

High precision laser processing of sensitive materials by Microjet?

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Material laser cutting is well known and widely used in industrial processes, including micro fabrication. An increasing number of applications require nevertheless a superior machining quality than can be achieved using this method. A possibility to increase the cut quality is to opt for the water-jet guided laser technology. In this technique the laser is conducted to the work piece by total internal reflection in a thin stable water-jet, comparable to the core of an optical fiber.

The water jet guided laser technique was developed originally in order to reduce the heat damaged zone near the cut, but in fact many other advantages were observed due to the usage of a water-jet instead of an assist gas stream applied in conventional laser cutting. In brief, the advantages are three-fold: the absence of divergence due to light guiding, the efficient melt expulsion, and optimum work piece cooling.

In this presentation we will give an overview on several industrial applications of the water-jet guided laser technique. These applications range from the cutting of CBN or ferrite cores to the dicing of thin wafers and the manufacturing of stencils, each illustrates the important impact of the water-jet usage.

Keywords: Laser cutting, water-jet, Nd:YAG laser silicon cutting, metal foil cutting

In 1993, scientists at the Institute of Applied Optics of the Swiss Federal Institute of Technology of Lausanne in Switzerland succeeded, for the first time, in creating a laser guided in a stable water jet, called Laser-Microjet[®] by its inventors.

The difficulty of this idea [1] lies in the geometry of the water chamber where water jet and laser are coupled. From laboratory experiments to the industrial machines working today around the world, the Laser-Microjet[®] passed over several optimization cycles. However, the original idea remained unchanged, proving constantly its efficiency and offering new machining possibilities in large application fields.

Laser-Microjet[®] principle

In order to couple the light into the water jet, the laser beam is focused into a nozzle while passing through a pressurized water chamber. With this unique laser cutting technique a free laminar water-jet is used as an optical wave guide in order to guide a high power laser onto the sample [2]. The main advantages of this method compared to conventional laser cutting are:

- ☞ parallel sidewalls (even in thick samples),
- ☞ very low thermal load of the sample due to the cooling between the laser pulses exactly at the place where it was heated before,

- ☞ an efficient expulsion of the melt due to the high momentum of the water-jet.

The schematic of the used setup is shown in Figure 1. The laser is coupled to a large core step-index fiber (200 microns core diameter) and then the fiber exit is imaged onto the nozzle entry with variable demagnification. Using a fiber between the laser and the basic machine is more practical for placing laser and machine in the lab, and the intensity profile of the laser on the nozzle entry is more flat-top like resulting in a longer nozzle lifetime than observed with a Gaussian beam profile. The used lasers are either flash lamp pumped pulsed YAG lasers with pulse durations of less than 120 ns or multimode Q-switched lasers operating at 1064 nm, 532 nm, and 355 nm. We use pure de-ionized and filtered water at 50 to 500 bars for the water jet. The nozzles are made out of sapphire or diamond in order to generate a long stable water-jet. The laser beam is focused through a quartz window into the nozzle, very much like a usual fiber coupling and is thereafter reflected in the water-jet at the air-water interface due to the refractive index step (Figure 2).

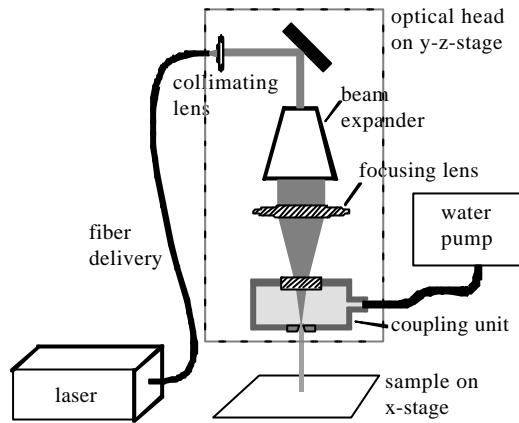


Fig. 1: Schematic of the water-jet guided laser

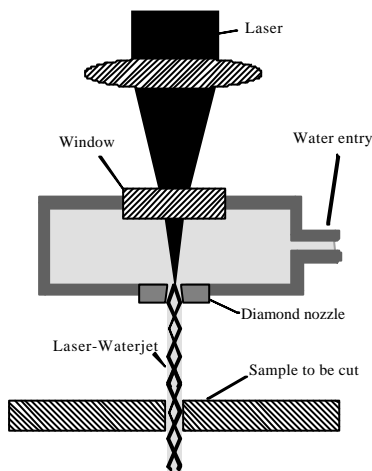


Fig. 2: Detailed sketch of the coupling unit setup

The samples are clamped onto an x-stage, the optical setup is implemented in a “optics head” that is mounted on the y-stage. The z-variation of the stage is only necessary in order to adapt to the different working distances of different nozzles sizes and water pressures and is not used during the cutting procedure.

This hybrid system allows to join the force of a powerful Nd:Yag laser and the softness of a low pressure water jet. LMJ is, in other words, particularly adapted for critical applications where the fragility of the material or its extreme hardness complicates the machining with other methods. The LMJ has its place in several industries like automobile, medical device manufacture, electronics, machine- tools, and solar energy.

The following examples show how much the LMJ allows to optimize cutting of various materials.

Production of CBN inserts for machine-tools

Cubic boron nitride (CBN) inserts used for abrasive machining, are generally cut from 4-inch discs with thickness varying from 1 to 4 millimeters. All standard geometries (triangle, rectangle and lozenge) inserts are easily processed with the LMJ since the system allows omnidirectional cutting. In fact, any shape can be cut with the LMJ, and high quality drilling is also possible.

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

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 in table 1.

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

The cutting process of the CBN inserts is made in two steps (see figure 3). 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.

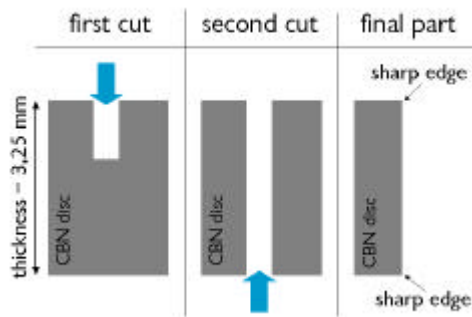


Fig. 3: Two-step cutting process.

Main advantages of the LMJ in comparison to other usual machining methods are essentially linked to the outstanding cut quality that does not necessitate a subsequent cleaning stage, or supplementary polishing. Much faster than Electrical Discharge Machining (EDM), much cleaner than conventional laser cutting, the LMJ is considered as the most efficient technology for cutting CBN by several machine-tool manufacturers.

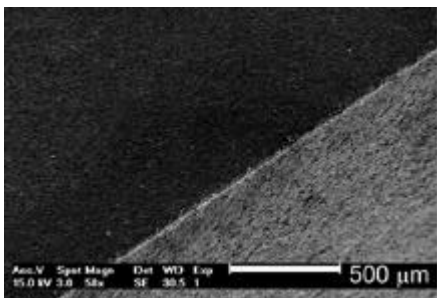


Fig. 4: Edge of a machine-tool insert cut in CBN as machined by the waterjet guided laser (without subsequent polishing)

Chip dicing for semiconductor industry

Dicing is one of the last operation in the transformation of silicon wafers into chips. The wafer's market value is highest at the time of dicing, necessitating fast and sure operation. Considering that the electronics market becomes always more demanding in terms of clock frequency and miniaturization, wafers get thinner and thinner. And also composite materials, at the same time very brittle and expensive, are used. The importance of composite semiconductors like GaAs is continuously increasing and already today Silicon is replaced in some specific applications. Besides the bad cut quality, cutting GaAs with traditional laser is very dangerous because of the arsine gas emissions. With the waterjet-guided laser all the arsine is constraint into the water that can be treated with usual filters. The LMJ efficiency on that kind of material is now proven [3] and a machine-tool especially intended for this market is on sale since two years now.

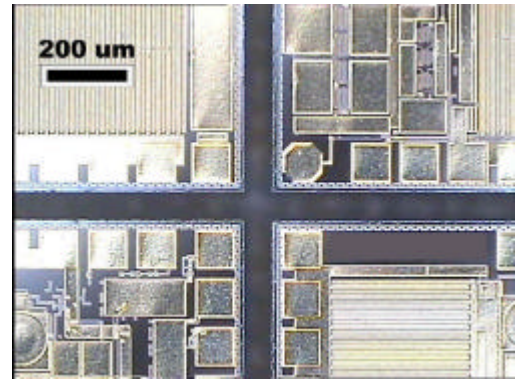


Fig. 5: Chip dicing in GaAs (wafer thickness: 75 mm; diameter: 60 mm)

In comparison to traditional methods like circular diamond saw or grinding and scribing, the LMJ is more flexible because it allows to cut chips of any shapes (even circular), or to separate chips of different size and/or different form being on the same wafer. The main advantage however for this application is the absence of mechanical and thermal stress on the extremely brittle work piece.

The gentleness of LMJ processing permits to avoid cracks, chipping and burrs. Wafers with thickness as fine as 50 micrometers can be cut with LMJ at high speed (up to 200 mm/sec) with an excellent cut quality.

Manufacturing air gap in ferrite cores for the electronic industry

Cores of small transformers for the electronic industry are generally ceramics composed of manganese oxide, zinc oxide, and/or iron oxide, called ferrites. Their structure makes them at the same time hard and brittle so they are very delicate to machine. Certain core shapes necessitate the machining of a gap with very high tolerances in order to optimize the output of the transformers. Because of the material hardness this slit is usually realized with a diamond saw-blade. The main disadvantage of this method consist in the high tool consumption rate, what induces problems concerning in tolerances and repeatability. Moreover, it is constantly necessary to lubricate the work-piece. With saw blades requiring to be changed and the huge DI-water quantity used for lubrication, this method is more expensive than the waterjet-guided laser.

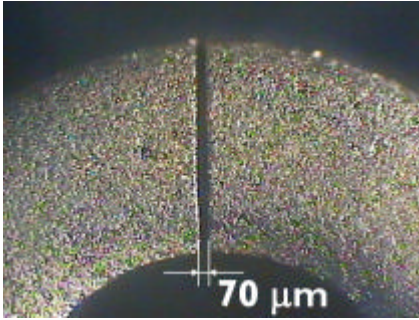


Fig.6: Air gap in a 2mm thick in circular ferrite core.

In fact, with the LMJ, cost of ownership for air gap cutting has been definitely reduced due to the absence of tool wear, and the small DI-water consumption (max. 100 ml/min). The slits can be realized very rapidly benefiting from a volumic ablation rate of 0.05 to 1 mm³/sec. Last, the waterjet-guided laser, and that is its speciality, assures a very good parallelism of the slit edges, even for only 50 microns wide gaps. The overall precision is strongly increased.

Cutting stencils with the LMJ

Solder mask stencils are mostly perforated metal sheets used to apply solder paste to land locations where the paste will be re-flowed to attached electronic components. These stencils are used for screen-printing solder paste or conductive adhesives onto printed circuit boards. Laser cut stencils are usually utilized for applying paste to boards containing fine pitch components. The precision of a laser cut stencil helps to eliminate bridging, improves paste release as well as the consistency across the stencil. Laser cutting has the advantage of high flexibility, high speed, and is able to cut very small apertures. The actual problem of laser cutting is the edge quality. In fact, the laser cut stencils need a post-treatment to clean the stencil and remove burrs on the backside. Using a short pulse laser, a burr-free, clean cut can be obtained. The water jet reduces any thermal damage and oxidation, to an undetectable level. The backside is completely burr free, without any post-treatment. In comparison with the conventional laser, the difference is at the very least, quite remarkable.

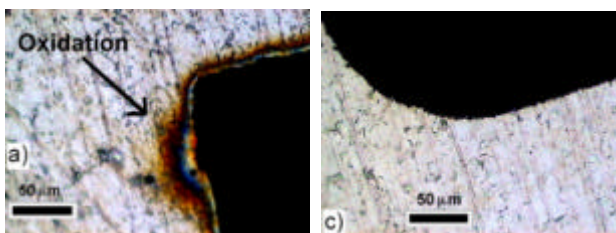


Figure 7: Optical microscope images of stencil apertures in 150 μm thick stainless steel. Upper row: Cut quality of a commercial conventional laser-cutting machine. a) Front side view of a corner, c) Front side quality of a rounded corner.

Summary and conclusion

In summary, the water jet guided laser has unsurpassed results compared to other standard methods in the domain of cutting of heat or force sensitive materials. The high cutting speed, kerf wall quality, and especially the ability of the system to cut any shaped and critical materials are the main reasons that render the LMJ very interesting for the tooling industry. After ten years of existence, the LMJ is continuously optimized to answer to the specific market demands, which are always more and more diversified and demanding.

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