SYNOVA HAS RE-INVENTED THE LASER: NO HEAT DAMAGE, NO BEAM DIVERGENCE, NO CUTTING GAS, NO DEPOSITION

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Abstract

Within a few years, the innovative water-jet-guided laser technology has revolutionized laser micro processing. With a water jet to guide a laser beam by total internal reflection, this new technology is much different from a conventional dry laser, regarding beam shape, heating, material removal and contamination. Thanks to its important advantages over dry lasers, the water-jet-guided laser is today accepted in many state-of-the-art industries, such as the semiconductor, electronic, medical device and flat panel display industries.

Introduction

The water-jet-guided laser (also called Laser MicroJet) is an innovative micro-machining technology, today used in various industries such as the semiconductor, electronic, medical and energy sector. Fundamentally different from a conventional dry laser (see Table 1), thanks to the use of water as a wave-guide, the Laser MicroJet obtains results in numerous applications that other laser-based technologies cannot reach.

In conventional dry laser cutting, the laser beam is focused directly on the work piece; between the focal point and the focusing lens, the beam has a conical shape. The laser ablates the material by heating in the focal point, where the intensity is high enough. An assist gas, coaxial to the laser beam, removes the molten material.

In Laser MicroJet cutting, the laser beam, passing through water, is focused in a water-jet-nozzle; the laser beam is then contained inside the produced water jet by total reflection at the water / air interface and guided to the work piece, where it ablates material by heating. The water jet cools the work piece between the laser pulses, and expels the molten material from the cut.

Table 1 The four fundamental differences between a dry and a wet laser

	Conventional dry laser	Water-jet-guided laser
Beam shape	Conical beam	Parallel beam
Heating effects	Heat-affected zone	Negligible heating
Material removal	Inefficient (with gas)	Efficient (with water)
Contamination	Particles attach to the surface	Particles are washed away by water

1. Parallel Laser Beam

Because laser beams are divergent, they have to be focused on the work piece in order to generate an energy-density sufficient to melt or ablate material. The depth of field (the area around the focal point where material ablation is possible) is limited to a couple of hundred microns, or to a few millimetres at the most, depending on the laser. Even so-called diffraction-limited lasers (M2 =1), which may be available in the future at high power, still require focusing.

In Laser MicroJet technology, the water jet, within which the laser beam is guided, is cylindrical and thus creates a "parallel laser beam" of the same diameter as the focal point – this being possible only because of the waveguide properties of the water jet. Indeed, the water jet presents a perfect geometry with no diameter variations when in its stable length. The length for which the water jet is stable is about 1000 times the water-jet diameter; this means that the available length for material ablation is about 100 times longer when using the water-jet guide than in conventional laser processing. As a result, the process does not need focus-distance control; kerfs are narrow and close to parallel, even in thick materials; at last, deeper cutting into the material is possible, making it possible to cut porous structures as well as sandwich structures.

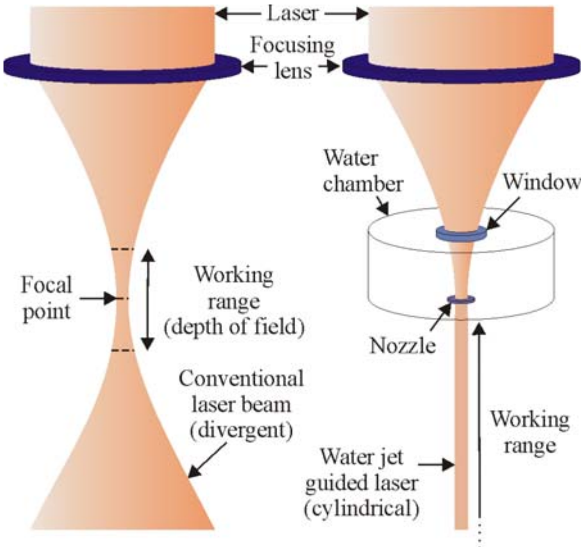

Figure 1 Conventional laser (left) and Laser MicroJet (right) – Difference in beam dimension

2. Cooling

Because material is ablated by localized heating, lasers generate a significant thermal load, especially in continuous-wave mode (applied for example for sheet metal cutting), which is therefore not suited for precision processing. Using pulsed lasers reduce this thermal load; however, each laser pulse deposits additional heat into the material, more than is necessary for material removal. That heat, on which the assist gas has only a negligible effect, is conducted into the material, generating the so-called heat-affected zone. Using lasers with short wavelengths and short pulses reduces this effect, but not sufficiently. In the case where the laser pulses are as short as pico- or femtoseconds (i.e. 10-12 to 10-15 seconds), the material removal is rather a photo-ablation, without heating, but as the average power of these expensive lasers is very small, the ablation rate is extremely low. Even if high power, short-pulsed lasers were available, the resulting processing speeds will remain low because much more energy is needed for material evaporation compared to melting.

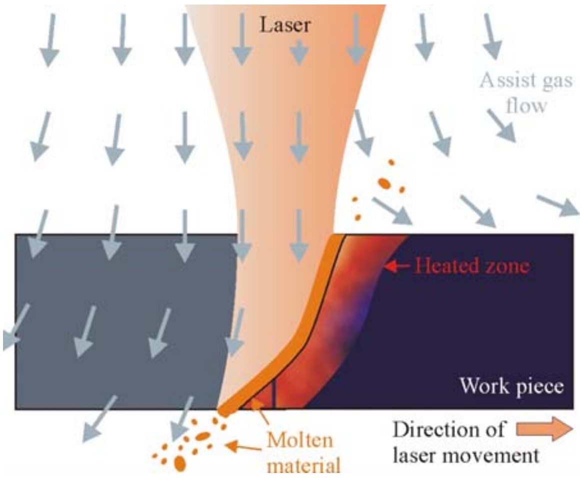

Figure 2 Conventional laser cutting: heat is conducted to the work piece

In Laser MicroJet technology, the water jet cools the cut edges in a most efficient way. After each laser pulse, the water jet immediately removes the deposited heat, so it is not conducted further into the material. The water jet speed is so high that even at a pulse repetition rate as high as 100 kHz, the heat is still removed in the very short pause between the laser pulses. The temperature of the cut edge very rapidly decreases to the water temperature. As a consequence, virtually no heat-affected zone exists. Only the edge surface of the kerf is thermally modified, but without penetration into the material. The negative effects of heating, such as micro cracks, oxidation, structural changes or low fracture strength, do not appear.

3. Material Removal

On the focal point (where the laser is applied) and in the immediate surrounding, the material becomes liquid or even gaseous due to light absorption; the heated material has then to be removed. In conventional laser cutting, this is performed by an assist-gas stream with a limited pressure (max. 20 bars, so to avoid damaging the work piece due to the implied mechanical force). However, only a small part of the gas stream penetrates into the kerf; because of its low density and its compressibility, the gas stream is not efficiently removing the ablated material.

In Laser MicroJet technology, the water jet pressure can be as high as 500 bars; the resulting force on the work piece is still much lower than the one generated by the assist gas stream of conventional lasers, because of the small size of the jet (< 0,1 N). The whole amount of water is used for material removal and the kinetic energy of the water passing through the kerf is much higher than in the case of assist gas usage. The water jet is therefore much more efficient for material removal than the cutting gas, allowing especially in the case of thin materials much higher cutting speeds than the conventional laser.

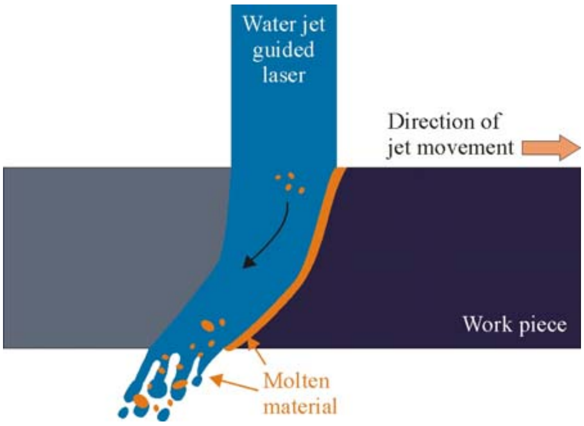

Figure 3 Laser MicroJet processing: the water jet removes the molten material

4. Cleanness

Once the material is removed, particle deposition on the surface of the material should be avoided, especially when processing delicate parts such as wafers, where circuits might be damaged by contamination. Indeed, it has been shown that even in vacuum and pure photo-ablation, part of the material is deposited onto the surface by aerodynamic effects in the vaporized material. Using short pulses reduces re-deposition, but still to an unacceptable value for cutting of sensitive material such as semiconductors. The only way to avoid any deposition with dry lasers is the application of a protective coating with subsequent removal. However, these additional process steps increase cost and maintenance.

As for the water-jet-guided laser, much less particles are spread over the surface of the work piece because the water jet takes away the ablated material. But the final cleanness is reached by a thin water film covering the work piece, which represents a perfect, very cheap protection layer – particles falling on the water film are immediately cooled down and cannot adhere to the surface of the work piece (see Figure 4).

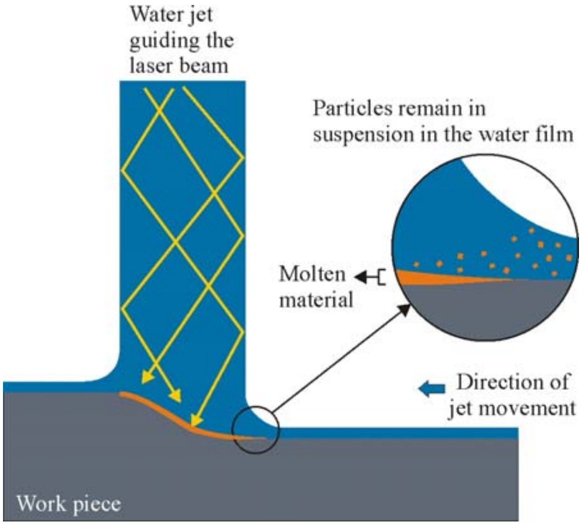

Figure 4 Laser MicroJet processing: thanks to the water film, the particles do not attach to the surface of the work piece

This water-film protection is not applied with conventional dry lasers because it represents an irregular refracting surface that inhibits precise control of the energy density of the laser on the sample.

Conclusion

From its invention eleven years ago, the Laser MicroJet has been constantly improved to become today the most gentle cutting technology. With the use of water, laser cutting has been completely transformed in a new process whose characteristics are different from those of conventional dry lasers.

Parallel laser beam, negligible heat load of the work piece, efficient molten material removal from the cut and no particle contamination are the four main benefits resulting from the coupling of a water jet with a laser beam. These exceptional properties guarantee a long future to the water-jet-guided laser – and definitely a place among the most advanced high-precision material processing methods.

Meet the Author(s)

Joseph Battaglia holds a bachelor’s degree in mechanical engineering from Wentworth Institute of Technology, Boston, Mass. After his degree, he worked for various state-of-the-art industries in various roles including product marketing, new business development and semiconductor corporate account sales. Before joining Synova as US Sales manager, he was field sales and marketing development manager for North America at EFD/Nordson Corporation.