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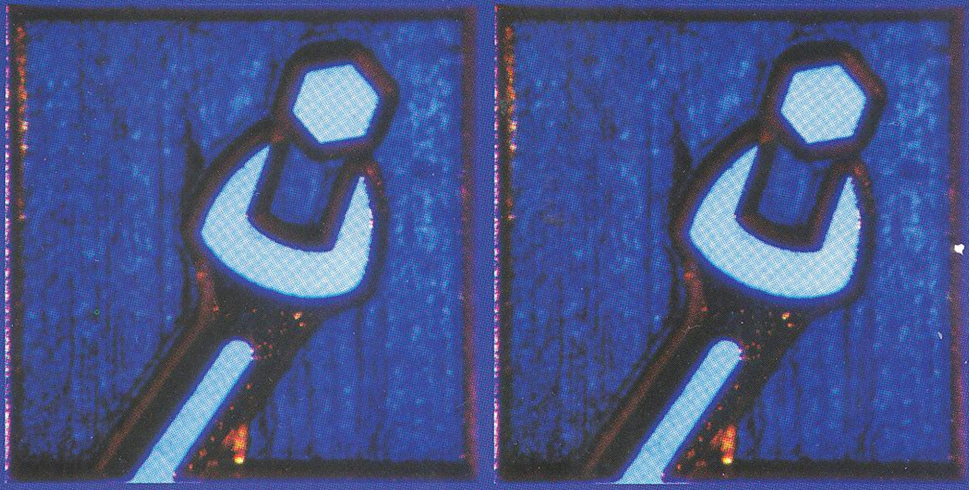
Laser Solutions In Manufacturing



- Microscale processing with ultraviolet lasers
- Comparing high-power lasers for welding
- How to focus a CO_2 laser beam

Laser processing works on a micro scale

Because of their good focusability and strong interaction with most substrates, UV laser tools can play an important role in the fabrication of miniature structures.

C. Paul Christensen

Many of the components used in modern products are getting smaller. Feature sizes in integrated circuit (IC) technology have been reduced by approximately two orders of magnitude over the last three decades.

Micromotors the size of a human hair have been fabricated with IC technology. Implantable medical devices such as pacemakers are shrinking to ever smaller dimensions. Catheters with miniature wires, fibers, probes, and sensors are increasingly used for minimally invasive surgical and diagnostic procedures. Tiny computers and wireless communicators are entering the commercial marketplace, along with miniature sensors in automotive. Demand for micromechanical structures is accompanied by demand for new microfabrication tools.

New lithographic, deposition, and etching tools for microfabrication on planar silicon substrates have led to remarkable advances in miniaturization of silicon devices. However, it often is desirable to fabricate microstructures in other materials as well. Metals are needed as structural components and electrical conductors. Glass finds application in optics, sensors, and fluid-control devices. Diamond is often useful for its high strength and resistance to wear. And ceramics are needed in actuators, high-temperature components, and harsh atmospheres. Lasers can play an important role in working these materials.

As feature sizes fall below 25µm, mechanical approaches to working these materials must be replaced with beam techniques. Lasers operating at ultraviolet (UV) wavelengths allow production of feature sizes needed for very small structures or very precise geometries. And the UV photon interacts strongly with many materials, to ablate, polymerize, or induce chemical reaction.

In the deep UV, transparent materials often begin to show strong absorption. Penetration depths of less than one micron are common for many solids. This combined with the short pulse duration of UV lasers allows good depth control in ablation processes, simplifying the use of ablation for material sculpting and shaping. In addition, UV sources etch material from a surface or add material to it by deposition. Building on these alternatives, an entire family of laser microfabrication tools is being developed.

As shown in Fig. 1, there are two different approaches to surface patterning with current UV sources, mask projection and direct writing. Mask projection techniques use the laser to backlight a mask, with the mask image transferred to the surface by appropriate optics. This allows rapid production of features over a large surface area and is well-suited to high-volume production applications of a fixed pattern or shape. Because relatively large surface areas are exposed simultaneously, a high-energy laser source is needed for mask projection.

Direct write techniques focus the entire beam of a smaller laser on the work surface and move the surface under the focused beam for pattern generation. Computer control of work surface motion allows direct production of CAD-generated shapes and rapid pattern changes. Processing may be slower, but the approach is well-suited to small batch production, prototyping, and customization. Direct write and mask projection techniques offer complimentary capabilities, and often both are needed in the design, development, and production cycle. Potomac Photonics specializes in equipment for direct write UV laser processing, so direct-write technique will be emphasized.

UV laser ablation of almost all materials requires energy densities in the range of 0.1 to 20 J/cm^2. Etching and depo-

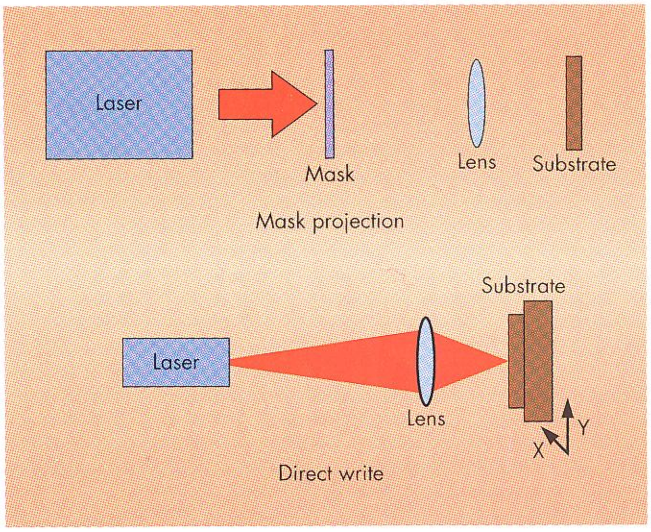


Figure 1. Comparison of mask projection and direct write process for surface patterning with UV lasers.

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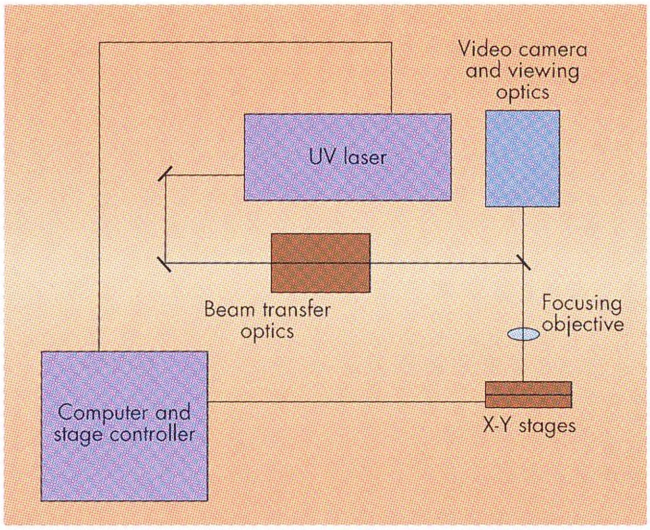


Figure 2. Layout of a generic direct-write UV laser workstation.

sition reactions and photopolymerization processes typically use energy densities near the lower end of this range. To address the spatial scales of interest, most UV direct-write processing uses focal spot diameters of less than 100μm. Consequently, the laser pulse energy in the focal spot is usually less than 2 mJ. Efficient beam utilization requires that the laser emission be focusable, and high pulse repetition rates enhance processing speed.

Several pulsed UV lasers are available, or under development, for direct-write processing. Waveguide excimer lasers, small conventional excimers, and frequency-multiplied Nd:YAG and copper-vapor sources all find applications in direct-write processing. The table summarizes the operating parameters of these lasers. In general, no single source is dominant, and it is often necessary to match the laser to the application.

Operating characteristics of UV lasers used in direct write micromachining

Laser	Wavelength (nm)	Pulse Rep. Rate (Hz)	Pulse Energy (microJoules)
Waveguide eximer	193–351	2000	50
Compact eximer	193-351	100	1000–5000
Nd: YAG	351,266	2000–4000	100–300
Copper vapor	255	2000–30000	50–200

Most direct-write UV laser workstations have the general form shown in Fig. 2. Motorized stages with submicron resolution are used to move the component in two or more dimensions under the focused beam. A microscope-like focusing system is used for video imaging at visible wavelengths and UV beam delivery. Design of high numerical aperture imaging optics for operation at both visible and ultraviolet wavelengths is a significant challenge, but both reflecting and refracting approaches are now available.

CAD/CAM interface simplifies motion programming and allows electronic control of processing speed, exposure parameters, and other features. This simplifies set-up, accelerates process development, and improves flexibility of the system in small batch processing. Video images generated by the viewing system can be digitized and processed to derive information used for autofocus, registration, orientation, edge-following, and other operations that make the laser tool easier and faster to use.

Integration of a computer into the direct-write system enables fabrication of three-dimensional structures by laser ablation. The strong absorption exhibited by many materials in the deep ultraviolet allows precise depth control in ablation processes. With the high lateral resolution also available at UV wavelengths, fabrication of three-dimensional microstructures by laser ablation becomes possible. The essence of the fabrication process is a variation of the local UV exposure over the work surface, as suggested by Fig. 3.

Potomac has investigated 3D microfabrication in a variety of materials using several laser and motion-control algorithms. Best results are usually achieved with materials that transform directly to a vapor phase at high temperatures, and when laser and material parameters are matched to maximize UV absorption. Good examples are excimer laser ablation of polyimide or diamond.

The photo shows a pyramid-shaped structure with sloping sides fabricated in diamond with a small KrF laser. The continuous surface height variation shown in the photo was achieved by repetitively scanning the substrate under the focused beam to remove material layer by layer. By slightly

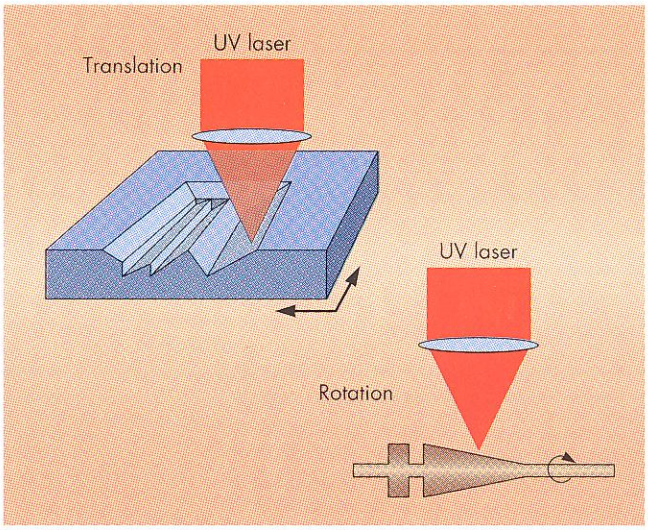
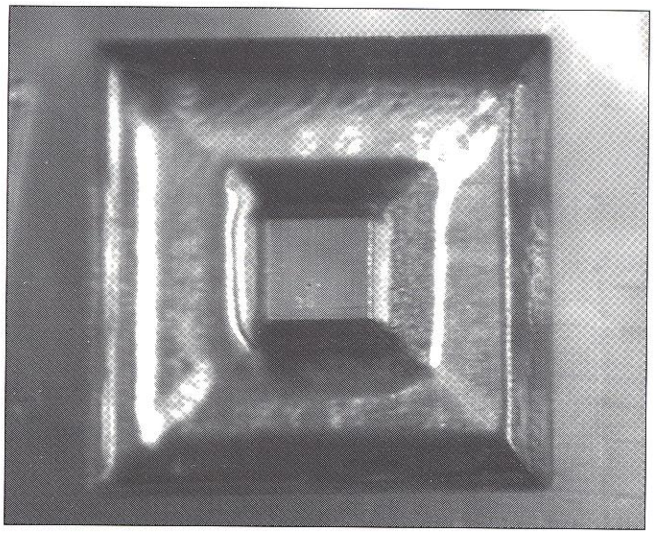


Figure 3. Fabrication of three-dimensional shapes by varying UV laser exposure over the surface.

changing the scan pattern at each successive layer, the gently sloping side walls of the pyramid were produced. Surface roughness in the ablated regions was typically a few hundred nanometers. This small pyramid is a simple example of



Pyramid structure fabricated in bulk diamond by UV laser ablation.

a structure that would be very difficult to fabricate mechanically, but which is easily addressed by a UV laser tool.

As microstructures evolve toward smaller scale dimensions and more precise geometries there is growing demand for improved measurement instruments with three-dimensional capabilities. Fortunately, optical microscopy is providing new measurement solutions.

Two promising techniques, confocal microscopy and interference microscopy, offer submicron resolution in three dimensions. Both techniques provide full field imaging and three-dimensional displays derived from 2D image slices. Additionally, scanning probe microscopes capable of very high spatial resolution over limited areas are becoming more affordable and easier to use. These improvements provide the equivalent of the caliper and dial gauge to the high-resolution micromachinist. With both fabrication and measurement relying on computer control and electronic imaging, video display is becoming a window on the microworld.

Large potential markets will continue to stimulate development of new technology for fabrication of micromechanical components. As spatial scales shrink and new materials become viable, laser shaping and patterning equipment will be joined with advanced optical imaging and measurement instruments to produce new microfabrication tools that are highly accurate and easy to use. □

Ablation of this 80μm nut and wrench in diamond is accomplished by a KrF eximer laser rapidly and accurately.
(Photo courtesy of Potomac Photonics)