As Vias Shrink, Opportunities for Laser Drilling Expand

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While lasers have long been employed for via drilling in PCB fabrication, mechanical drilling still remains the predominant production technology. However, as via diameters shrink to support various advanced packaging techniques, mechanical drilling becomes more expensive, and ultimately technologically unfeasible. A variety of laser technologies are now poised to step in to extend production via drilling down to the micron level. This article reviews the various laser sources that are available to support the latest packaging technologies as they become more widely adopted, and describes the characteristics and capabilities of each.

CO_2 Lasers

Carbon dioxide (CO_2) lasers have been used in PCB via drilling for more than two decades and currently service about 20% of the market. The reason for this relatively low market penetration is simple. Even though CO_2 lasers are a non-contact method that eliminates the need for frequent tool replacement, their sweet spot is at hole diameters around 100 µm diameter and below. As the industry transitions to smaller vias, mechanical drill replacement costs start to increase exponentially, and the use of CO_2 lasers will expand significantly to cater to the growing demand for ever smaller micro-vias.

CO_2 lasers drill vias through a thermal interaction. That is, the material absorbs the infrared light output of the CO_2 laser, which heats it until it vaporizes. Many dielectrics absorb well in the far infrared, while nearly all metals are highly reflective at these wavelengths. As a result, copper layers act as a natural stop when drilling with a CO_2 laser. In order to drill through copper (such as a top clad layer), it must first be oxidized to create a dark patina which absorbs the laser light.

While the CO_2 laser can readily produce a smaller via than a mechanical drill, there are limitations on the smallest via diameter it can reach. One limit is caused by light diffraction. Specifically, the smallest focused spot size to which a laser beam can be focused is directly related to its wavelength. Longer (e.g., far infrared) wavelengths, cannot be focused as finely as visible or ultraviolet wavelengths. Also, the thermal nature of the light/material interaction produces a small heat affected zone (HAZ) around the drilled hole, limiting how close it can be placed to other features. As a result, the practical lower limit on via diameters for CO_2 lasers is about 70 µm. But what if the hole diameter needs to be smaller than 70 µm?

CO Lasers

This is where carbon monoxide (CO) lasers come in. This type of laser was first developed about 50 years ago, but lifetime and reliability issues prevented this technology from becoming commercially viable. However, in the past year, the advent of new technology is making CO lasers practical, yielding products with very high output powers, and which demonstrate lifetimes in the thousands of hours range. The reason that CO lasers are of interest is that they output over the 5–6 µm spectral range, or about half the CO_2 wavelength of 10.6 µm, allowing for a smaller focused spot.

For via drilling, this shorter wavelength provides several important advantages. For example, it lowers the minimum via diameter that can be produced down to about 35 µm (due to diffraction). But even when producing larger diameter vias, the CO laser has an edge over CO_2. Specifically, the focusing lens used to achieve a 70 µm diameter via with a CO laser has twice the focal length of the lens required to achieve the same via size with a CO_2 laser. This longer focal lens provides greater depth of focus, which increases the field of view. The longer focal length and increased depth of field facilitate an increase in scanning speed, and therefore faster via production, with the shorter wavelength CO laser.

Because the CO laser can be focused to a smaller spot, it's easier to reach higher power densities with it than with a longer wavelength CO_2 laser of the same power. (Since the CO laser has roughly half the wavelength of the CO_2, it forms a spot size that is half as big, and which therefore has one-quarter the area, or four times the power density.) Conversely, achieving a given power density requires only one-fourth the total output power with a CO laser as with a CO_2 laser. Depending upon the exact parameters of a particular via drilling task, this makes it possible to use a much lower power CO laser for a specific job. This lowers the cost of the laser and the cost of the electricity and reduces the carbon footprint for the process.

In addition to the optical benefits, there are also differences in light absorption characteristics at the shorter wavelengths. This can be especially true in the case of polymers, which have an infrared absorption spectrum that consists of numerous sharp peaks. As a result, some polymers exhibit high absorption at 10.6 µm, and much less in the 5 µm to 6 µm band, and vice versa.

Another important material which exhibits very different absorption characteristics at 10.6 µm and 5 µm is glass, a material now of great interest for interposers in 2.5D and 3D advanced packaging techniques. Specifically, although glass has much lower absorption at the shorter wavelength, the use of the shorter wavelength actually produces superior results. This is because the lower absorption enables the CO laser beam to penetrate farther into the material. Together with the superior focusing ability of the 5 µm wavelength, this enables very small holes with high aspect ratios to be drilled in glass with precise depth control. The photo shows 35 µm diameter vias drilled in glass. Vias of this size and quality simply couldn't be produced with a CO_2 laser in glass.

Figure 1: A 50 µm-thick glass substrate drilled with successively more pulses from a CO laser demonstrates the ability of this source to drill glass interposers. CO_2 drilling of this material typically results in heat-related cracking.

UV Solid State Lasers

In addition to CO_2 lasers, diode-pumped solid-state (DPSS) lasers operating in the ultraviolet (UV) at 355 nm are a well-established source for drilling microvias, and are employed in other microelectronic fabrication tasks, such as wafer and micro-SD card singulation. The UV output of these lasers delivers two important benefits for micro-via drilling applications. First, with a wavelength that is over ten times smaller than CO_2 and CO lasers, plus their excellent beam quality, these lasers can be focused down to even smaller spot sizes. Second, shorter wavelengths are absorbed more strongly than infrared light by the vast majority of materials, including both metals and dielectrics. Because they don't penetrate as far into the bulk material during processing, they deliver the ability to more precisely control the depth of the removed material, and produce a much smaller heat affected zone (HAZ).

Together, these factors make UV DPSS lasers the first choice for producing microvias in the 25–35 µm diameter range. These applications also benefit from the ability of the UV laser to drill both copper and composite lasers. They are generally not used for vias above about 70 µm, since these lasers typically have a higher cost of ownership than infrared (CO and CO_2) lasers.

One major limiting factor in the overall lifetime and service frequency for UV DPSS lasers is the frequency tripling crystal. Specifically, this is the non-linear optical element that converts the native, near infrared output of the solid-state laser crystal (typically at about 1 µm wavelength) into the UV. There are two basic configurations in which this crystal can be used. It can be placed intracavity (within the laser resonator) or external to the laser cavity. Intracavity frequency tripling more readily delivers high output power than external cavity tripling. However, exposing the crystal to the higher optical powers experienced within the cavity also significantly shortens its lifetime and reduces service intervals for a given power rating. Instead, Coherent UV DPSS lasers for microvia drilling use external cavity tripling in order to ensure the highest possible reliability. Using this approach, Coherent is able to supply UV lasers with up to 40W of power that operate for more than 10,000 hours without a crystal change, which is more than sufficient for current microelectronics processing tasks.

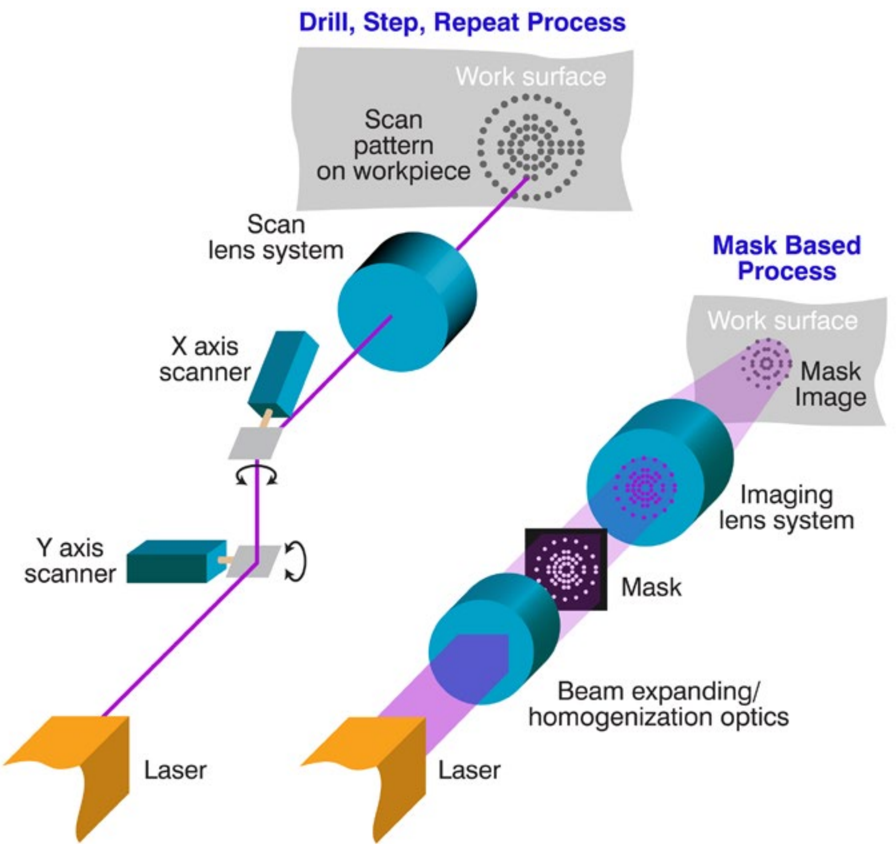

Figure 2: Schematic illustrating the difference between the direct write and mask-based writing technique for laser via drilling.

Excimer Lasers

Excimer lasers are another, even deeper UV source (usually at 308 nm or 248 nm), although they have vastly different output characteristics than DPSS lasers, leading them to be employed for microvia drilling in a very different manner. Specifically, the pencil-shaped beam from a DPSS UV laser is typically utilized in a drill, step, and repeat mode. In this mode, the focused laser beam is moved to a desired hole location, the laser drills the hole and, once finished, the laser beam is moved to the next hole location, all in sequence. In this approach, the throughput is linearly dependent on the number of vias being drilled.

In contrast, excimer lasers produce a large rectangular-shaped beam that is ideal for use in a mask-based writing process. A photomask containing the pattern of vias for a panel, or region of a panel, is illuminated with the laser. This photomask is then re-imaged onto the work surface, and all holes within the beam section are drilled simultaneously.

In mask-based writing, laser fluence and pulse frequency dictate the maximum field size that can be exposed at once, but not the total number of holes that can be produced within this field. Thus, as pitch size decreases (and the number of holes produced in a given area increases), parallel, mask-based drilling becomes increasingly efficient. In fact, the parallel drilling rate increases with the square of the pitch size. This makes it an increasingly attractive alternative as feature size and spacing decreases, and tends to "future proof" the technique as via diameter and pitch decrease over time. Because of the higher capital cost of excimer lasers, these tools typically make economic sense at production rates around 50–100 panels per hour or higher, or if the desired feature sizes get down to 5–10 µm.

Because of their short wavelength output, excimer lasers have similar processing characteristics to UV DPSS lasers. Specifically, there is strong absorption by most materials, both metal and dielectrics, which allows them to produce micron-scale feature sizes with nearly zero HAZ.

Our laboratory has also investigated the use of excimer lasers for via drilling in glass interposers. In these tests, 25 µm diameter holes, with a pitch (hole-to-hole spacing) of 50 µm, were produced in glass substrates ranging in thickness from 100–300 µm. The laser wavelength of 193 nm was used, with a 600 mJ pulse energy, in a mask-based process that produced a fluence of 7 J/cm² at the work surface. The 193 nm wavelength was chosen because glass exhibits strong absorption at this wavelength.

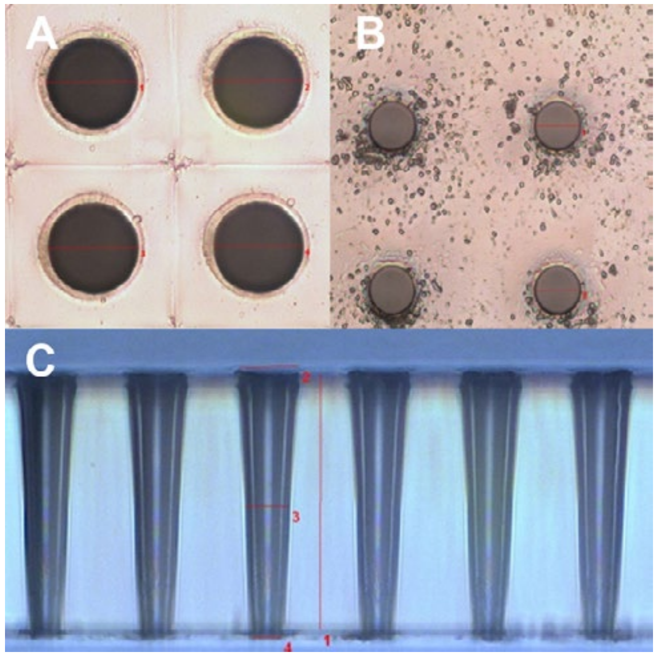

Figure 3: Excimer laser (193 nm) vias drilled into glass. A) The 25 µm diameter entrance hole; B) the exit hole; and C) the cross-sectional view.

Clean, round, symmetric vias were successfully produced in all the thicknesses tested using a total of 700 pulses or less. Hole taper was seen in the higher thicknesses, but sequential drilling from both sides of the glass reduced this effect substantially. This is relatively easy, since the transparent glass makes it easy to register fiducial marks on one side of the glass when it is flipped over for drilling from the second side. Overall, this testing showed that vias down to 5 µm diameter could be successfully produced.

In addition, mask-based excimer laser ablation provides excellent control of feature depth and wall angle. Unlike CO_2 laser via drilling, which usually takes just three laser pulses, excimer laser drilling utilizes numerous pulses, each of which removes just a small amount of material. Thus, via depth is precisely controlled by varying the number of laser pulses delivered. Wall angle is highly dependent upon laser fluence, so this parameter can also be varied to produce exactly the desired results.

In conclusion, most of the advanced packaging techniques that are currently on line, or becoming popular, require microvias that are beyond the capabilities of mechanical drills. In

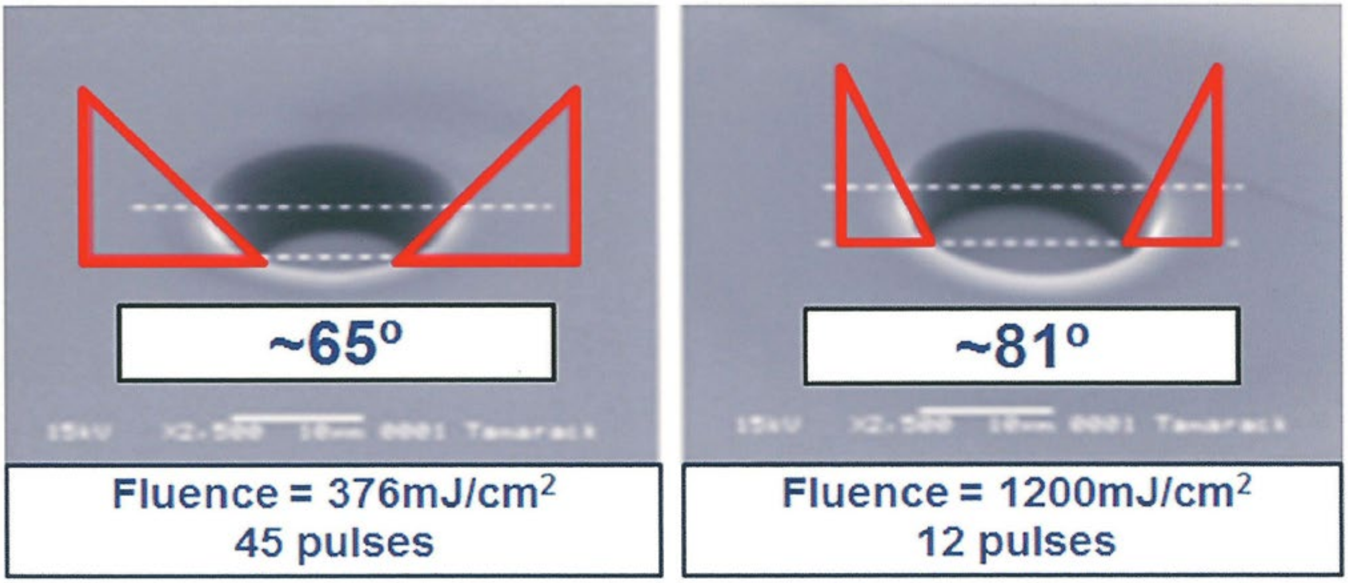

Figure 4: Varying laser fluence enables manipulation of feature side-wall angles, which can be important in subsequent deposition steps.

response to this need, laser manufacturers have already developed a variety of tools to optimally support next generation PCBs, substrates and interposers for today's advanced packages, and which deliver the performance overhead to support expected miniaturization trends in all these areas for the foreseeable future. **PCB**

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