Laser-Microjet®: Introducing New Cutting Capabilities for the Tooling Industry

Laetitia Mayor (mayor@synova.ch), Ochélio Sibailly (sibailly@synova.ch) &
Bernold Richerzhagen (richerzhagen@synova.ch)

Synova SA
Ch. de la Dent d'Oche 1a
CH-1024 Ecublens
Switzerland

In 1993, Scientists at the Institute for Applied Optics of the Swiss Federal Institute of Technology Lausanne in Switzerland succeeded in creating a laser light guiding water jet, called Laser-Microjet® by its inventors. The laser beam is focused into a nozzle while passing through a pressurised water chamber. The low-pressure water jet emitted from the nozzle guides the laser beam by means of total reflection at the transition zone between water and air, in a manner similar to conventional glass fibres. Because a pulsed laser is used, the continuous water jet is able to immediately cool the cut, inducing only minimal thermal penetration. The result is a very narrow, parallel, burr-free, clean cut, without any thermal damage.

Ten years later, the technology has proven its efficiency and reliability in the semiconductor and electronics industries among others. Recent tests showed outstanding results in the cutting and drilling of hard materials, and especially cubic boron nitride parts employed in the tooling industry. Indeed, the water jet guided laser has indisputable advantages over the classical electro-erosion or laser cutting method. The presence of electricity conducting metal not being required, the manufacturability of a larger range of CBN parts is possible. In addition, the cutting speed is very high and the feed rate of up to 35 mm/min can be obtained in cutting of standard 3.25 mm thick CBN plates. There is a huge difference in quality between conventional laser and Laser-Microjet® cutting of CBN. All the heat damage, burrs, adhering particles, etc. associated with the former technology are avoided. The edges obtained with this new laser process are almost perfect, making any further grinding steps unnecessary.

Introduction

The capability of laminar water jets to guide light was used as early as the European Renaissance in water fountain shows that were coordinated to music. In literature, one can find research work on a light-guiding water jet by Prof. Colladon of the University of Geneva dating back to 1886. Over a century later, in 1993, at the Swiss Federal Institute of Technology in Lausanne, the principle was further developed into a refined, material treatment method using a laser beam and named "Laser Microjet" (LMJ) by it's inventor.

Today, ten years after the LMJ development, the technology has proven its efficiency and reliability in the semiconductor and electronics industries among others. Recent tests showed outstanding results in the cutting and drilling of hard materials, and especially cubic boron nitride parts employed in the tooling industry.

Cutting with laser and water

The laser beam is focused in a nozzle while passing through a pressurised water chamber (see Fig. 1). The water jet emitted from the nozzle guides the laser beam by means of total internal reflection at the water-air interface, in a manner similar to conventional glass fibres. The water jet can thus be referred to as a fluid optical wave-guide of variable length.

The water jet is essentially transparent for the laser beam. However, if the laser beam encounters a body, which absorbs it, the surface of the material is heated to such an extent that plasma is created. The plasma separates the water jet and the material from one another and it efficiently couples the energy to the work piece.

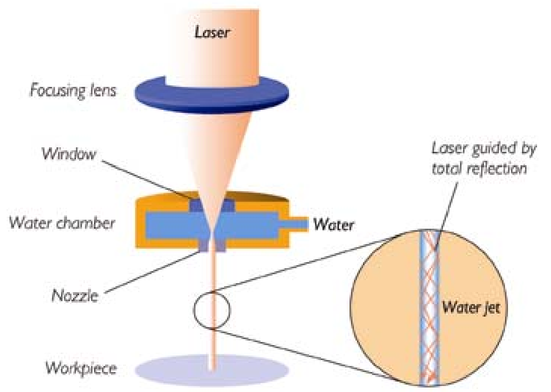

Fig. 1: Microjet® principle.

The plasma only remains as long as the laser beam is activated. Because a pulsed laser is used, the continuous water jet is able to immediately re-cool the cutting kerf, resulting in a strongly reduced thermal load of the work piece.

The liquid used is de-ionized, filtered water.	
water pressure	20-500 bars
water jet speed	up to 300 m/s (at 500 bars)
water jet diameter	40, 50, 60, 75 or 100 microns
water flow rate	5-100 ml/min

Table 1: Characteristics of the water jet.

The main advantage of the system is its excellent cutting quality obtained because of:

- the absence of thermal stress, and contamination burrs due to constant cooling and rinsing by the water jet.;
- the absence of mechanical constraints on the pieces to be cut, the water jet pressure being kept low (50 to 500 bars with a jet diameter varying from 40 to 100 microns).

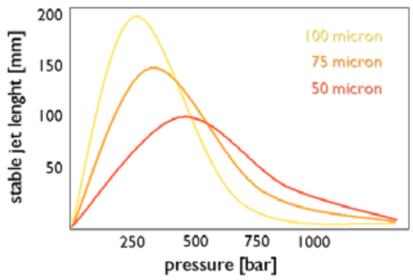

Fig. 2: The stable jet length is measured from the nozzle inlet until the position where the first drop is formed. The maximum working distance of water jet guided laser cutting is closely correlated to this value and varies analogously concerning nozzle diameter and pressure.

LMJ Versus Conventional Manufacturing Processes

The LMJ has not to be confounded with the conventional laser method, which is the state of the art in CBN cutting today. The LMJ has indeed indisputable advantages over this older technology. The main difference lies in the light guiding and cooling effects of the water jet. Because of the cylindrical shape of the jet, kerf walls are parallel, and there is no conical shape effect (see fig. 3). The running water of the jet also enables continuous cooling - the LMJ is sometimes referred to as “cold laser cutting”- which ensures the absence of burrs, the deposition of slag, and material changes due to heating, inherent to the conventional laser. Finally, the edges obtained with this new laser process are almost perfect, making any further grinding steps unnecessary.

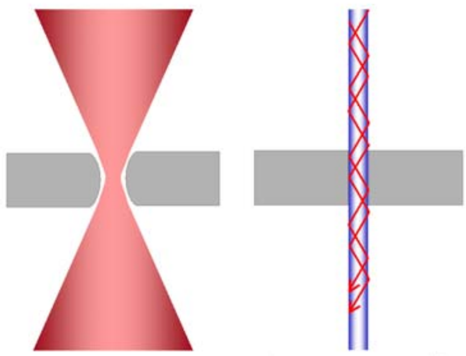

Fig. 3: On the left, the conical shape effect that

appears in conventional laser cutting. On the right, the laser beam is guided in the water jet and kerf walls are parallel.

Electro-discharge machining (EDM) is used for ultra-hard materials, but it is only usable in the case of electrically conductive materials, which is not the case for most of the pure ultra-hard materials. The presence of electrically conductive material is not required for the LMJ process. In addition, EDM is a very slow process. Achievable speed with the LMJ is much higher, enhancing throughput as well.

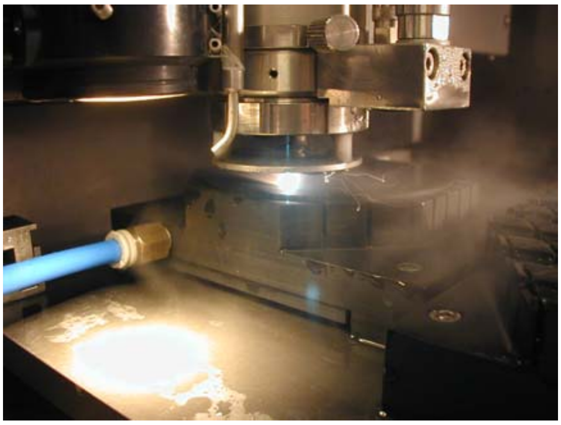

Fig. 4: The LMJ in action cutting a CBN disc on a special vacuum chuck designed for this application.

Diamond wheels are sometimes used to cut CBN inserts. Due to the hardness of materials such as CBN and Si_3Ni_4, cutting with diamond wheels results in high tool wear, inducing a slowed process with inconstant results. With the LMJ, once the nozzle is aligned, cutting can be performed for hundreds of hours without replacement. LMJ running costs are therefore lower than those of the diamond wheel method. Also, large amounts of liquid coolant are required when using diamond wheels. Of course, the LMJ uses de-ionised water, but in small quantities (maximum 50 ml/min).

Cutting CBN inserts with the LMJ

Cubic boron nitride (CBN) inserts usually have to be cut from 4 inches discs with thickness varying from 1 to 4 millimetres. All usual geometries of triangle, rectangle and lozenge inserts are easily processed with the LMJ since the system allows omni-directional cutting. In fact, just about any shape can be cut with the LMJ, and high quality drilling is possible (see fig. 4).

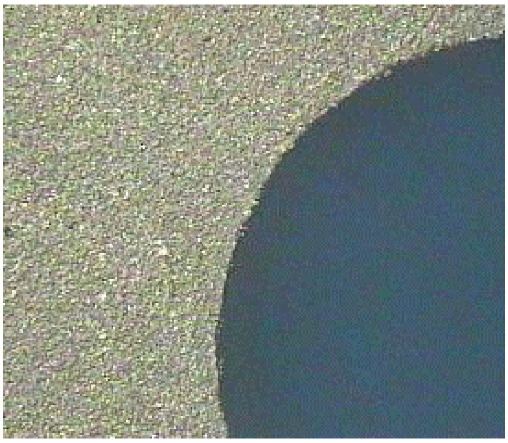

Fig. 5: hole drilled in CBN by LMJ magnified 30 times (hole diameter: 2,6 mm; CBN thickness 3,25 mm)

Very low tolerances can be achieved since the machine has an absolute precision of +/- 3 microns for a processing area of 300 x 300 mm and a maximum axis velocity of 1000 mm/sec. To insure a good fixation during cutting, a special vacuum chuck has been developed for the CBN discs. The achievable cutting speed depends on the hardness of the ceramic. Two different types of CBN have been tested, the results can be found on table 2.

	CBN A	CBN B
Composition	TiC matrix binder, 50% CBN, fine grained structure	Al matrix binder, 90% CBN, coarse structure
Cutting speed	35 mm/min	15 mm/min
Drilling speed	5 mm/min	4 mm/min

Table 2: Cutting speeds for CBN discs of 3,25 mm thickness.

Best results with CBN are achieved with a nozzle of 75 microns in diameter. This parameter is of importance, since it determines the kerf width; knowing that CBN is still a precious material, the narrower the kerf is, the smaller the loss in material.

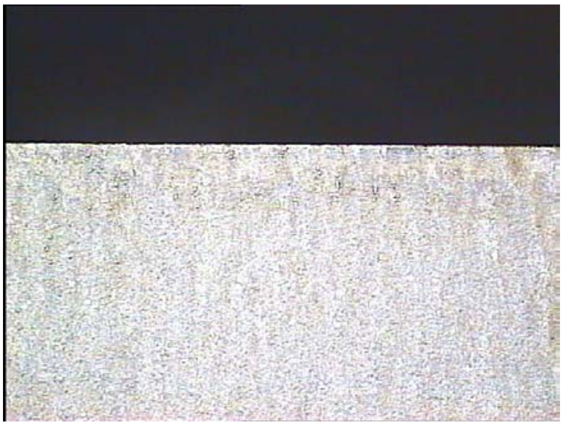

Fig. 6: CBN edge cut with LMJ without any post-processing; magnified 70 times.

The cutting process of the CBN inserts is made in two steps (see fig. 7). First, a grooving (partial cut) is performed on one side of the discs. Then the disc is flipped and its position adjusted to finish the cut from the other side. This two step process allow to obtain very sharp ridges on both sides, avoiding the chipping on the back side that occurs when the cut is made from one side only. The recovering difference between the two faces is of maximum a few microns.

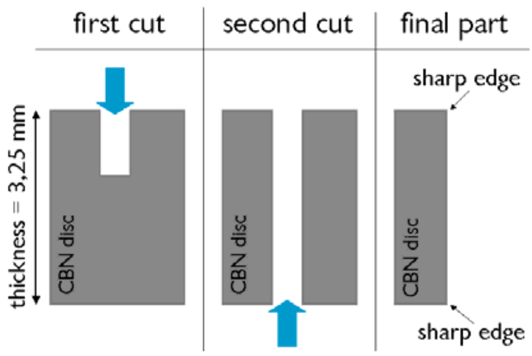

Fig. 7: Two-step cutting process.

Cutting Other Hard Materials with LMJ

The processing capabilities of the LMJ are not limited to cubic boron nitride inserts. Other hard materials such as synthetic diamond and silicon nitride can be cut efficiently as well. In fact, any material can be processed by the LMJ when its absorption coefficient at the laser's wavelength is sufficient. The LMJ was first developed using the infrared wavelength, because it was the most interesting in terms of power (up to 300 W).

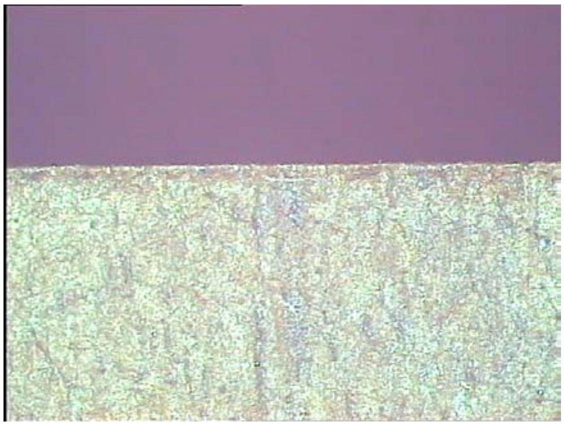

Fig. 7: Si3N4 edge cut with LMJ magnified 70 times.

The absorption of the infrared laser radiation in CBN and Si_3N_4 is excellent, but this is not really the case for transparent materials such as synthetic diamonds. Nevertheless, good cutting results can be obtained when using a short-pulsed infrared laser, enabling the processing of low absorption materials. Fig. 7 shows an example of a hole cut in a dark-yellow diamond.

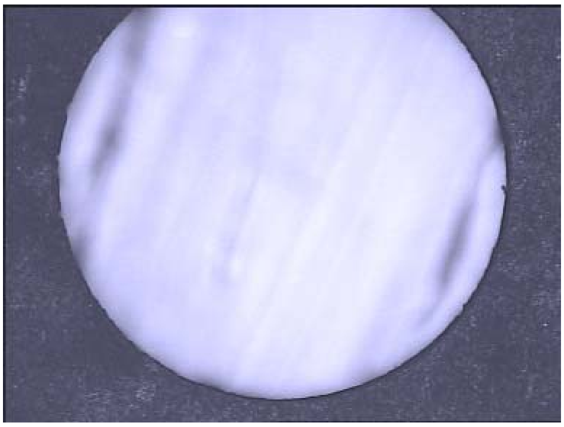

Fig. 8: hole cut in 0,5 mm thick synthetic diamond.

Summary and Conclusion

In summary, the water jet guided laser has unsurpassed results compared to other standard methods. The high cutting speed, kerf wall quality, and especially the ability of the system to cut any shaped insert are the main reasons that render the LMJ very interesting for the tooling industry. With these capabilities, new CBN products in terms of material and shape, or new services such as custom-shaped tools available in 24 hours, have now become realistic.