Wet vs. dry

DELPHINE PERROTTET, TUAN ANH MAI, AND BERNOLD RICHERZHAGEN

NOT YOUR CONVENTIONAL LASER, THE WATER-JET-GUIDED LASER OFFERS BENEFITS FOR MICROMACHINING

Over the past few years, lasers have become popular for many applications due to their flexibility and processing speed. However, today conventional lasers reach their limitations when confronted with delicate operations such as wafer dicing, as there are significant contamination, low throughput, and thermal problems. A new approach to overcome these drawbacks is to combine a laser beam with a water jet. By using water, the cutting depth is increased, contamination can be prevented, and thermal problems become nonexistent. Because of the differences with conventional laser-based technologies, the water-jet-guided laser succeeds in applications that were until now inaccessible to lasers.

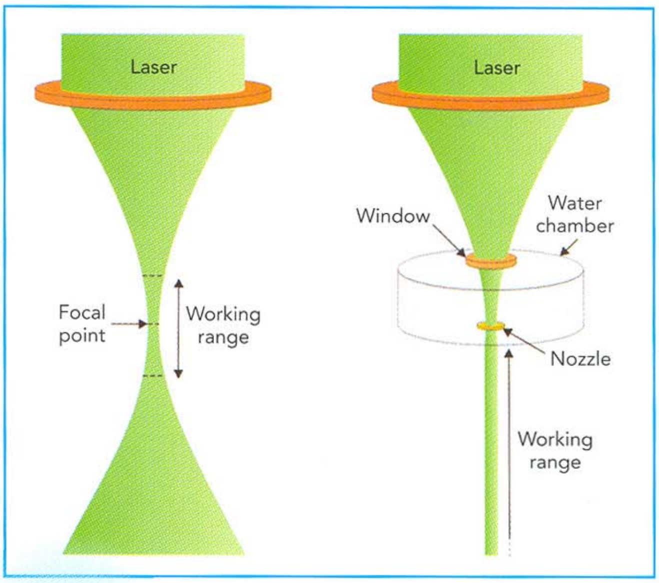

FIGURE 1. Fundamental differences between a conventional laser (left) and a water-jet-guided laser (right).

Fundamental principles

Lasers are focused through a lens so that at the focal point the power density is sufficient to ablate material. For materials processing, a focus-control system is necessary to correctly position the laser to the workpiece, as the depth of field is limited. The depth of focus, hence the working range, is typically less than a millimeter (see Figure 1, left). This is the case even with low-power, diffraction-limited lasers.

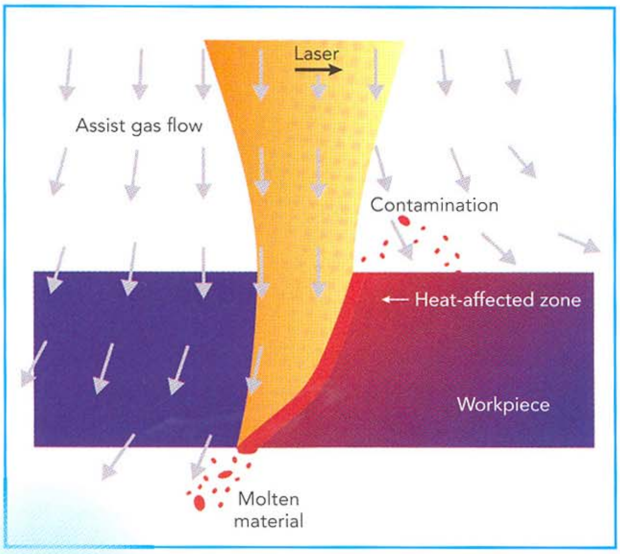

FIGURE 2: Conventional laser cutting.

To create a parallel laser beam, the laser is focused through water into a nozzle, under which a hair-thin, low-pressure water jet is generated. The laser beam is completely contained in the water jet because of total internal reflection at the water/air interface, and is guided to the bottom of the kerf with negligible power loss (see Figure 1, right). The diameter of the water jet does not vary on its stable length, which is roughly 1000 times the diameter of the jet. Therefore, the working area is much longer than with conventional lasers (up to several centimeters long). As focus control is not required, corrugated pieces can be processed. Micro kerf widths with a cutting depth of several millimeters are obtainable. The cut edges are parallel.

Because the diameter of the water-jet-guided laser beam is solely determined by the orifice diameter of the nozzle, common problems in conventional laser cutting— such as inconsistency and direction-dependency of cutting results due to beam ellipticity, astigmatism, and polarization—do not exist.

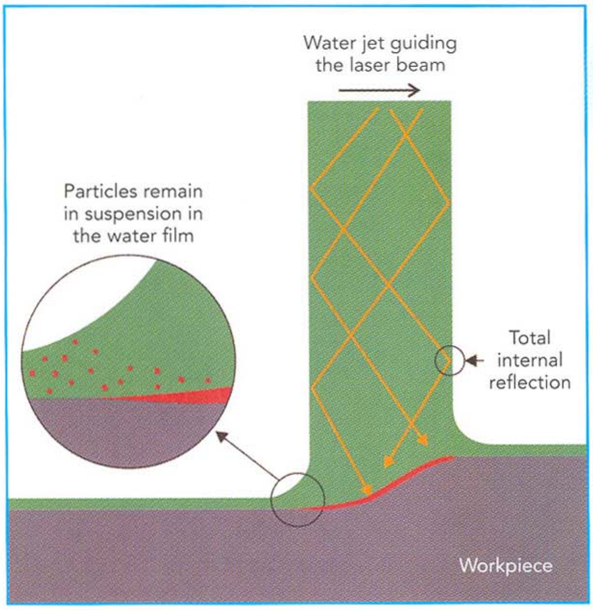

FIGURE 3. Water-jet-guided laser cutting.

Conventional lasers: thermal effects and contamination

Lasers in continuous-wave mode are not usable for precision processing because the laser power, concentrated on a small spot, generates a high thermal load in the material. Pulsed lasers, if they reduce thermal load, still generate a heat-affected zone (HAZ) as each pulse adds heat that spreads into the material. This HAZ has negative effects such as oxidation, micro-cracks, structural changes in the material, and low fracture strength. Reducing the pulse duration can prevent a HAZ from forming, but these kinds of lasers are very slow in machining speed and therefore can not be applied for volume production.

The second main problem is contamination, as the molten and condensed material remains in the kerf and in the cut surface. To remove it, an assist-gas stream with limited pressure (up to 20 bars) is usually produced around the laser beam. However, this gas stream is not very efficient, because only a small part of the gas penetrates into the kerf. In addition to burrs along the kerf, particles of molten and vapor material are redeposited onto the surface (see Figure 2). The only way to completely avoid contamination is to add a protective coating during the cutting process, but this solution is usually not used due to the additional steps required and extra cost.

Water-jet-guided laser: damage-free machining

The water-jet-guided laser uses pulsed lasers, so between the laser pulses, the water jet cools the cut edges. Because the heat cannot accumulate into the material, the HAZ is negligible. The water jet is also used for material removal. This is more efficient than gas-assisted removal because the water jet involves higher levels of kinetic energy. As most of the ablated material is removed by the water jet, only a small amount of particles remain. To avoid deposits, a thin film of water is generated onto the surface of the workpiece. Particles that fall onto the film are immediately cooled down and cannot adhere to the surface of the workpiece (see Figure 3). A protective water layer cannot be used with dry lasers due to focus sensitivity and power loss.

Because the water jet is very thin (with a typical diameter ranging from 25 to 75 microns), the force applied onto the workpiece is negligible, even at a 500-bar water pressure (less than 0.1 N). The water consumption is minimal (in the range of 1 l/min).

Conclusions

With very different characteristics, dry and wet lasers are dissimilar technologies. The two processes are thus not used for exactly the same application. Conventional lasers are efficient for drilling small and deep holes. Because water has to be evacuated, the aspect ratio is limited in such applications to around 1:1 using the water-jet-guided laser technology.

High-power dry lasers are more efficient than the water-jet-guided laser on low-absorption materials. For example, the Laser-Microjet can cut copper up to 150 microns thick, whereas conventional laser cutting can produce 1-mm cuts in the same material by way of heat accumulation. Aside from such cases, as it does not generate any thermal damage, the water-jet-guided laser can process a wide range of materials much better than dry lasers. For cutting and grooving applications requiring micro dimensions and no damage at all, the water-jet-guided laser will be preferred. Examples of potential markets for this technology include thin wafer dicing, stencil and stent cutting, and solar cell processing. The Laser-Microjet technology is also particularly suitable for machining of heat-sensitive or hazardous materials such as shape memory alloy Nitinol or GaAs.

The way the beam is formed and guided, together with the water cooling and cleaning effect, makes the Laser Microjet an unmatched tool for material micromachining with high quality and high throughput by applying multimode, high average output power lasers.

Delphine Perrottet, Tuan Anh Mai, and Bernold Richerzhagen are with Synova SA, Ch. de la Dent-d'Oche, Ecublens, Switzerland, www.synova.ch.