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UV Goes Deep

Pulsed, diode-pumped, solid-state ultraviolet lasers provide users with a smaller, sharper cutting tool for micromachining applications in thin metals and nonmetals. New deep ultraviolet lasers offer even more precise cutting quality.

Pulsed, diode-pumped, solid-state ultraviolet lasers have become the tool of choice in many micromachining applications. The solid-state reliability, long life (pump laser diodes have typical lifetimes greater than 20,000 hours) and compact size of these DPSS lasers enable machine tool builders and parts manufacturers to view the focused laser beam as a valuable cutting tool. Shorter-wavelength ultraviolet DPSS lasers offer better resolution than longer-wavelength DPSS lasers (near-infrared and visible wavelengths), making the former more appropriate for small-scale machining because the laser can be focused on a smaller area than other lasers.

Current applications for ultraviolet DPSS lasers involve plastic, metal, ceramic and glass, and range from drilling microvia holes (holes with diameters up to 0.15mm) in printed circuit boards to cutting holes and slots in disposable medical devices. Until recently, ultraviolet DPSS lasers were only available with an output wavelength of 355nm, but new "deep ultraviolet" models have a shorter wavelength output of 266nm. (Deep ultraviolet refers to a region of the light spectrum with a wavelength less than 300nm.) There are several trade-offs between 266nm and 355nm processing in terms of precision, throughput and material compatibility. This article describes the relative benefits of these two lasers.

Pulsed Ultraviolet Lasers

Pulsed ultraviolet and deep ultraviolet DPSS lasers offer two distinct advantages over longer-wavelength lasers. The first is superior spatial resolution. The minimum size of a spot created by a focused laser beam increases with wavelength due to an optical effect called diffraction. As a result, only ultraviolet and deep ultraviolet lasers are capable of machining at the micron and submicron scale.

The second advantage is cold processing. Near-infrared and visible wavelength lasers machine materials by producing an intense, highly localized spot of heat, essentially removing material by boiling it. But heat spreads, leading to unwanted peripheral thermal effects, such as charring, melting,

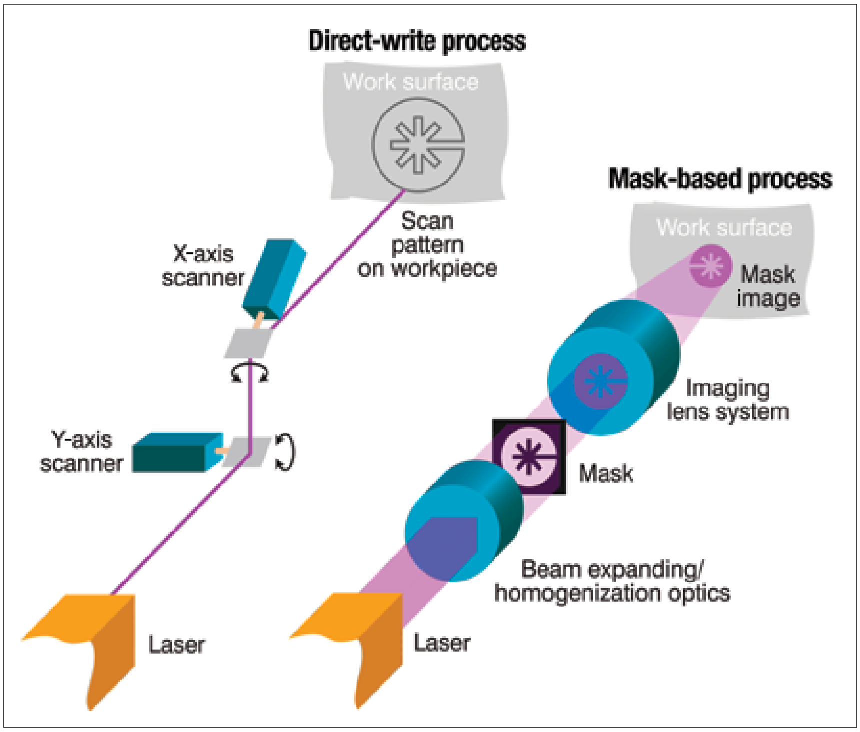


Figure 1: There are two ways of machining with a laser beam: photomask and direct-write. The focusable pencil-shaped beam from DPSS lasers makes them most suitable for direct-write photomachining.

All images and charts: Coherent

cracking and recast material deposition. This is referred to as a heat-affected zone (HAZ) on the workpiece.

In many plastics and other nonmetals, ultraviolet and deep ultraviolet light works differently, directly breaking molecular bonds in a process called photoablation. This is a relatively cold process that produces a small, if any, HAZ. Depending on the material, an ultraviolet laser typically creates HAZ effects less than 10 percent of that created by an infrared laser of the same power. Photoablation enables the production of sharper, cleaner edges and the creation of tiny features that would be melted by thermal processing.

In laser micromachining, a fast, pulsed laser is preferred over a continuous-wave laser because any heat produced by a short pulse has time to dissipate before the next pulse arrives, avoiding workpiece damage from cumulative heating effects. In addition, pulsed output maximizes processing power while minimizing peripheral thermal effects. With pulse durations in the nanosecond range, a pulse energy of just a few microjoules translates into peak power of up to 10kW, enabling even difficult-to-cut materials to be machined with a laser rated at less than 20w overall power.

266nm vs. 355nm

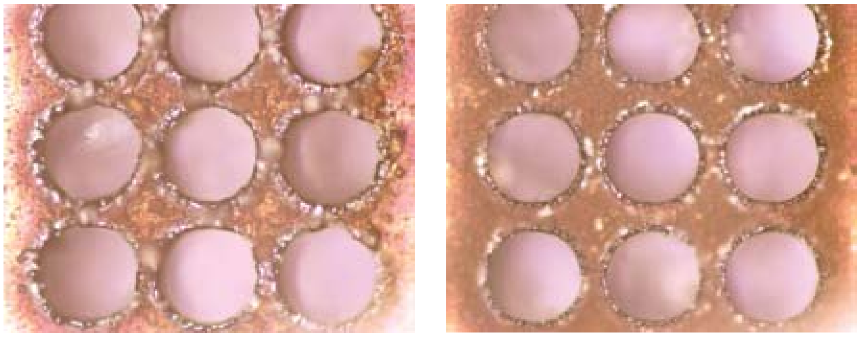
There are two complementary types of commercially available pulsed ultraviolet lasers: excimers and DPSS. Excimers produce a high-power, large cross-section output beam that cannot be focused to a small spot. As a result, a photomask is used to create the desired pattern on the workpiece. This makes excimers most useful for machining large, complex or repetitive patterns. In contrast, ultraviolet DPSS lasers deliver lower power in a beam that can be tightly focused to a small, concentrated spot. This makes these lasers appropriate for direct-write applications. Here, the focused laser beam is scanned across the workpiece using 2-axis, fast-scanning (galvanometer-mounted) mirrors or by moving the part on a precision X-Y table (Figure 1).

These methods support raster and vector scanning. (Raster refers to

Deep ultraviolet DPSS lasers, such as this 3w unit, are characterized by their compact platform and are available with a choice of output wavelengths.

scanning in the X direction as the Y direction is slowly increased. Vector scanning refers to making moves in arbitrary directions, including straight lines at different angles as well as curves.) This scanning can be fast (up to tens of meters per second) because of the high (up to 100kHz) pulsing rates of DPSS lasers. Specifically, a high pulse rate enables the laser spot to be scanned at a higher speed before it starts to cut a dotted rather than continuous line. Obviously, a dotted line is unacceptable in most applications.

Because only 355nm ultraviolet DPSS lasers were previously commercially available, product development was focused on increasing the power and service life of these lasers to improve throughput and reduce total cost of ownership. In the past 18 months, however, DPSS lasers with deep ultraviolet (266nm) output have become commercially available.



Figures 2a and 2b: These 0.0012"-thick stainless steel samples show 120µm holes cut with a 170µm pitch. The holes in Figure 2a (left) were created using a 355nm laser wavelength and in Figure 2b using a 266nm laser. All other conditions were identical. The 355nm laser did a good job, but its holes are surpassed in quality by the 266nm laser's holes.

Moving from 355nm to 266nm enhances the benefits of ultraviolet laser machining—particularly photoablation efficiency, which increases at shorter wavelengths. This increases the ratio of cold processing to thermal processing on each workpiece. Improved photoablation, combined with a decrease in spot size because of diffraction, means 266nm lasers can produce smaller features than 355nm lasers while inflicting less thermal damage.

But 355nm lasers have been on the market longer, so higher-power models are available. The highest power 355nm model has more than 20w of output. In contrast, power levels for commercial 266nm lasers are less than 5w. This means processing time and cost must be considered when choosing a laser for micromachining.

Metalworking

The choice between 355nm and 266nm lasers comes down to trade-offs among speed, cost and cut quality. Virtually any metal can be processed with both wavelengths. However, there is always some localized workpiece heating, even at 266nm. This is manifested as debris (recast and redeposited material on the surface) and dross (recast material on the cut edges). Results from a 0.0012"-thick stainless steel workpiece demonstrate that the 266nm laser clearly produced the best results (Figures 2a and 2b). This makes the 266nm laser a suitable tool for thin foils and metal films on glass and other substrates. At thicknesses of more than 0.010", however, higher-power 355nm lasers generally cut much quicker.

Most of the 266nm applications at PhotoMachining Inc. involve stainless steel foils, brass and nickel. (Of all the metals we work with, molybdenum provides the best edge quality.) We are also seeing growing demand for patterning and drilling gold, aluminum and copper films for specialized electronic circuits, such as medical disposables, i.e., blood glucose monitors. In many applications, ultraviolet lasers are replacing conventional lithography for patterning these circuits because of the lower overall cost of this dry, one-step process. It is particularly well suited to short-run products because of the CAD/CAM flexibility it offers vs. physically generated lithographic artwork. With laser processing, software can be used to change the part design. With lithography, new artwork must be generated for each different design or even for minor design changes.

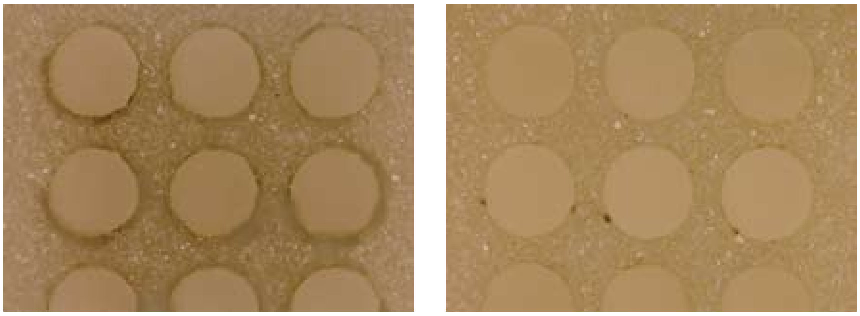
Ceramics

Thin-sheet ceramics are drilled and otherwise cut for a range of applications. These include microelectronics, for critical component mounting and packaging, as well as for probe testers to calibrate patterned semiconductor wafers. There are also emerging medical applications that require drilling tiny holes in ceramics. These materials can be processed in an unfired (green) or fired (hardened) state.

Surprisingly, fired and unfired alumina-type ceramics have similar ultraviolet laser machining characteristics, providing shops with process flow flexibility. In addition to delivering higher spatial resolution, ultraviolet lasers are preferred in many ceramic drilling applications because they avoid undesirable side effects from laser drilling, such as microcracking, bellmouthing and glassy-phase buildup.

As with metals, the choice between 355nm and 266nm in ceramic applications involves several trade-offs. Because of the availability of higher power lasers (up to 20w), 355nm turns out to be a good choice for many applications. However, with 3w of output power, 266nm can process an alumina ceramic with less than 0.005" thickness quickly and with demonstrably cleaner edges and higher resolution than 355nm. As a result, 266nm is a good choice in thin substrates if hole size and quality are critical, i.e., small holes with tight spacing. But doubling the thickness to 0.010" increases the 266nm processing time by a factor of three to five, depending on the size and proximity of the holes being drilled. Currently, this appears to be the upper thickness limit for practical processing of ceramics with 3w of power at 266nm. At greater thicknesses, 355nm is a better option. Even so, the upper thickness limit for a 355nm laser is only about 0.020". (Figures 3a and 3b show results from cutting an 0.008" workpiece.)

(PhotoMachining made 0.008"-thick ceramic parts that took about 12 hours on the 10w 355nm laser because there were lots of holes. The 266nm laser took at least three times longer, so the company did not actually make these parts with the 266nm laser unless spacing issues required it and the customer was willing to pay the extra cost.)

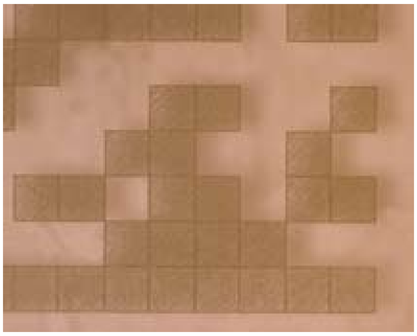


Figures 3a and 3b: Comparison of 355nm (left) and 266nm laser wavelengths for cutting 0.008"-thick alumina ceramic. These holes have a diameter of approximately 120μm and a pitch of 170μm. The 266nm clearly produces superior edge quality.

Plastics, Nylon and Teflon

Almost all plastics can be machined with a 355nm laser, and most of those that can't are readily processed with a 266nm laser because light absorption in plastics tends to increase with shorter wavelengths. But while this is true overall, plastics are hydrocarbons with discrete covalent molecular bonds, and their absorption spectrum is characterized by narrow peaks and valleys, so the fastest processing speeds will be obtained with a laser wavelength that nearly matches an absorption peak. At the same time, 266nm creates better results in terms of resolution and HAZ. However, the final laser choice with these materials involves a trade-off between quality and throughput—operating cost is not a factor.

One of the fastest growing ultraviolet laser applications in plastic involves cutting biodegradable stents from blank tubes. With conventional stents, treated blood vessels can sometimes reclose within a few months via a process called restinosis, which happens in part when the body reacts to the stent as a foreign object. Better results are being obtained by coating stents with a biodegradable



Because many types of glass only partially absorb 266nm laser light, a tightly focused 266nm laser can machine or mark within glass without damaging the surface layer. This example shows details of a 2-D matrix code marked within a glass sample.

coating that slowly erodes, releasing an antirestinosis drug. In the latest devices under development, the entire stent is made of this biodegradable plastic, which disappears in a few months.

Lastly, it is important to mention two “difficult” molecular materials, Teflon and nylon. Both have low thermal conductivity and Teflon has very low light absorption, even at 266nm. For these reasons, pure Teflon and nylon can both be marked with a 266nm or a 355nm laser, but even the 266nm laser will produce poor quality cuts with noticeable thermal damage. However, most commercial products use Teflon with additives rather than pure Teflon. The absorption by these additives usually means that the 266nm laser can machine these subjects, whereas 355nm will not.

Micromachining with solid-state ultraviolet lasers impacts many different applications and industries. The advent of 266nm lasers enables better results in many of these applications, but often at the expense of throughput. Choosing the right laser for a given application requires an understanding of the interaction of a particular material with laser light and a careful analysis of economic factors. The development of higher-powered 266nm lasers will be driven by market demand. Most likely this will come about from applications requiring higher processing speed (throughput), rather than higher power to reach a threshold level for a new application. △

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