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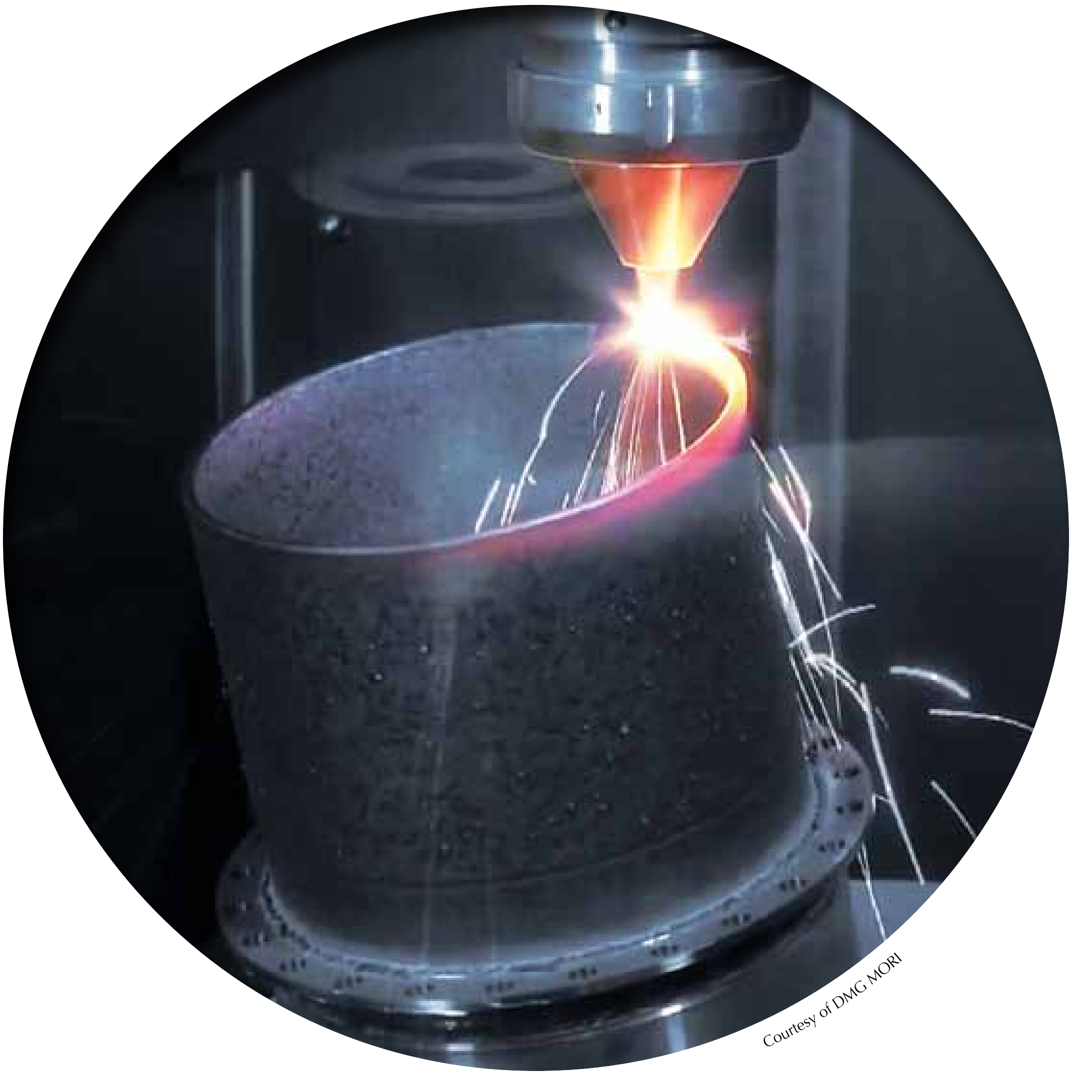
ENGINEERING

LASER FOCUS — A SPECIAL SECTION



Courtesy of DMG MORI

LASERS TODAY: A LIGHT OVER ALL PROCESSES

CNC-POWERED LASER INNOVATION

LASER USE IN MANUFACTURING GROWS

WELDING APPLICATIONS EXPAND

A laser cutting head, mounted to the end effector of a robot, is robust and compact to withstand the challenging environment while having internal sensors and mechanisms that provide accuracy and feature capabilities that are beyond the normal capacity of the robot.

Courtesy of Laser Mechanisms Inc.

LASERS: A LIGHT OVER ALL PROCESSES AND MARKETS

SME's Industrial Laser Community
Geoff Shannon, PhD, Laser Technology Manager—Miyachi America, and Mark Taggart, President—Laser Mechanisms Inc.

As we approach the 50-year anniversary of laser use in manufacturing, the use of lasers to make things is accelerating and expanding. Laser applications that just a few years ago were thought to be impossible or too expensive are becoming feasible and cost effective.

Lasers, in fact, touch all of our lives on a daily basis. With great precision and efficiency, lasers:

- cut the glass for our smartphone and tablet screens;
- weld the hard disk drives in our PCs and laptops;
- cut airbag material and weld airbag detonators in our cars;
- drill the fuel injectors in our engines to increase fuel economy; and
- cut medical stents that enhance our lives.

What's more, remarkable, fast-paced advances in computers, sensor technologies, and wireless communications are creating increasingly sophisticated tools such as process monitors and system diagnostics that are enhancing the performance, reliability and ease of use of industrial laser systems.

The use of lasers in manufacturing dates back to the late 1960s and their growth has been unsteady. One of the first applications, which is still in use, was the laser drilling of over 30,000 holes in components that build up jet engines. Early adoption of laser technology in the automotive industry, however, proved to be too much too early. But today, lasers are commonly used across a wide variety of industries, including aerospace, defense, medical, automotive, and consumer electronics, as well as a wide variety of processes. That includes cutting, welding, drilling, marking and micromachining, and industrial lasers have proven their robustness in the highest-volume markets.

The largest market share for laser technology has been and continues to be in the fabrication industry for flatbed laser cutters. As laser powers have increased, cost per watt has decreased. Motion systems have also delivered faster speeds and positional accuracy, which has grown almost 10% year over year. Another growth area has been in the use of lasers for marking, one of the fastest growing segments for the past few years. The need for tracking and traceability of parts across all industries, for both regulatory and cost reasons, has driven demand.

Looking to the future, where will laser technology expand? The explosion of laser technology in the last 10 years has opened up their use for virtually all processes and markets. The "tool-less" noncontact nature of lasers combined with a heat source that can be manipulated by optics to any shape offers unrivalled flexibility.

Within the technology, there are rapid and exciting developments in ultrafast and direct-diode lasers, specialized optics and high-speed beam delivery systems, and non-metals welding and processing. Advancements in the field of laser additive manufacturing have also caught the attention of the public and the media.

Just as today's realities may have been inconceivable to the industry's earliest pioneers, the future promises even more incredible developments.

Additive Manufacturing

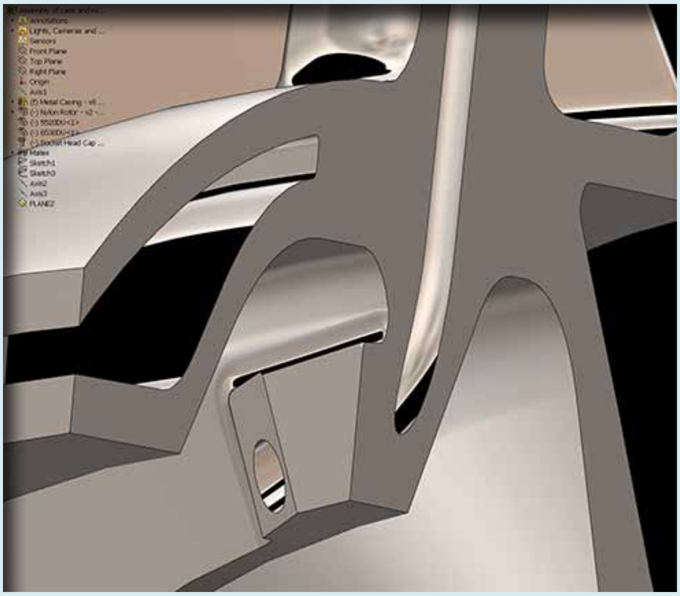
By Tim Morris, Vice President North America—EOS of North America Inc.—Electro Optical Systems

One of the fastest growing manufacturing technologies in recent years is additive manufacturing, often referred to as 3D printing. This process is capable of creating three-dimensional objects of virtually any shape and level of complexity directly from digital data. Additive manufacturing can produce components virtually impossible to create with conventional manufacturing techniques, in terms of geometrical complexity and overall part performance.

There are many different additive processes used in this manner; however, the laser-based processes are recognized as the leaders with regards to industrial manufacturing capabilities, superior detail resolution and as-built material properties. The primary laser-based processes are laser metal deposition (LMD) and the power bed processes of direct metal laser sintering (DMLS) and selective laser sintering (SLS) for polymers.

The LMD process uses either solid-state or CO_2 lasers up to several kilowatts, to deliver sprayed metal powder to a base component via laser melting. Most recently, the availability of high-power fiber delivered solid-state lasers has expanded the use of robotics in this field. Although historically used primarily for high deposition cladding and hard facing applications, when combined with precision power nozzles and small laser spot sizes, higher definition additive manufacturing can be performed.

The powder bed processes are capable of processing most weldable engineering metals as well as a number of high-performance polymers. The move of this technology from rapid prototyping to true manufacturing applications is accelerating in all major industrial fields, including aerospace, automotive, consumer goods, medical components and tooling.



Internal cavities and oil lines, Material: EOS StainlessSteel PH1

Courtesy of EOS of North America

For DMLS the developments in robust Yb:YAG fiber lasers has greatly advanced the capabilities of this manufacturing platform. Single-mode fiber lasers ranging from 200 W to 1 kW combined with high-speed digital scanners are critical for the success of this technology. With layer thicknesses commonly as small as 20 microns, small laser spot sizes, precise laser power control and accurate high-speed scanner trajectories are critical.

SLS is powered by sealed CO_2 lasers for optimum laser absorption in the polymer materials. These maintenance-free lasers in the 50–100-W range are the perfect power source for precision melting of polymer powders used in the SLS process.

Unlike subtractive manufacturing methods (i.e., drilling, machining) where one starts with a bulk material with known material properties, in additive manufacturing the material properties are formed during the additive process. This requires a detailed knowledge of the effects of the laser/material interactions as well as the thermal influences on material properties of both the heating and cooling cycles. This is a major area of current study to further understand the capabilities of this technology.

Laser Cutting

By Richard Neff, Manager Market Development—Cincinnati Incorporated, and Gary Cican, Sales Engineer—Laser Mechanisms Inc.

It's hard to imagine we might call laser cutting a mature technology. But thousands of laser cutting systems are now making great parts for companies large and small in every corner of the globe. Most are safe, reliable, productive, accurate, serviceable and easy to use. If you operate a modern laser, you will find it is even better than a similar machine just a few years old.

As we look back on laser technology, the first innovation in the early 1980s was to strap a CO_2 laser resonator and focusing lens on a punching machine to create a laser cutting machine. Dual pallet design machines then made lasers more productive. In the 1990s, higher power resonators increased the capacity of cutting systems. Upgraded drive systems with linear motors and improved beam quality boosted cutting speeds in light-gage material. Better programming software maximized material utilization, productivity and ease of use. In the 2000s, automation in both programming and material handling further improved machine utilization.

The most recent innovations are the use of solid-state lasers that deliver the laser energy directly to

Cincinnati Laser Cutting System piercing heavy plate material.

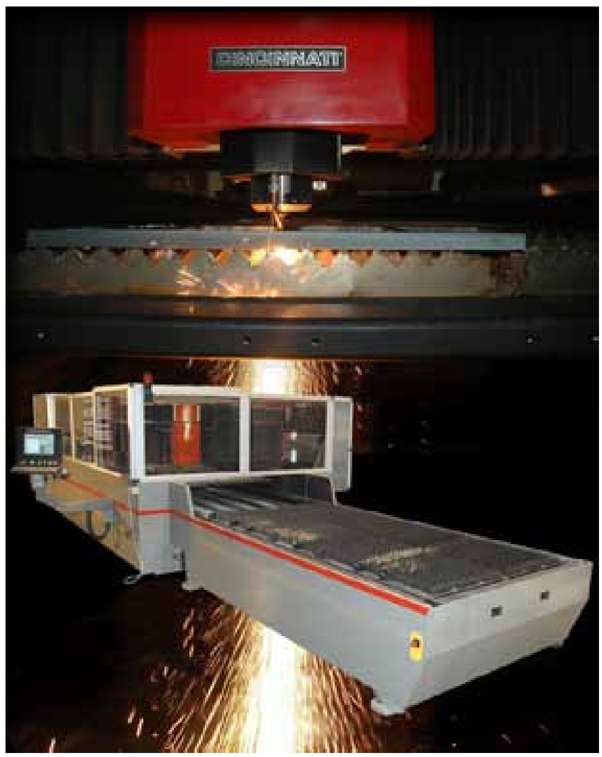
Courtesy of Cincinnati Inc.

the cutting head with an optical fiber. Three different laser technologies are available: fiber, disk and direct diode. Fiber lasers can be delivered using a small-diameter fiber core with high beam quality. The laser energy can be focused to a very small spot providing high-power density at the workpiece. Disk lasers are similar in performance. Direct-diode lasers do not have the same beam quality as fiber or disk, but this is improving and they are also starting to be used for laser cutting. All three forms of solid-state lasers start by generating energy using laser diodes. Fiber and disk lasers use diodes to excite another laser medium that generates a specific wavelength of light. Direct-diode lasers generate laser light directly from the diodes. All three solid-state lasers are more reliable and affordable to run than CO_2 lasers.

For a fiber laser, the focusability and wavelength allow machines to cut very small kerf widths in thin material. Cutting with a small kerf requires less energy, and so, for a given power level, fiber lasers can cut thin material much faster. If you purchased a 2000-W CO_2 laser in 2007 to clean cut 20-gage steel, the feed rate is about 290 ipm (7 m/min). A 2000-W fiber laser using air assist gas can cut the same material over five times faster at 1615 ipm (41 m/min). In addition, the hourly operating costs of a fiber machine are less. This can be a real game changer if you are processing thin material.

Integrating lasers and material handling is also improving. Lasers are becoming more stable and able to run untended. Process monitoring can verify the cutting process and stop the laser from making scrap parts. Furthermore, there are many methods of automating the setup so untended operation is more practical.

In addition to adding more power and features to machines, many manufacturers are also looking for ways to reduce the cost and complexity of their lasers. Some lasers today have improvements in productivity, reliability and operating costs at a price that is lower than just a few years ago. Some companies also offer machines with less power, slower drive systems and fewer options for customers with budget constraints.



Cincinnati Laser Cutting System.

Courtesy of Cincinnati Inc.

Micromachining

By Ronald D. Schaeffer, PhD, CEO—PhotoMachining Inc., and Neil S. Ball, President—Directed Light Inc.

Laser micromachining involves the machining of small features into various materials using lasers through material removal. By "small," we define the feature size as being less than 1 mm and the material thickness as being less than 1 mm, and both are usually a lot less.

Lasers are used for a variety of reasons. First, the noncontact nature minimizes the risk of damage to the material and does not introduce tool wear. The feature resolution when using UV lasers is unmatched by any traditional machining technology, with the smallest attainable features on the order of a few microns, using UV lasers and high-quality optics. By choosing the correct wavelength and energy density on target, selective material removal can even be achieved. Finally, the use of lasers provides great flexibility especially in the prototyping and R&D stages.

For micromachining applications the key to clean and low taper processing is peak power intensity, which is energy density per unit area. In other words, the best results are obtained when using lasers with high-pulse energy and short-pulse length and where the laser spot is focused to a small size. This is one of the reasons that USP (ultra-short pulse, meaning picosecond and femtosecond lasers) are becoming very popular—the short-pulse length greatly increases peak power at the target, even with relatively low pulse energy. Figure No. 1 shows a graph of wavelength vs. pulse length where all of the micromachining applications are on the lower half of the *Y* axis, where longer pulse lengths are used primarily for applications requiring a lot of heat on target.

Armed with a variety of lasers with wavelengths from the IR through the UV, and pulse lengths from milliseconds to femtoseconds, numerous applications can be addressed in the fields of automotive manufacturing, semiconductors, microelectronics, medical devices, alternative energy, aerospace and defense. All materials can be addressed by using the right laser and optical setup with the stipulation that maximum material thickness is somewhat dependent on the output power of the laser, especially when speed/cost are an issue. Hard/brittle materials like ceramics and glass have a higher ablation threshold and therefore require higher energy density on target to achieve material removal, while soft materials like polymers generally require less energy density on target to affect clean removal. For the same laser and optical setup, much greater material thickness can be processed with soft materials than with hard. The factor of overriding importance, however, is absorption. The more photons a material absorbs at a particular wavelength and optical setup, the better the processing will be.

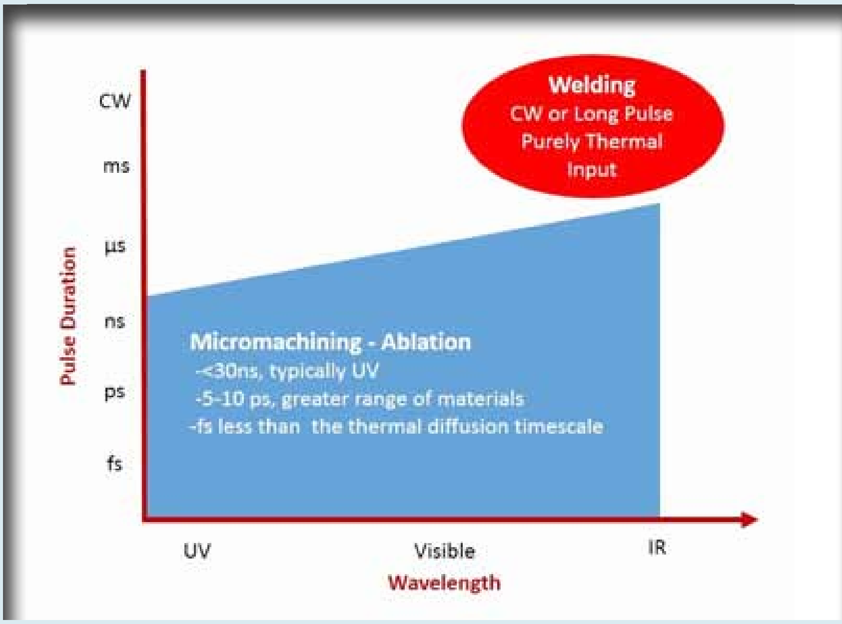


Figure No. 1: Courtesy of PhotoMachining Inc.

Laser Micro Welding

By Geoff Shannon, PhD, Laser Technology Manager—Miyachi America Corporation

Laser micro welding generally covers applications with less than 0.04" (1-mm) penetration. This noncontact process for spot and seam welding offers low heat input, tailored weld dimensions, high-speed welding, and wide range of joint geometries and materials. The foundation and continuing growth of laser micro welding is largely based on medical device manufacture, automotive sensors and airbags, batteries and consumer electronics.

The lasers that are suitable for micro welding are pulsed Nd:YAG, fiber and diode—each offers unique features that align to specific applications. The pulsed Nd:YAG laser has by far the largest install base with peak powers and pulse widths designed for micro welding; 25–50-W pulsed Nd:YAG lasers are routinely used to seam weld 0.015" (0.381-mm) thick titanium cases for implantable devices. More recently developed fiber lasers offer excellent flexibility in tailoring weld dimensions and the best penetration per watt performance that enables high-speed seam welding. A 300-W fiber laser can seam weld 0.01" (0.25-mm) thick airbag detonator casings at 2 ips (50 mm/s), a 20-W pulsed fiber laser can produce a 0.001" (0.025-mm) diameter spot weld in 0.001" (0.025-mm) thick foil. The diode laser is a well-established laser technology that been used for many plastic welding applications, notably in the automotive industry for welding the rear light housing. Welding of plastics with lasers is a current growth area, particularly with the development of laser-friendly plas-

ILC Laser Micro Welding Pulsed Nd:YAG laser micro welding of computer battery.

Courtesy of Miyachi America

tics and lasers that can weld visually clear plastics.

Laser Macro Welding—High-Power Laser Welding

By David Krattley, Industrial Sales Manager—Materials Processing, IPG Photonics

Some general specifications and limits of high-power laser welding are weld speeds in the range of 40–350 ipm (1–9 m/min) and weld depths up to 5/8" (16 mm).

Lasers have been an industrial tool for more than 30 years. The laser sources being used for high-power laser welding before 2003 were CO_2 and flashlamp pumped CW YAG lasers. Since 2003, diode-based lasers have taken over the majority share of this industrial laser market segment. This is partly due to the commercial benefits of these diode-based products such as smaller size, reduced power consumption, and decreased maintenance and partly due to the improved optical and delivery characteristics. There are a variety of these laser types, the main ones being fiber lasers, disk lasers, and fiber delivered direct diode (for the purpose of high-power welding this laser can do some hybrid and limited keyhole welding as the beam quality is not as good as fiber or disk lasers).

Most often laser welding is done autogenously and part fit-up and fixturing are key elements. For difficult material combinations, poor part fitup, and welds with deeper penetration than autogenous methods permit, hybrid welding is used. Methods include the addition of either cold or hot wire with laser. Some of the benefits of the fiber and disk lasers (in addition to being fiber delivered which makes integration to robots or equipment easy) are very good beam quality which allows the use of long focal lengths and the ability to do remote welding. Remote welding uses special optics or a high-power galvanometer to steer the beam and produce very fast welds.

High-power laser welding is used by aerospace, automotive, mining, construction, and agriculture in a variety of applications. The benefits of speed and repeatability make lasers an excellent choice for high production parts that demand quality welds. Some such applications are transmission gears, muffler components, axles, and body in white. New applications are constantly being developed for these new diode-based high beam-quality sources, one such application is a laser seam stepper that replaces a traditional resistance spot welder.

Laser Seam Stepper (replacement for resistance spot welder).

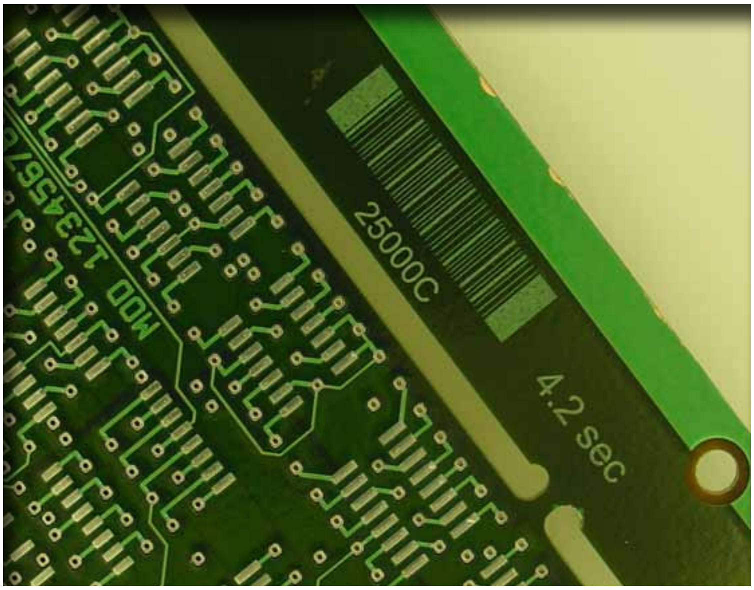
Courtesy of IPG Photonics

Laser Marking

By Daniel R. Gold, President and Founder—LNA Laser Technology, and Dale A. Sabo, Vice President Sales & Marketing—SCANLAB America Inc.

Laser marking or engraving remains one of the largest laser application segments in terms of units sold and revenue. Almost all items manufactured today need to be marked for traceability or branding and the process is used across a wide range of industries: medical devices, automotive, aerospace, defense, electronics, semiconductor, industrial tools, firearms and jewelry.

Lasers used for marking can range in the wavelength spectrum from UV (355 nm) to far infrared (10,600 nm), depending on the material and application requirements. The majority of lasers used for marking in manufacturing fall in the infrared 1 micron (1064 nm) or the far infrared (10,600 nm). The choice is mainly material driven. One micron infrared (1064-nm) lasers, either DPSS (diode-pumped solid state) or fiber laser technology, are used to mark mainly metals and many plastics, whereas far infrared (10,600 nm) CO_2 lasers are used to process mainly organic materials such as wood, leather, glass, foam, stone and plastic engraving. The shorter wavelengths such as Green (532 nm) and UV (355 nm) are reserved for applications requiring high material absorption and low impact on the material (such as heat affected zone, recast, etc.). Short wavelength marking applications include solar panels, computer hard disk components, semicon-



Printed circuit boards that are laser marked.

Courtesy of LNA Laser Technology

decades.

The biggest changes in technology in this area have come in the 1 µm and under spectrum. The trend in technology over the last 20 years has allowed the lasers to become increasingly compact, efficient and maintenance free, at a significantly lower cost. Fiber laser technology, in particular, has had the most impact in the majority of industrial manufacturing applications.

It is likely that future developments in laser marking will follow the trend of sub-nanosecond technology, particularly as the laser costs fall more in line with this market segment's expectations.

ductor components and medical device implants. In addition, short wavelength lasers have a smaller focused spot size allowing for very small marking in certain micro applications.

CO_2 lasers are the most mature of the marking laser technologies. The applications fields are well established—used for awards and gifts and high-speed packaging across many industries—and the architecture has remained relatively stable over the past few

Examples of items that are laser marked.

Courtesy of SCANLAB-AG

Laser Drilling

By Doug Scheidt, Senior Technologist-Laser Processes – Special Products and Combustor Lean Lab, GE Aviation

Laser drilling is a noncontact process that removes material via photon interaction with the material being drilled. The mechanisms of removal are melting, evaporation, and ablation, sometimes in combination. Processed materials have different optical (absorption at wavelength) and thermal properties (thermal conductivity, heat of melting/vaporization), which allows for selection of the correct wavelength and pulsing properties of the laser.

Advantages of laser drilling over other nonconventional methods include shorter processing time, less expensive fixtures, changes to hole diameters without changing "electrodes" or other "drill bits," changes to hole locations by programming, and the ability to drill hard and nonconductive materials.

Disadvantages of laser processing include possible thermal damage to material, the need for post drill processes, potentially harmful vapors and initial capital equipment costs.

Like any material removal process, optimization studies must be conducted to achieve the correct balance of cycle time, part quality, and part cost. The studies should focus on key process parameters for the material, and their effect on key quality characteristics of the part. Typically, wavelength, pulse width, energy/pulse and focal properties will have the biggest influence on hole quality. Optimal cycle time can be achieved by adjusting pulse repetition rate with two important caveats. The allowable adjustment is finite, in that pulse repetition rate will change the laser average power, and the beam quality of many lasers can change negatively with increased pulsing. Secondly, pulse repetition rate can change the substrate temperature through sidewall conduction and cause degradation in hole quality and time.

In addition to the primary laser characteristics, there are multiple factors to consider for achieving a stable process. Beam quality, in conjunction with lens focal length and input beam diameter, will determine the focal spot size, and the depth of focus, essentially the "drill bit" diameter and length. Assist gases are also used for multiple reasons. One primary reason is to protect the lens or cover slide from ejected matter, but gas can also influence the drilling rate. Gases can also assist in removal (O_2) or help reduce oxides (N). Pressure/flow will have to be balanced to protect the lens without suppressing the expelled material. Gases should be free of any moisture.

Laser drilling has been demonstrated at aspect ratios (depth/diameter) of greater than 20:1.

Future Technological Development

By Silke Pflueger, General Manager—
Direct Photonics

Two main drivers are pushing the technological development of lasers for material processing: Improving sources for traditional applications such as metal welding and cutting, and developing new sources for new applications, such as glass cutting.

To increase the market for lasers in cutting and welding, laser developers are reinventing the way the radiation is generated. Modern laser sources are very reliable machines, used in production lines around the world. Size, efficiency, and price are the main drivers for new laser development at 1 μm, with direct-diode lasers pushing into high brightness applications. As an example of how specialized lasers are becoming, consider this: To enable a wider range of material to be cut, fiber and disk lasers were developed that have switchable beam quality to cut both thin and thick metal efficiently.

Ultrafast lasers are an example of new technologies opening up completely new applications for lasers. They have now become production tools, cutting Gorilla Glass and sapphire in a manufacturing environment. Reliability, ease of use and a reduction in price are the main development drivers, ultimately enabling more applications and markets.