SYNOVA

Comparative

Four reasons why *conventional dry lasers* will never reach the performance of the *water jet guided laser*

Coupling a water jet with a laser beam has revolutionized the field of precision cutting. The Laser-Microjet®, which incorporates this concept, is today used in various industries such as the semiconductor, electronic, medical, energy or automotive sector; Synova is the inventor that has developed the water-laser process and transformed it into powerful cutting tools.

The innovative water jet guided laser should not be confused with a conventional dry laser (see Table 1). Indeed, several major differences exist between the water jet guided laser and the dry laser, which explain the significant dissimilarities that can be seen regarding cutting results. These fundamental differences all come from the concept of the technology itself: the use of water as a wave-guide in laser processing.

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.

With the water jet guided laser, 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 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.

From these essential process differences, four very important consequences for the cutting result can be highlighted, that clearly separate the water jet guided laser from all the other cutting technologies using lasers.

Table 1: dry and wet laser comparison

	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)	Efficent (with water)
Contamination	Particles attach to the surface	Particles are washed away by water

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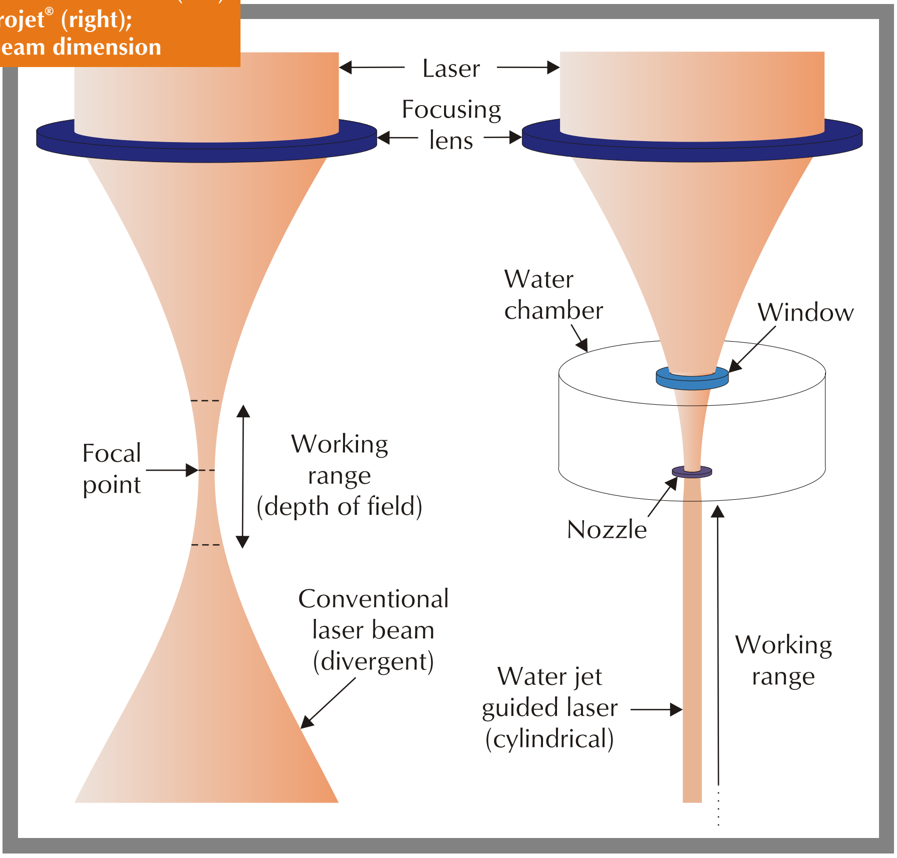
① Parallel laser beam

Each light beam has a divergence. That means that parallel light does not exist in nature. Lasers, even having the highest possible beam quality, are still divergent. So-called diffraction-limited lasers (M^2=1) may be available in the future at high power. However, the laser light has still to be focused 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.

Diagram 1: Conventional laser (left) and Laser-Microjet® (right); difference in beam dimension



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 100 times longer when using the water-jet guide! Whereas conventional lasers get stuck at a certain material depth, the water jet guided laser reaches a multiple of the kerf depth compared to conventional lasers.

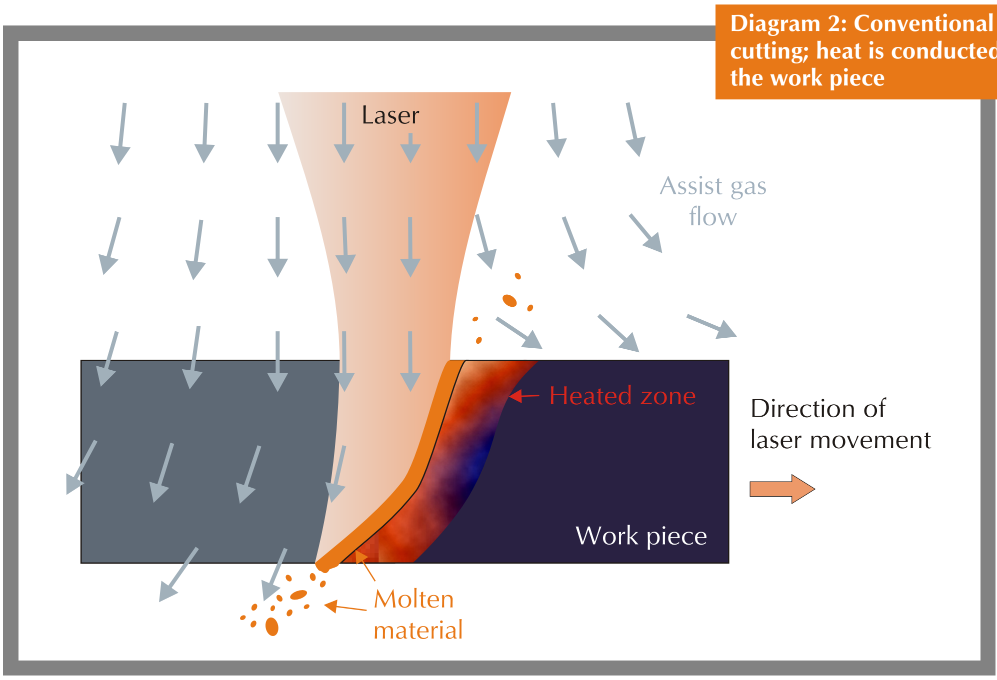
This particular, artificially-created parallel beam geometry is revolutionary in itself. Its consequences are very interesting for the majority of applications requiring high precision processing for the following reasons: 1) no need of focus-distance control; 2) close to parallel cutting kerfs; 3) narrow kerfs, even in thick material; 4) at last, the possibility to cut porous structures as well as sandwich structures.

② Cooling

When using lasers (visible or infrared), material is ablated by localized heating. In continuous-wave mode, applied for sheet metal cutting, lasers generate a thermal load of the sample much too high for precision processing. Using pulsed lasers reduce this thermal load; however, each laser pulse deposits additional heat into the material in fact, 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.

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.

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



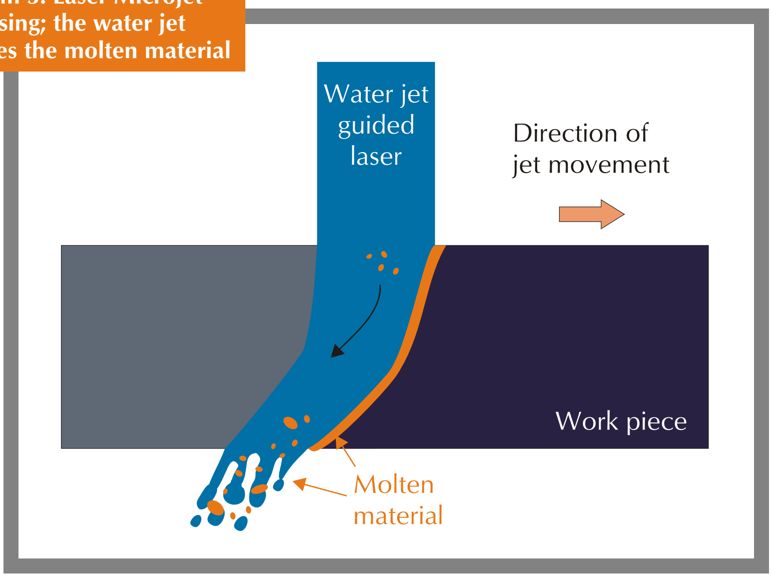
In the case where the laser pulses are as short as pico- or femtoseconds (i.e. 10^{-12} to 10^{-15} seconds), the material removal is rather a photo-ablation, without heating, but as the average power of these expensive lasers is very small, the ablation rate is extremely low. Even if high power, short-pulsed lasers were available, the resulting processing speeds will remain low because much more energy is needed for material evaporation compared to melting; there is no guarantee that results as good as those obtained with the Laser Microjet, in terms of speed and quality, would be reached for volume ablation.

Unless revolutionary future improvements, it is quite certain that no laser, even with short wavelength and short pulse duration, could process material as efficiently and without heat damages as the water jet guided laser.

③ Material removal

The basic principle for ablation with lasers is heating. In the area surrounding the point where the laser is applied, 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); otherwise the force on the work piece would be too high. Only a small part of the gas stream penetrates into the kerf and is used for removal of the heated material. assist gas stream of conventional lasers, because of the small size of the jet. The whole amount of water is used for material removal. The kinetic energy of the water passing through the kerf is much higher than in the case of assist gas usage. As a consequence, the water jet is about 800 times more efficient for material removal than the cutting gas - allowing especially in the case of thin material much higher cutting speeds than the conventional laser.

Diagram 3: Laser-Microjet® processing; the water jet removes the molten material



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

In the future, using lasers with short wavelengths and short pulses may increase the part of vaporisation, reducing the need for material removal; but for vaporizing the material, the required energy is much higher than for melting, making this solution quite inefficient for volume ablation.

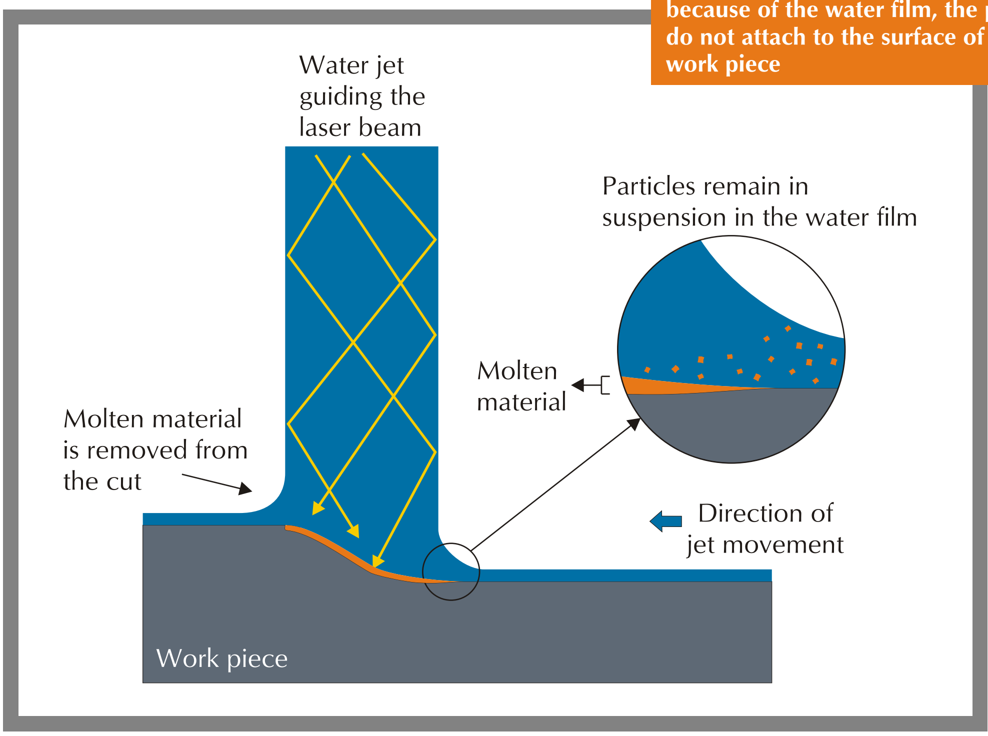
④ Cleanness

Once the material is removed, there is one last aspect to take into consideration to obtain high quality cuts: avoiding particle deposition on the surface of the material. Indeed, it has been shown that even in vacuum and pure photo-ablation (meaning very low processing efficiency), part of the material is deposited onto the surface by aerodynamic effects in the vaporized material. Using short pulses reduces re-deposition at the expense of reachable processing-depth and efficiency, but still to an unacceptable value for cutting of sensitive material such as semiconductors.

The only way to avoid any deposition is the application of a protective coating with subsequent removal. However, it would be preferable not to have additional process steps as required by this method, since more steps mean an increase in 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 real cleanliness is reached by another aspect of the process: the water film on the work piece 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. In addition, the water film has a cleaning function: work pieces are even cleaner after processing by the water jet laser than before. It is impossible to apply a water film 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 (see Diagram 2).

Diagram 4: Laser-Microjet® processing; because of the water film, the particles do not attach to the surface of the work piece



Today, dry lasers cannot, without post-processing or additional steps, achieve the level of cleanliness obtained with Laser-Microjet® processing. In addition, it is highly improbable that future developments of dry lasers will improve this important aspect of the ablation process.

Conclusion

From its invention eleven years ago, the Laser-Microjet® has been constantly improved by Synova, the company holding all intellectual properties on this technology, to become today the most efficient laser-based cutting technology. With the use of water, laser cutting has been completely transformed in a new process whose characteristics are totally 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 features 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 and important material processing methods.

With its outstanding cutting performance, the Laser-Microjet® is now an alternative in high precision cutting technologies, surpassing conventional lasers by far; even with new developments, dry lasers will quite certainly not be able to catch up.

Synova SA, August 2004