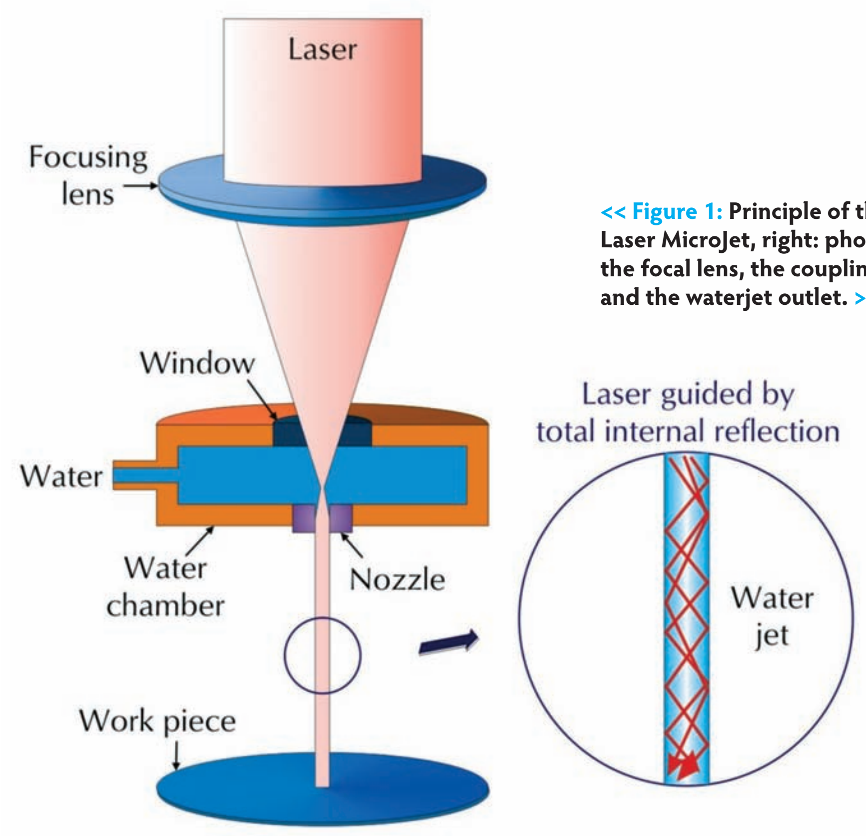
Laser MicroJet (LMJ):
Reliable Micro Manufacturing of Diamonds and Watch Parts

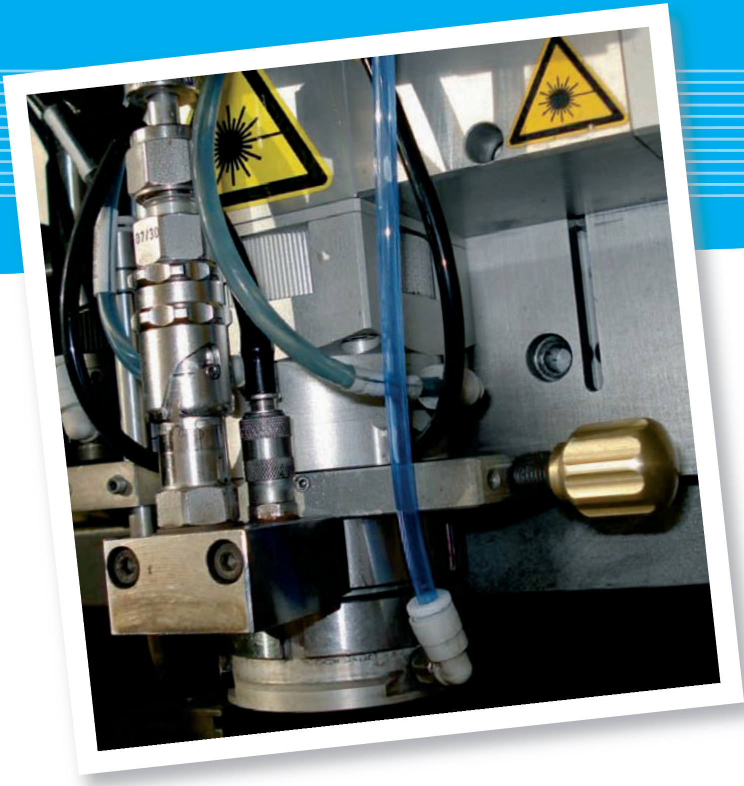


<< Figure 1: Principle of the Laser MicroJet, right: photo of the focal lens, the coupling unit and the waterjet outlet. >>

The waterjet-guided laser technology, first presented in 1995, has found a broad range of applications in the precision micro machining field. The waterjet-guided laser (also called Laser MicroJet or LMJ) is used today in a wide range of industrial fields, such as semiconductor, solar, electronics, medical, tooling, high-brightness LED, watch and automotive industries.

The Laser MicroJet principle and setup

The LMJ principle is to couple a high power, pulsed laser beam into a hair-thin, low-pressure waterjet. A schematic view of the principle is shown in Figure 1. The beam of a high power laser is transmitted by a fibre optic cable to an optical head. In the optical head the laser beam is focused through a transparent window into a nozzle placed at the bottom of a thin water-filled chamber. Pure deionised, degassed and filtered water is introduced into the water-filled chamber. The water pressure ranges from 50 to 500 bar, depending on the nozzle diameter. Larger nozzle diameters require a smaller water pressure. Typical nozzle diameters range from 30 µm to 80 µm but may also be larger, up to a few 100 µm. The laminar waterjet exiting the nozzle guides the laser beam by means of total internal reflection at the water/air interface, similarly to conventional glass fibres. When it reaches the workpiece, the laser ablates the material by melting and vaporisation.

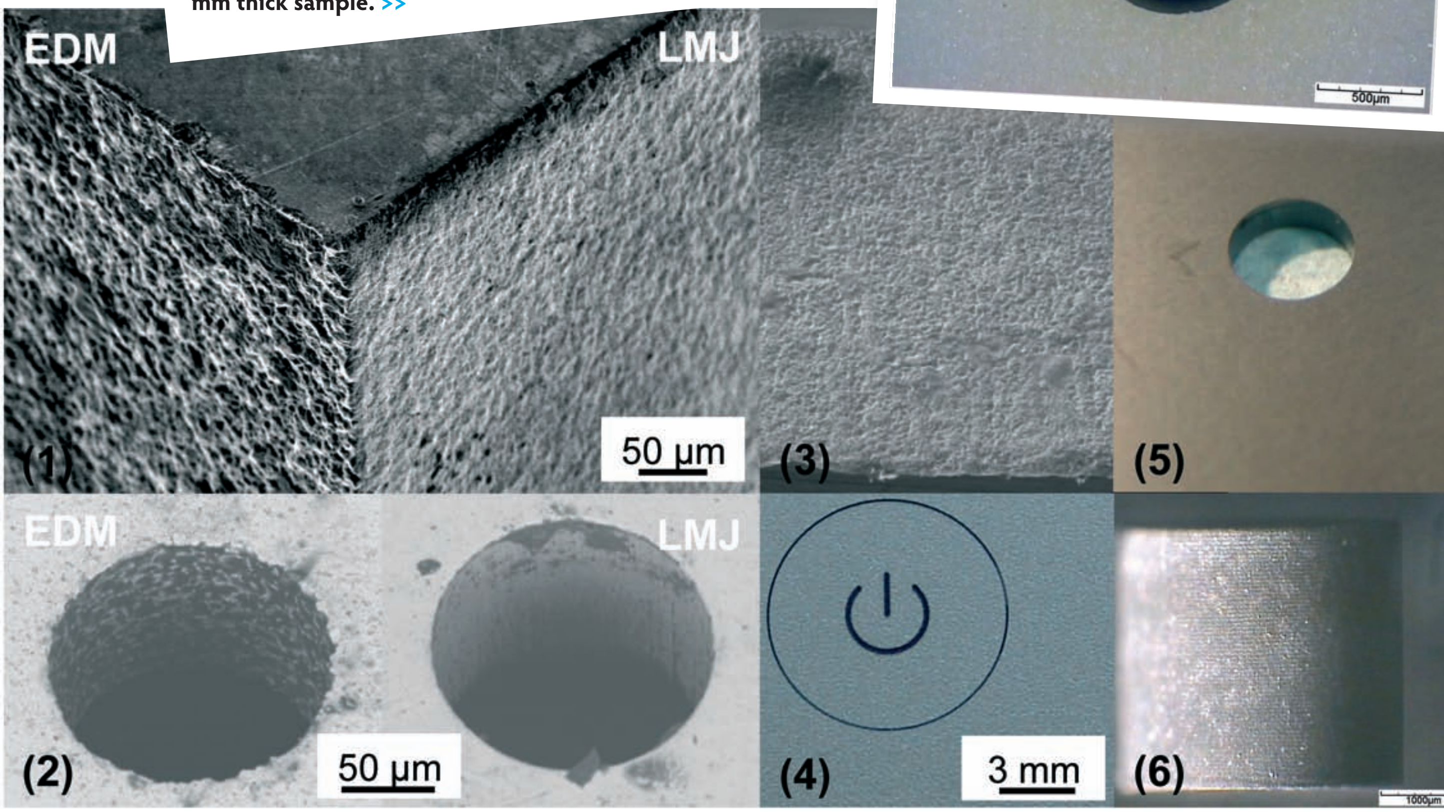


The capabilities and performances of this process are different from those of conventional 'dry' lasers. Due to a cylindrical waterjet, in which the laser beam is guided, kerf walls are highly parallel. The working distance — corresponding to the stable length of the jet — can be several centimeters long, depending on the jet diameter and consequently only on the size of the nozzle. The length, over which the waterjet is stable, is around 1000 times the size of the nozzle so that aspect ratios of up to 1000 in cutting may be reached. For drilling of holes <1 mm the aspect ratio is lower at about 20. The smallest diameter of the holes does depend on the size of the nozzle. That is why working distances in excess of 10 cm are possible with the largest nozzle diameters (100 μm and more). Given the long working distance, there is no need for expensive focus control systems.

Additionally, the waterjet-guided laser prevents heat damage to the material by cooling the cutting edges in between the laser pulses. Contamination by particle deposition is avoided thanks to a thin water film that covers the wafer surface during the cutting process. The particles, already cooled down by the waterjet, do not adhere to the workpiece surface. The mechanical force of the waterjet onto the wafer is negligible (<0.1 N) due to the small jet diameter and the low water pressure. This leaves the material unscathed when exposed to the bare jet. The process does not generate chipping or micro cracks. Water consumption is very low, averaging about 1.5 l/hour.

<< Figure 3a >>

<< Figure 2: Digest of application where the LMJ is already used in industry for cutting or drilling of different materials (1): PCD comparing EDM and the LMJ, (2) Drilling of holes with EDM and LMJ in stainless steel, (3) side wall of a 700 µm thick cut silicon wafer, (4) Aluminium, (5) Silicon carbide, (6) side wall of a PcBN piece cut off a 3 mm thick sample. >>



Different solid-state laser sources with a wavelength of 1064 nm and 532 nm with pulse lengths of 80-200 ns have been used with the water jet-guided laser technology. In recent years disc and fibre lasers have been deployed with success in a wide range of demanding applications, where the LMJ system operates in 24/7 production environments.

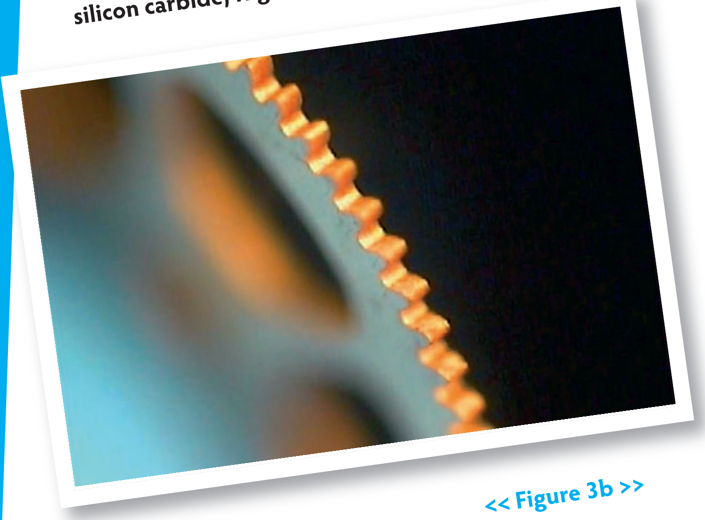
Laser sources operating at 532 nm and 515 nm have become the standard laser sources for most of the LMJ applications due to their excellent compatibility with the water absorption spectrum. The only constraint on the laser wavelength is that it must be compatible with the water transmission spectrum, which exhibits a minimum in the green region of the optical spectrum. The absorption coefficient α in the waterjet is the lowest ($\alpha = 4*10^{-4}$ cm^{-1}) at wavelengths around 532 nm. The absorption coefficient is about 500 times higher around 1064 nm ($\alpha = 0.2\ cm^{-1}$). The light transmission over a 2.5 cm water jet is as high as 99.9% at 532 nm, and 60% at 1064 nm. This means that the light absorption at 532 nm can be neglected. At 1064 nm the absorption in water is not an issue as long as the average power remains below about 500 W.

Applications

This cutting technology is already used in a wide range of applications covering the material selection of diamond, ceramics, semiconductors and stainless steel. A digest is given in Figure 2.

With the LMJ metals, ceramics and hard materials can be cut with very good edge quality. Figure 2 (1) shows a piece of PCD which has been cut with EDM and with the LMJ. Below (2) drilling of holes in stainless steel with a diameter of 80 µm with EDM and the LMJ compared. Both examples show that the edge quality when using LMJ is better — no chipping and no cracks are visible. Also the surface quality of the kerf is lower for the LMJ. In Figure 2 (3) an example of cutting of thick silicon is shown. Also, toxic materials like GaAs which are quite common in the solar industry can be

<< Figure 3: Left: Hole of 1 mm diameter in 3 mm thick silicon carbide, Right: Wheel cut out of a brass sheet. >>



<< Figure 3b >>

treated with the LMJ. The velocity of the process with up to 100 mm/s is about 100 times higher than for cutting of hard material. Also less hard materials like aluminium can be cut (4). In Figure 2 (5) and (6) two more samples for cutting hard materials are shown — in this case alumina and 3 mm thick PcBN. Another very important application is cutting of diamond. Because of the absolute parallel kerf widths with the LMJ less material is wasted when cutting the stones. As diamond — especially natural diamond — is a very expensive material it is a big benefit for the manufacturer when using LMJ-cutting. Also very big stones can be cut with the LMJ technique because of the high aspect ratios which are possible with this technique.

Recent approaches

Recently new results on cutting of thin sheet metals have been achieved by using new laser sources having shorter pulses (in the range of 10 to 20 ns) and an improved processing strategy. Some results are shown in Figure 3.

In Figure 3 on the left a 1 mm hole in 3 mm thick silicon carbide is shown. No cracks or chipping is visible and the roughness of the kerf could be halved down to 300 nm Ra compared with the results shown in Figure 2. In Figure 3 on the right a gear wheel from a watch, which has been cut out of a brass sheet material, is shown. Again, no cracks or chipping are visible. The same edge quality has been achieved on stainless steel, CuBe and gold. The velocity of cutting those thin metal sheets at the quality shown in Figure 3 is about 1 mm/s.

Future developments

One future research topic for the Laser MicroJet is using new laser sources to further decrease the surface roughness of the kerf and be able to cut also other material which could not have been cut up to now like glass and plastics. Up to now cutting of any type of sapphire is not yet feasible but recently carried out experiments on this material are very promising. Additional smaller nozzle sizes are required to decrease the kerf width especially for the application of cutting diamond.

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