bearing function into a small area. This may necessitate the use of reinforcements around these stress points, which then increase the total assembly weight. Finally, the metal fasteners themselves may significantly increase the weight of the assembly. These last two factors degrade the high strength-to-weight characteristics that are the most useful feature of CFRPs.

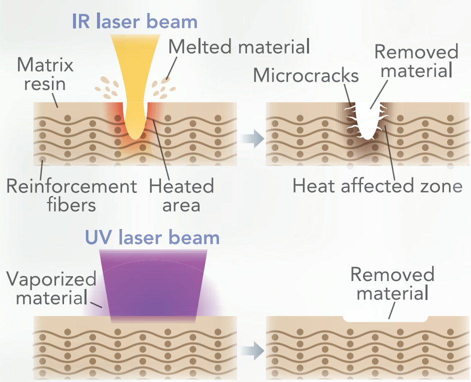

FIGURE 1. (Top) Infrared and visible wavelength lasers remove material by thermal means, resulting in a large heat affected zone and cracking within the material. (Bottom) Ultraviolet lasers utilize cold ablation, which allows precise material removal and produces no HAZ.

Adhesive bonding

Adhesive bonding offers an alternative that avoids these problems. Specifically, it does not require puncturing the CFRP; it spreads the mechanical loading evenly over the entire bonded surface; and it doesn't add significant weight to the finished assembly.

To achieve a high strength adhesive bond, it is necessary to remove any mold release agents and other trace contaminants remaining on the surface from previous manufacturing steps. This is critical because it is well established that adhesive bond strength is highly dependent upon surface cleanliness prior to bonding. However, this surface cleaning must be accomplished without producing any damage to the underlying CFRP, and the load-carrying fibers, in particular.

Techniques for surface pre-treatment

Several techniques are currently used for cleaning and preparation of CFRP parts prior to adhesive bonding, including mechanical abrading and grit blasting. Unfortunately, each of these methods has drawbacks. For example, most mechanical abrading processes suffer from low throughput speed and are usually performed wet, necessitating subsequent rinsing and drying and introducing further production cost and process time. Grit blasting also leaves residues and dust that make cleaning necessary. Plus, mechanical methods introduce the risk of damaging the carbon fibers.

In the aerospace industry, peel-plies are also used for CFRP surface preparation. Peel-plies are sheets of woven fabric material that are laminated onto the CFRP surface prior to curing the matrix resin. They are removed before adhesive bonding, leaving a clean surface. The main drawback of peel-plies is that they increase CFRP manufacturing complexity. Furthermore, the repeatability of CFRPs processed with peel-plies is limited because these produce thickness variations in the resin layer. Also, peel-plies are not suitable for CFRP repair work.

Laser treatment advantages

Laser surface preparation involves ablating a thin layer of material from the CFRP. It is a cleaning method proven in other applications that has the potential to avoid virtually all of the drawbacks of these other techniques and that can effectively remove virtually all contaminant residues. Unlike mechanical techniques, laser cleaning requires virtually no surface preparation, is performed dry, doesn't require that the surface be cleaned of debris afterward, and avoids fiber damage if suitable parameters are chosen. Additionally, laser processing is compatible with the preparation of large surface areas, can be readily automated, and delivers highly consistent results because it is a wear-free and contact-free process. Plus, laser surface preparation is applicable to CFRP repair applications.

However, for the laser process to deliver better results than mechanical methods and peel-plies, it is essential that it not induce any damage to the bulk resin or load-carrying fibers. This can be problematic when using longer wavelength lasers such as far infrared CO_2 and near infrared solid state and fiber lasers because all these remove material through thermal means. Heating of the bulk material can cause fiber damage as well as cracks in the matrix. In contrast, ultraviolet lasers remove material primarily through photoablation, rather than thermal mechanisms, resulting in essentially no heat affected zone and enabling highly precise material removal (**FIGURE 1**).

Of currently available ultraviolet laser technologies, pulsed excimer lasers offer the highest pulse energy (up to 2 J). Plus, the large rectangular beam produced by excimer lasers can easily be shaped and homogenized to match the geometry of typical CFRP surface preparation applications. Together, these characteristics enable rapid material removal and high throughput, even with larger CFRP parts. Current excimer lasers have also established an excellent track record in other industrial applications due to their ability to run essentially maintenance-free for periods of over one year in three-shift, high duty-cycle operations.

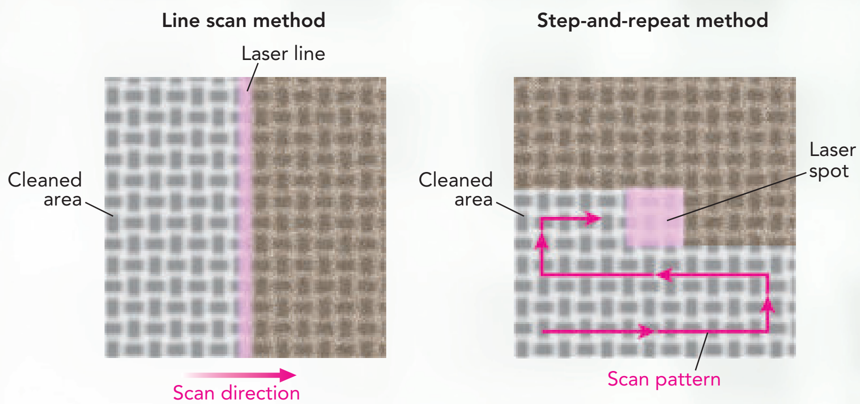

FIGURE 2. Schematic comparison of line scan and step-and-repeat methods for excimer laser cleaning. With both methods, the CFRP is typically moved and the laser is held stationary to create the scan.

Excimer laser cleaning

The exact way in which the excimer laser is employed for a given surface preparation application depends upon the specific geometry of the CFRP, the output fluence of the particular laser model, and the desired throughput. However, all CFRP processing schemes are typically variants of two basic approaches, namely, the line scan or the step-and-repeat method (**FIGURE 2**).

In the line scan method, the laser beam is shaped into a line (that is, a very high aspect ratio rectangle) and then swept continuously across the surface to be cleaned. The number of pulses to which a given spot on the material is exposed is determined by a combination of line width, line travel speed, and laser repetition rate. If the line length is shorter than the width of the area to be cleaned, then several adjacent passes of the area are made.

In the step-and-repeat method, the laser beam is formed into a square or nearly square rectangle. The laser spot is positioned at a fixed point on the CFRP surface, and an exposure is made (consisting of one or more laser pulses). Then, the beam is translated a distance corresponding to its width, and the process is repeated. The entire area to be cleaned is sequentially exposed in this manner. For both methods, the size and weight of typical excimer beam delivery optics usually make it more practical and economical to move the CFRP relative to the laser beam, rather than vice versa.

Excimer laser test results

The Adhesive Bonding and Composite Technologies Department at the Technical University of Braunschweig, Germany, tested the bond strength of CFRP surfaces prepared with a Coherent LPXpro 305 excimer laser. This was then compared with the bond strength obtained utilizing traditional surface preparation methods. In this study, the excimer was configured to output at a wavelength of 308 nm and a pulse duration of 28 ns. Raw laser output was transformed into a 30 mm × 1.8 mm field size, having less than a 1% rms overall variation in fluence over its entire length, and a Gaussian profile along its width. The line scan method of exposure was used, with laser fluences of between 400 and 800 mJ/cm^2. By varying laser repetition rate and line scan speed, total pulse exposures for a given point on the CFRP could be varied from 1 to 48. The CFRP tested was a typical aerospace material purposefully contaminated with a polysiloxane-based mold release agent. The SEM photos (**FIGURE 3**) demonstrate the technique's ability for highly controlled bond and matrix material removal without damage to the exposed fibers.

After laser cleaning, specimens were bonded, and bond strength was measured. Maximum bond strength in this experiment occurred at an exposure of two pulses at 600mJ/cm^2. Furthermore, the bond strength achieved was higher than that obtained using abrading or peel-plies. When failure did occur, it was within the matrix itself, rather than at the adhesive boundary, meaning that the adhesive bond was stronger than the bulk matrix material.

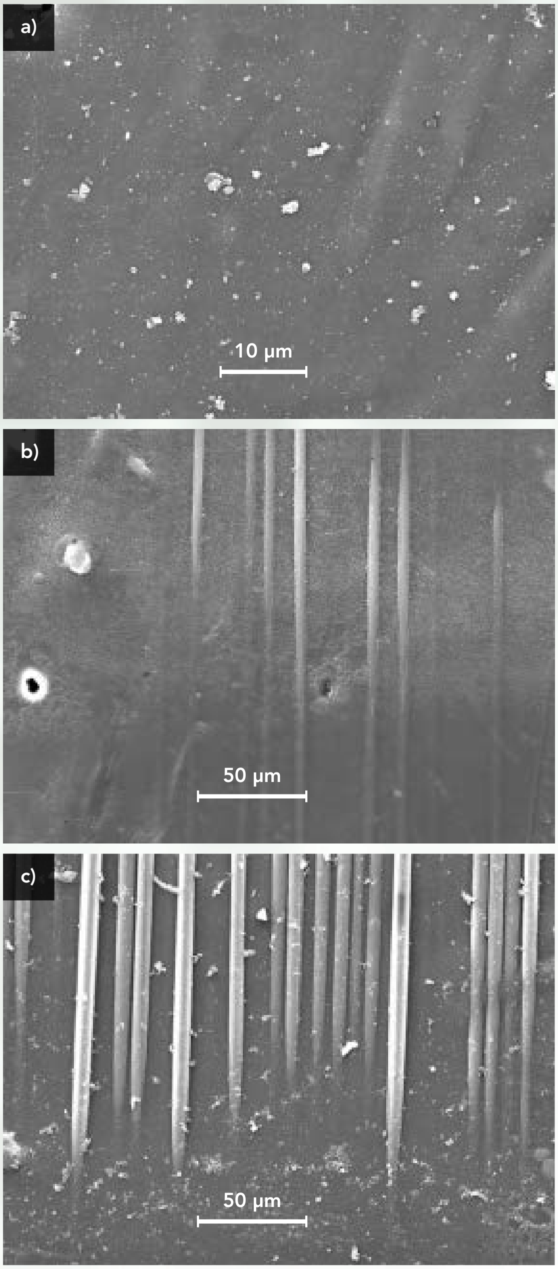

FIGURE 3. SEM pictures of excimer laser surfaces treated with 800 mJ/cm^2: a) untreated with no exposed fibers; b) two laser pulses where fibers become exposed; and c) six laser pulses where fibers are clearly exposed but not damaged.

Lower exposure levels than the optimum failed to completely eliminate all the surface contaminants. This weakened the resultant bond, and failure in these cases occurred in the adhesive layer.

At exposure levels above the optimum shot number/fluence combination, the laser completely eliminated the overlying pure epoxy resin layer, and, at the very highest exposures, it began to damage the sizing of the fibers (sizing is a chemical coating applied to the carbon fibers that enhances their bonding to the matrix resin). The result was lower total shear strength and failure at either the adhesive boundary, or within the fibers themselves.

While the optimum pulse number and fluence combination might vary for other bond and matrix material formulations, this testing clearly indicated that excimer treatment at the right parameters is capable of achieving or exceeding the maximum shear strength obtained using abrading. The rate of excimer laser cleaning with the parameters employed in this testing was 0.16 m^2/min (9.6 m^2/h), which is a bit slow for commercial uses. However, there are substantially more powerful industrial excimer lasers than the 30 W (average power) model used here. For example, the Coherent LSX Series laser delivers 540 W of average power. Using this laser at the same pulse energy and overlap as employed in this testing, but a repetition rate of 600 Hz, would deliver cleaning rates of 0.97 m^2/min (58.3 m^2/h), making it suitable for many typical CFRP production applications.

In conclusion, adhesive bonding of CFRPs offers several advantages over other joining techniques if the surfaces can be properly prepared prior to bonding. Excimer laser surface preparation promises to deliver superior results over other methods in terms of final bond strength, while also being more economical to implement. Furthermore, it has proven to be highly reproducible, making it a consistent and stable process that is well-suited for volume production applications and even repair work. ✺

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Laser technologies in the hot stamping process chain

EFFICIENT SOLUTIONS HAVE LED TO WIDESPREAD ADOPTION

STEFAN WISCHMANN AND FRANZ-JOSEF LENZE

The rising requirements of legislation in the EU, the US, and other countries to reduce the greenhouse gas emissions of motor vehicles have started a global trend that increases the pressure on the auto industry to significantly reduce the weight of its products. At the same time, demands on performance and crash safety are also continuing to rise. In the past, meeting these demands has resulted in considerable weight increases. Resolving these conflicting requirements while also taking cost aspects into account is a development challenge that the steel industry is helping to meet with new products and adapted processing technologies.

In the past decade, the hot stamping of auto body parts has evolved from a niche technology into one that is now indispensable for weight reduction with high-strength steel. This evolution has resulted in significant reductions in vehicle weight, made possible by the extremely high strengths of the steels used. The development efforts of steel manufacturers in the field of manganese-boron steels were a pre-requisite for this.

New challenges

From the users' viewpoint, the increasingly widespread use of these manganese-boron steels and their improved coatings poses diverse new challenges for the hot stamping process chain in general and for laser technology in particular. The different processing conditions required by manganese-boron steels compared with the cold stamping steels previously used, and their widely varying properties depending on

FIGURE 1. Hot stamping press in the test facility of ThyssenKrupp Steel Europe AG.

the carbon content in the individual processing steps, particularly under the influence of heat, showed a need for corresponding process development.

This concerns the use of lasers, beginning with the manufacture of welded manganese-boron steel blanks, so-called Hotform Blanks. These blanks are produced by laser welding and are manufactured in very large volumes in different material thicknesses and also in combinations with other steel grades. From a metallurgical viewpoint, it is important to mention the hardening effect caused by martensite formation due to the high carbon content and rapid cooling. However, this hardening does not have a disruptive effect on subsequent processing by hot stamping as the temperatures in the furnace are above austenitization temperature (A_{C3}) and the cooling rates in the die during subsequent stamping result in a homogeneous martensitic microstructure throughout the part, including the laser weld (see **FIGURE 1**). However, it is well known that edge preparation, geometric accuracy, and coatings are keys to the quality of the laser weld.

In the case of the above hot stamping steels, a high-melting-point aluminum-silicon (AS) coating is used to protect the steel in the furnace. However, this affects the laser weld metal deposit so unfavorably that the coating has to be removed prior to the welding process. Lasers have proven a successful high-energy tool for this as well. In production equipment, Q-switched lasers achieve full decoating of the blank edges. In addition, the LIPS process (laser induced plasma spectroscopy) is used for quality monitoring. In this process, the areas of the blanks to be decoated are bombarded with Nd:YAG lasers with pulse lengths in the nanosecond range and the metal vapor plasma produced is analyzed by spectroscopy to determine the aluminum content. Another proven method is to monitor the weld plasma in the subsequent laser welding process.

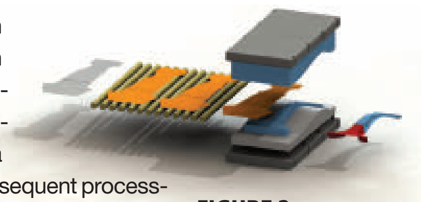

FIGURE 2. Schematic of hot stamping with functional strength matching Hotform Blanks.

Other approaches

In addition to the use of the above-mentioned Hotform Blanks, other developments have taken place in hot stamping aimed at matching functional strength to crash requirements. Relevant processes include tailored tempering, in which the cooling rate in the die is varied, and furnace technologies that allow different starting temperatures for the press hardening operation. Both processes produce different microstructure zones in the part (**FIGURE 2**).

Another approach is to produce these different microstructure zones after hot stamping. The advantage lies in greatly increased degrees of freedom in part configuration. This can be achieved by hardening unhardened microstructure zones or by softening hardened microstructure zones. In a project sponsored by the Federal Ministry for Education and Research called "Local heat treatment of sheet materials to improve forming and functional properties," this was demonstrated effectively by means of induction and laser techniques. The laser material treatment used linear diode lasers of the kind also used for hardening high-carbon tool steels. This configuration allows high 3D capabilities with high surface treatment speeds.

Looking at the steps downstream of the hot stamping process chain, it is necessary in most cases to trim the parts. Due to the high hardness and the associated high wear in conventional mechanical trimming operations, this should be carried out in unhardened microstructure zones. As this is often not possible, lasers have proven widely successful as a "wear-free" tool despite the disadvantage of lower output. In other applications, for example, cutting blanks to size, a number of factors favor trimming by laser rather than by mechanical press:

- lower investment cost,
- lower cost per part,
- higher flexibility when starting production and in low-volume runs,
- shorter setup times for part changes,
- optimized storage costs and batch sizes, and
- no wear through contact cutting when processing high-strength steels.

The lower output is mainly due to the cutting speed. To offset this disadvantage, users favor a variety of specific solutions, ranging from parallelization of the process and equipment modifications to new developments such as remote laser cutting.

The final use of lasers in processing hot-stamped manganese-boron steels takes place during welding in the body-in-white line. Here, laser welding has established itself alongside conventional methods such as resistance spot welding. It should be noted that, in the region of the weld deposit, high cooling rates again result in martensite formation and hence in hardness and strength levels corresponding to the hardened condition of the part. Heat input from the welding process into the hardened base metal is problematic. This leads to a tempering effect in the heat-affected zone and hence to a metallurgical notch that must be taken into account in part design. **FIGURE 3** is a hardness profile of a laser beam weld in hardened manganese-boron steel (MBW 1500 +AS).

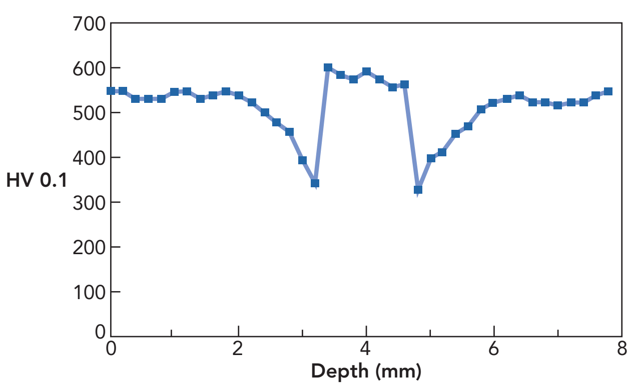

FIGURE 3. A hardness profile of a laser beam weld in hardened manganese-boron steel (MBW 1500 +AS).

In summary, it can be stated that the use of laser technologies has led to efficient solutions in the hot stamping process chain and contributed greatly to the widespread adoption of hot stamping.

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Femtosecond lasers for manufacturing **implantable medical devices**

ATHERMAL ABLATION PRODUCES CLEAN MICRO-SCALE MACHINED FEATURES

RAJESH PATEL, VICTOR MATYLITSKY, AND HERMAN CHUI

Implantable medical devices such as stents, intraocular lenses (IOLs), and prosthetics have transformed medical treatment over past decades. For example, millions of stents are implanted worldwide each year to treat various vascular and endovascular diseases caused by the narrowing or blockage of blood vessels. Similarly, many millions of IOLs are implanted yearly as artificial lenses to restore vision for patients suffering from cataracts.

Lasers play a critical role in the fabrication of implantable medical devices. With their accurate control, lasers can be used to effectively micromachine a variety of selected materials to intricate and precise geometries needed for these implantable medical devices. In the case of coronary stents, laser cutting was employed with success almost from the very beginning. Early-generation stents were made from stainless steel and were relatively large with part geometry and feature tolerances of ±25 μm or more [1]. Laser cutting, implemented with nanosecond-duration pulsed infrared lasers, easily met the accuracy requirements for machining at this level.

The thermal interaction of nanosecond laser pulses with the material, however, generally result in non-optimal surface finish on metal parts: burring, melting, and re-cast are common. In addition, heat deposition in the material results in a narrow heat affected zone (HAZ) bordering the cut edges. Within the HAZ, material properties or composition are altered. These effects have meant that laser cutting technology could only be scaled to volume stent production with the development and refinement of several costly and time consuming post-processing steps to remove rough edges. Cleaning, deburring, etching, and final polishing are routinely employed to bring the stent's surface properties to the level and consistency required of implantable devices.

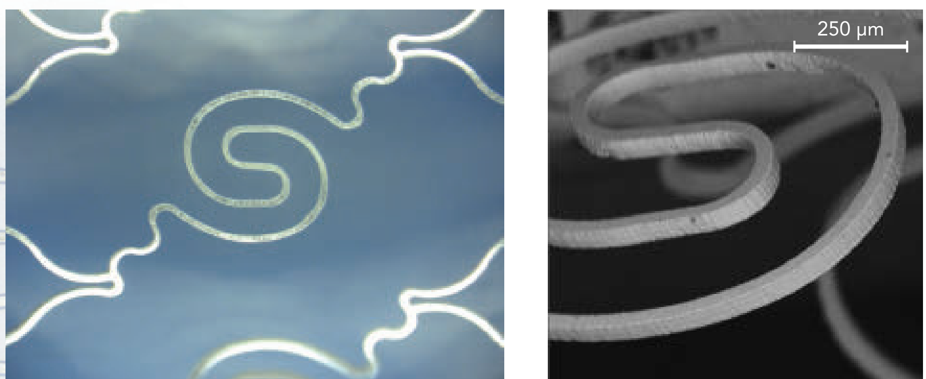

FIGURE 1. Two photos of micro-stents machined by the Spirit laser.

Improvements with femtosecond lasers

In recent years, implantable medical devices have become increasingly intricate and utilize materials that are more difficult to machine. For example, stents are now being used for peripheral arteries with tiny dimensions. Another trend is to add a controlled surface texture or geometry to stents and prosthetics to improve bio-compatibility, for example to reduce the risk of restenosis. New materials that are bio-absorbable add another dimension to the challenge of fabricating these devices.

Femtosecond lasers are an enabling technology for micromachining the ultrafine structures and new materials for this new generation of implantable medical devices. Femtosecond lasers have pulse durations 100,000 times shorter than that of conventional nanosecond (ns) lasers. With these ultrashort pulses, the laser energy enters the material and departs with the expanding plasma before it can be transferred within the material as heat. The result is often called "cold" or "athermal" laser ablation. Its salient characteristic is the remarkably clean micro-scale machined features it produces, generally free of burrs, melting, re-cast and HAZ.

Femtosecond lasers have been around for several decades. Until more recently, though, they were complex, expensive, and required frequent tuning to sustain the demands of the production floor. However, products such as Spectra-Physics' Spirit industrial femtosecond laser, a proven, highly reliable, and robust laser, is widely deployed in demanding medical and manufacturing applications around the world.

To demonstrate the capability of the Spirit industrial femtosecond laser, we micro-machined ultrafine Nitinol metal stents as shown in **FIGURE 1**. The tube diameter and wall thickness are only 4.25 mm and 45 µm, respectively, and the strut width is 35 µm. We observe tight machining tolerances, absence of HAZ, no heat-induced distortion of the delicate lattice structure, and very clean-cut edges.

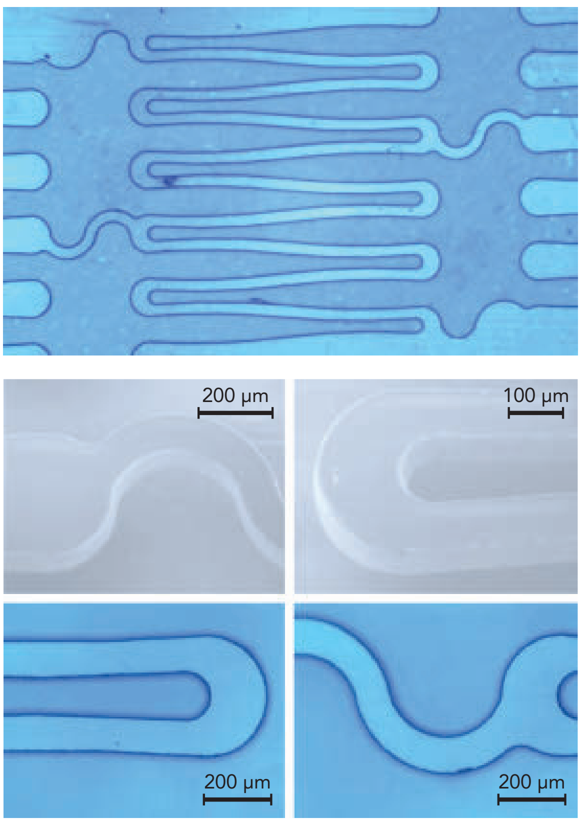

FIGURE 2. Bio-absorbable PLLA stent structures machined by femtosecond laser pulses.

Bio-absorbable stents

Most commercially available stents are made from metals that remain in the arteries permanently after implantation and have a potential risk of causing serious medical complications. One potential solution to avoid such complications is to use stents made out of bio-absorbable materials that dissolve in the human body after serving their purpose [2]. However, machining of bio-absorbable material is a highly challenging task.

Some common materials for bio-absorbable stents are poly-L-lactic acid (PLLA) and poly-lactic co-glycolic acid (PLGA). These materials have low-melting-points and therefore cannot tolerate the heat effects of conventional nanosecond-laser machining. Athermal ablation carried out by femtosecond lasers fundamentally enables the bio-absorbable stent technology by providing a viable manufacturing solution. It should be noted that, in these highly sensitive materials, even femtosecond lasers can leave behind heat-induced damage. However, by careful tuning of the laser output parameters, athermal ablation can still be achieved. The same cannot be said of lasers with longer pulses. For example, with a picosecond laser, only thermal machining of these materials was observed, resulting in strong melting and bubbling of the PLLA material. **FIGURE 2** shows some recent results achieved with the Spirit industrial femtosecond laser. The material is 80 µm thick PLLA, and the struts are 100 µm wide.

Conclusions

Femtosecond lasers have enabled the fabrication of next-generation implantable medical devices. As these devices continue to increase in complexity with shrinking feature sizes and tolerances, novel geometries and surface texturing, and new bio-absorbable materials, the use of femtosecond lasers becomes increasingly necessary. Industrial-grade, reliable, and robust femtosecond lasers are critical to enabling the manufacturing of these complex medical devices with higher quality, minimal additional post-processing steps, and higher throughputs. ✺

Acknowledgments

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A high-power diode laser primer

AUTO PRODUCTION, MARKET SCANNERS, AND SPACE ELEVATORS

SILKE PFLUEGER

The majority of industrial lasers in use today are CO_2, solid state, or fiber lasers. But slowly, diode lasers are making inroads into many of today's applications as the power and beam quality of these lasers is increased. Keep on reading for a look at the history of diode lasers, their technology, and their many uses, with a special focus on laser material processing.

The early years

The first laser diodes, discovered shortly after LEDs in 1962, had to be cooled with liquid nitrogen to generate continuous-wave light. A breakthrough occurred in 1970, when Alferov and Kroemer independently discovered the double heterostructure laser diode (http://www.nobelprize.org/nobel_prizes/physics/laureates/2000/alferov-lecture.pdf), which enabled operation at room temperature, in continuous wave (CW) mode, and at a potentially wide range of wavelengths. The remainder of the 1970s was put to good use developing materials and fabrication methods for these diodes, leading to the development of reliable, relatively low power devices.

The 1980s saw the wide deployment of diode lasers replacing HeNe-lasers in grocery store scanners and enabling CD players, prices of which dropped rapidly, driven by falling prices of the laser diodes.

Aside from reducing cost, another big push of the mid-1980s was to increase the output power of diodes. In 1990, Lawrence Livermore National Labs presented a 1.45 kW stack-to-pump solid-state slab laser.

From "dumb" high power to focusable energy

Optically pumping a solid state slab laser was all about meeting the right wavelength band with as much power as possible, but not about focusing the light to a small spot.

High power diode lasers, on the other hand, have a very distinct beam, and consist of a large number of individual laser diodes, each with very high beam quality in one axis (fast axis) and low beam quality in the other (slow axis). To get to high power, rather than separating the semiconductor wafer into individual diodes, 19 or more emitters form an array on one piece of semiconductor, called a diode bar, which typically is 1 cm wide. These are then mounted on thin coolers and stacked — resulting in hundreds of beamlets, not one single beam as with conventional lasers.

To preserve beam quality, the fast axis of the entire bar is first collimated with a micro-cylinder lens. The resulting beam is

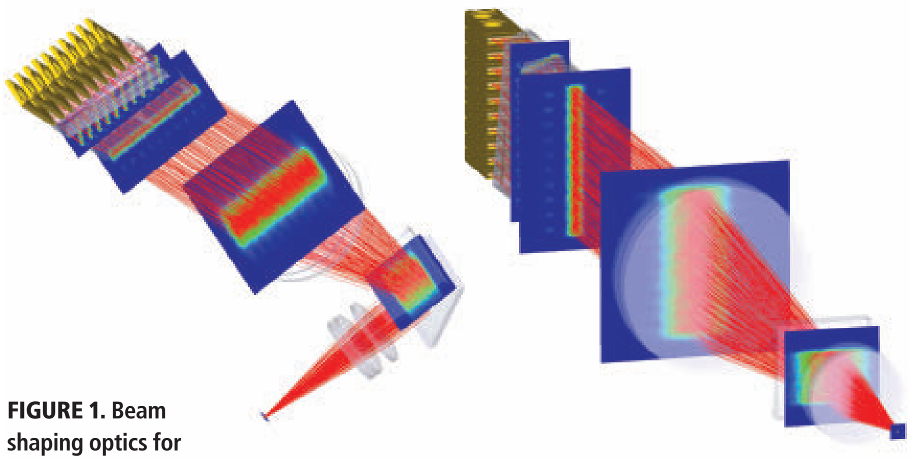

FIGURE 1. Beam shaping optics for high power diode laser stacks, with fast axis collimators, beam reformatting, and focusing optics. (Courtesy of Laserline)

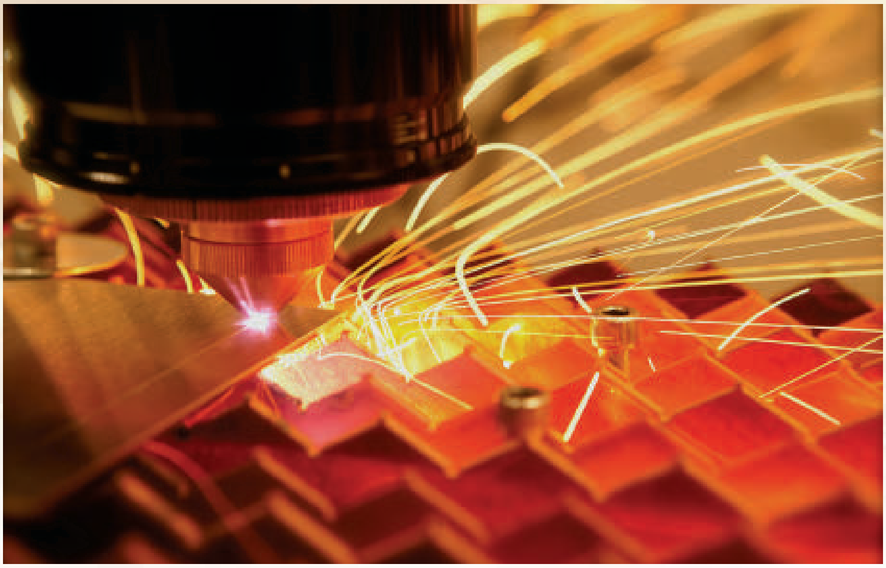

FIGURE 2. Ultra-high brightness diode laser cutting steel. (Courtesy of TeraDiode)

rectangular, with vastly different beam qualities in the two axes, requiring beam shaping optics that will square the beam quality.

Dilas and Laserline, both located in Germany, as well as Nuvonyx in St. Louis, MO, were the first companies to develop high power diode lasers specifically for the industrial laser market. It all started with low-power, low-beam-quality applications such as plastic welding, heat treatment, and paint stripping, the latter two applications also lending themselves to line focusing. These companies subsequently drove the development by refining the mechanical and optical designs and by taking advantage of the ever-increasing power levels out of diode lasers.

Expanding into mainstream applications

Fiber coupling, and increasing the output power to several kilowatts, turned high power diode lasers from a niche product to a major player in the market. Brazing automobile body-in-white parts became the breakthrough application, showing that diodes were reliable and energy efficient competitors, able to vie with established laser technologies and also with traditional welding technologies because of easier energy accessibility to the weld joint and improved stiffness of the welded components.

With higher power and efficiency, 6 to 10 kW diode lasers became the choice for cladding applications in energy generation, which were being fueled by increasing oil prices and improvements in laser cladding technology. The water walls in coal-fired boilers and oil drilling equipment are laser coated to withstand corrosive atmospheres and abrasive forces. Competing with conventional technologies such as thermal spraying, diode lasers were able to produce better coatings with a metallurgical bond to the base material and less heat input, which reduces or eliminates secondary post-processing operations, with similar or improved cost structure.

Ultra-high brightness diodes

Getting to the largest and most lucrative of laser applications, laser cutting, requires a shift in the optical design of the diode. Conventional stack based architectures are limited in brightness by the dark space between the emitters and between the bars. The key to ultra-high brightness diodes is to design an optical system that allows access to the brightness of the emitters and combines the beams while preserving the brightness.

Several companies are working on ultra-high brightness diode lasers. The key technology they all share is dense wavelength multiplexing (**FIGURE 1**). Individual laser diodes or banks of them are lasing at slightly different wavelengths, typically in the 900–1000 nm range, and combined with filters or gratings. TeraDiode, a Massachusetts-based company, reaches 2 kW with 3.1 mm*mrad. DirectPhotonics (Berlin, Germany) is targeting 2 kW with 7.5 mm*mrad. Two large government programs, the European BRIDLE and the German BrightLas, are aiming to reach similar performance levels, while at the same time investigating additional technologies surrounding high power diode lasers. Initial cutting tests have shown TeraDiode's lasers producing results that are equivalent, if not superior, to fiber lasers (**FIGURE 2**).

Why the drive to diode lasers instead of the existing technology, especially fiber lasers? One reason, in this writer's perhaps-biased opinion, is that all high-power diode lasers only use passive, free space optics. Fewer components, often automatically assembled, leads to higher efficiency, smaller size, better reliability, and ultimately a better cost structure.

And finally: Space elevators

Space elevators are essentially long cables, anchored on a planet or a moon, with the center of mass located in geostationary orbit. Climbers would be used to transport goods up the cable into orbit. One challenge among many others is powering the climbers, and this is where diode lasers come into play. Functioning as a "cordless extension cord," they send energy in the form of light to the climber, which converts it into electrical energy. However, even though a Japanese company plans to build a space elevator by 2050, laser cutting is certainly going to be the short term market for all ultra-high brightness diodes currently in development.

Between improvements in semiconductor laser material, mounting technologies, and the new optical combination schemes, it is foreseeable that the diode laser will revolutionize the CW material processing market for cutting and welding. While fibers and disks will continue to have a role in energy storage for pulsed systems, their days as brightness enhancers for low brightness diodes could likely numbered.

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Challenges for the laser job shop

ATTENTION TO THE DETAILS OF LASER MARKING JOBS IS CRITICAL

GARY NIEMENSKI

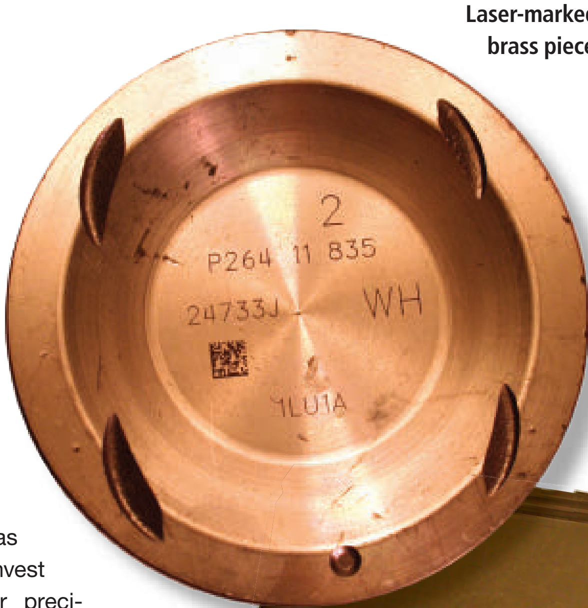
EDITOR'S NOTE: *Laser marking is becoming ubiquitous in manufacturing products today.* ILS *asked Gary Niemenski, owner of a busy laser marking shop, to give readers an idea of what the technology has wrought. — D.A.B.*

The need for laser job shops has never been greater than it is today as companies that cannot invest in laser technology for precision machining are looking to laser job shops for help. For example, there is more emphasis on product identification, anti-counterfeiting protection, permanent marking without inks, adhesive labels, and personalizing or customizing industrial and consumer products. These applications are becoming the norm in most manufactured products where laser job shops are involved. Because of the need for identification in medical, automotive, and military applications, the demand for laser job shops will increase.

General challenges of ownership

Owning a job shop doesn't require that you carry much inventory, which lowers operating cost. This helps to better address the growing needs of your industrial customers.

However, one of the main concerns laser job shops have is being able to engrave or cut a component they have never seen before. It is the job shop owner's responsibility to consult with the customer on how his product should be processed. Some job shops provide a guarantee or insurance if the laser process does not work.



Laser-marked brass piece

Laser-marked mustang

There are additional costs that a laser job shop needs to be communicating to their customers. You will be required to unpack the customer's product and repack it as well. We sometimes spend more time with the logistics of the project than actually using our lasers. In such cases, a nominal handling charge is usually acceptable to our customers. Another cost that needs to be discussed with the customer is setup charge. Time is money, whether you are running a short or long run. This is an important challenge that a job shop deals with every day. Today's laser job shop is under extreme competition for laser processing services and sales. Thus, job shops are now expanding their services to differentiate themselves from competitors by offering added-value services such as welding, forming, painting, barcode reading and verification, bending or forming.

Today, more laser job shops have upgraded to fiber technology to perform innovative applications. Companies have started to realize the advantage of fiber laser processing and are comfortable outsourcing their work. Job shops that used traditional cutting methods, for example, are replacing those with fiber lasers. Besides laser cutting contract work, these fiber lasers can weld, mark, and engrave. Using fiber laser technology and innovative ways to process the work, medical device manufacturers, for example, are outsourcing their work to the laser job shop. Even though these opportunities exist, fiber laser processing has not reached full potential for the average job shop.

Part marked with a barcode

Laser marking

One of the most requested job shop tasks is laser marking. Laser marking systems have made it possible to achieve fast, permanent, non-contact marking of a wide range of materials, including metals, plastics, semiconductors, ceramics, marble, and glass. Clean, crisp markings can be made with high accuracy as a result of extremely small spot diameters, some as small as 0.003 inches. Laser marking is fast, flexible, permanent, and doesn't require the job shop to have consumables on hand. Laser marking is a non-contact process for any material needing this method. Metals such as stainless steel can be marked, annealed, or engraved cleanly. Over 75% of our customers require 2D data matrix barcodes for direct part marking (DPM), especially for traceability so job shops are now being asked to provide laser marking for 2D DPM.

The most common reasons for DPM are:

- Traceability is required after the product is separated from its temporary identification.
- The part is too small to be marked with bar code labels or tags.
- The part is subjected to environmental conditions that preclude the use of add-on identification means.
- The use of DPM methods may be more cost efficient than individual item labels.
- Identification is required for at least the anticipated life cycle of the part, as defined by the manufacturer.

The use of DPM may also be beneficial in the following manufacturing related processes:

- production automation,
- inventory management,
- traceability/part path history,
- lot control,
- select fit,
- error proofing,
- serialization,
- product identification, and
- quality control/defect containment.

Quality control

Customers require lasers for marking mainly because of the quality and resolution of the mark. The fiber laser provides the ability to produce high resolution for text, serial numbers, and data matrix barcodes based on the small beam diameter and the close focus of the marking area. The marking area of an item should be perpendicular to the laser beam, and the focal distance or item shape should not vary by more than 0.250 in. or the mark may appear out of focus.

Manufacturing processes and material property variations in the item being marked can also affect mark consistency, for example:

- differences in metallurgy between lots or between suppliers,
- variations in coating thickness, and
- consistency of surface finish.

Unique identification marks and device identifiers

Customers that are awarded military contracts rely on laser job shops to mark unique 2D matrix identification code issued for tracking. This code is known throughout the military industry as a UID or a unique identification mark. Complying with the military standards is essential for the laser job shop that wants to work with the US defense industry. The job shop needs to encode proper data strings into the 2D Barcode and are required to provide the correct encode. All parts or products must be registered for full compliance. Laser marked parts or products from the job shops are then shipped to their customers with the unique identification codes.

More than 50% of laser marking in a job shop may be associated with UID marking. This identification is necessary for traceability, better maintenance records, and asset tracking. Laser job shops offering UID marking and verification need to invest in verification equipment, software, and fiber laser technology for quality marking. Quality marking assists in 99.99% verification of the barcode marking. A quality laser marking from a job shop will need to be tracked from cradle to grave. It is the goal of the laser job shop to produce high quality marking that is legible and permanent for the life of the part.

Medical devices being sold in the US are required to provide traceability to improve consumer and patient safety. The FDA mandate for a unique device identifier (UDI) offers an opportunity for laser job shops to be involved. According to the FDA, a UDI is defined as a unique numeric or alphanumeric code specific to a device model, acting as a key to identifying device information: name of manufacturer, type of device, its expiration date, batch and lot number, etc. The laser job shop can provide permanent marking to meet traceability concerns and demands on medical products. The laser job shop would need to develop a process that passes all corrosion, passivation testing, salt baths, or other medical durability tests.

There are many new demands and applications that a laser job shop faces now and in the immediate future. Paying special attention to details will reduce problems. The end result is becoming more profitable and attracting new business for improved growth.

GARY NIEMENSKI *(sales@lasermarkingguy.com) is owner of LMG Technologies Inc., Farmington, MI.*

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CALENDAR

FEBRUARY

25-27 Laser Safety Officer Training, Phoenix, AZ; www.lia.org/education/calendar/

27-28 International Laser Symposium 2014, Dresden, Germany; www.lasersymposium.de/en.html

MARCH

12-13 LAM (Laser Additive Manufacturing Workshop), Houston, TX www.lia.org/conferences/lam

18-20 Laser World of Photonics China 2014, Shanghai, China; www.world-of-photonics.net

25-27 IPC APEX Expo 2014, Las Vegas, NV; www.ipcapexexpo.org/html/main/default.htm

APRIL

16-18 Photonix Expo & Conference 2014, Tokyo, Japan; www.photonix-expo.jp/en/

22-24 First Smart Laser Processing Conference 2014, Yokohama, Japan, www.jlps.gr.jp/slpc2014/

24-26 The 2nd China (Shanghai) International Technology Fair, Shanghai, China; www.wes-expo.com.cn/

MAY

7-9 AKL- International Laser Technology Congress, Aachen, Germany; www.akl-ev.de

14-15, Rapid.Tech, International Trade Fair and Users' Conference, Erfurt, Germany; www.rapidtech.de

14-17 Lamiera: International Sheet Metal Working Exhibition, Bologna, Italy; www.lamiera.net/home/

JUNE

9-12 Rapid 2014 Conference & Exposition, Detroit, MI; www.sme.org/rapid

17-20 15th International Symposium on Laser Precision Microfabrication (LPM 2014), Vilnius, Lithuania; www.lpm2014.org/

24-25 Stuttgart Laser Technology Forum–SLT '14, Stuttgart, Germany; www.ifsw.uni-stuttgart.de

24-26 LASYS–International Trade Fair for Laser Material Processing, Stuttgart, Germany; www.messe-stuttgart.de/lasys/

28-29 The International Conference on Materials Science and Energy Research, Wuhan, China; www.mser.org/index.htm

JULY

8-10 SEMICON West & Intersolar North America, San Francisco, CA; www.semiconwest.org/

AUGUST

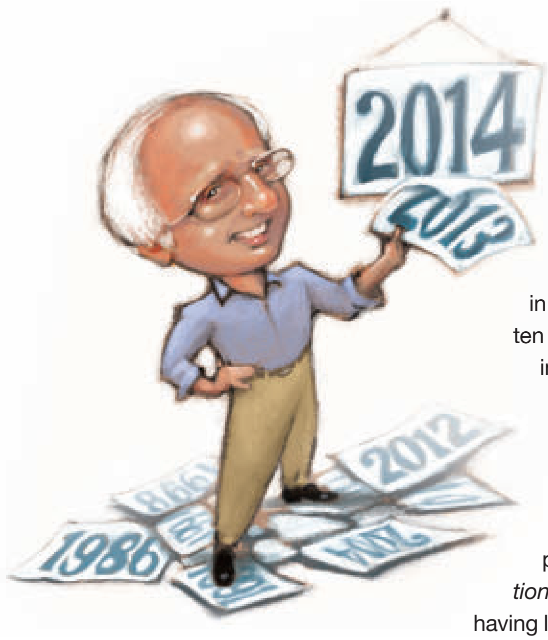
24-29 Europhoton, 6th EPS-QEOD Conference on Solid-State, Fibre, and Wavequide Coherent Light Sources, Neuchatel, Switzerland; www.europhoton.org

INDEX OF ADVERTISERS

28 and still counting

THE ROOTS OF *ILS*

This issue of *ILS*, the first in Volume 29, marks the beginning of my 30th year of editing and writing on industrial laser materials processing under this masthead. When I review back issues, I can honestly say that we have chronicled the growth of this technology, and in some ways have contributed to and/or influenced the advance of the technology in the field of manufacturing. This is not an empty claim because we can document this from the magazine's archives.



We didn't do it alone, as there have been hundreds who graced the ranks of ILS contributors, writers who willingly shared with our readers their knowledge of laser material processing. By doing this, they helped us promote the technology in developing markets. As an example, in 2013, we published 24 features written by 49 authors, covering topics ranging from laser additive manufacturing to hybrid welding to aerospace component drilling to precision scoring of packaging materials.

When I look back at the early issues of *Industrial Laser Review* (the predecessor to *Industrial Laser Solutions*), I recall how it all got started. I was having lunch with the then-publisher of *Laser Focus*, and I mentioned that a group of young university post-docs attending a conference in Germany where I was an invited speaker peppered me with questions about laser materials processing developments. Later they continued asking about sources for more in-depth details, pointing out the dearth of detailed processing information in the open literature. This raised the question from my luncheon companion of how this information could get disseminated and from this followed the idea to produce a handbook containing this information. Thus was born, in 1986, the annual *Industrial Laser Handbook*, which that year was the only collection of detailed laser processing specifications and procedures.

The Handbook was a great success, but several of the students who had germinated the idea now asked for more current information rather than once a year. This prompted the idea of a monthly paid subscription newsletter called *Industrial Laser Review* that premiered at a trade show in 1986. This caused laser manufacturers to place ads, so *ILR* was born, the first publication focused on industrial laser material processing. *ILR* morphed into *ILS* in *1999*, and we have never deviated from our stated mission of educating current and potential laser users to the benefits of the technology.

I think we can lay claim to defining and coining the term "industrial laser" to set the technology off from the other applications that today are grouped under the term "photonics". Many in that group of young university graduates continued to work in the technology, and today they hold highly visible and prestigious positions in industry and academia.

When we first reported on the laser market in 1989, the value of lases sales was $161 million, starting a trend that saw the CAGR through 2013 at 11.9%.

The first Opinion column, a precursor to My View, appeared in December of 1986, and the subject was a call for a finer classification of industrial lasers by power output, an idea the industry nixed — so much for editorial clout.

The big news in 1986 was the formation of the European Union's BRITE program, which was designed to stimulate interaction between industry and academia, and the Eurolaser project, EEC, funded to expand the European laser industry. These two programs have had a major impact on the growth of industrial lasers in the global market. Out of these came volumes of technology information on which *ILS* has reported in the past 28 years, much of it the result of efforts by those former students.

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