WATER-JET GUIDED FIBER LASERS FOR MASK CUTTING

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Abstract

The water jet guided laser technology is a new machining process which combines a laser beam and a hair-thin, low-pressure water jet by focusing a laser beam through a pressurized water chamber into a nozzle. 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 fibers. This technology is well suited for micro machining because it generates no thermal and mechanical damages, no contamination and produces small, parallel kerfs. Recently, the fiber laser technology has been successfully adapted to the process. Due to exceptional beam quality, thinner water jets (such as 25 microns and smaller) can be used, resulting in very accurate cutting.

Fiber lasers represent an improvement for many applications, including mask cutting. Using an infrared Q-switched fiber laser, the water jet guided laser process is able to cut a large number of small apertures at high speed, with a high level of repeatability and accuracy; the need for post-processing steps is greatly reduced. For example, round openings (diameter 80 microns) can be drilled in 50-micron thick stainless steel at a rate of 30,000 openings per hour.

Introduction

Fiber lasers entered the field of material processing recently, offering new possibilities thanks to their compactness, absence of maintenance, long diode lifetime, exemplary beam quality, and high efficiency.

One rapidly growing application field for lasers in materials processing is the manufacturing of metal masks, as they offer speed, accuracy and free-shape cutting. The water jet guided laser is, in essence, a liquid optical conduit, guiding a high power laser beam due to the total internal reflection at the water/air interface. The water jet guided laser offers several advantages: high cutting speed, minimal heat affection, and no contamination on both front- and backsides.

Equipped with a new, pulsed fiber laser source, the water jet guided laser system is able to cut materials with exceptional quality and with very high production availability.

Fiber Laser Features

The fiber laser is a groundbreaking, new laser source. Recently, machines using the water jet guided laser technology have been adapted to integrate pulsed fiber lasers.

The characteristics of Q-Switched fiber lasers built on a Master-Oscillator Power-Amplifier (MOPA) concept are very similar to the characteristics of conventional bulk optics MOPA lasers: up to 100 W average power can be reached at pulse repetition rates of 20-50 kHz, and pulse lengths in the hundreds of ns up to 1 µs are obtained [1].

Using a multi-mode delivery fiber with a 100 µm core diameter, the beam product (radius x half angle of divergence) of the Q-Switched fiber laser output is 4,5 mm*mrad. The high pulse repetition rate of up to 50 kHz makes it possible to achieve smooth cutting edges, even at high cutting speeds, thanks to the spatial overlap between the pulses. Continuous wave fiber lasers are available with average powers up to as much as several kilowatts. For the water jet guided laser, average powers of 100 W are usually sufficient due to high power density within the small spot diameter on the work piece.

For industrial use, the advantages of the fiber laser become apparent: it has no need for maintenance, therefore maintaining the up time at virtually 100%. In addition, the beam characteristics are constant over the entire range of pulse repetition rates, as well as pump currents. This makes it a potent tool for intricate material processing applications like cutting stencils and stents [2].

The Laser-Microjet Technology

In the water jet guided laser technology – also called Laser-Microjet –, the component conducting the laser to the work piece is a liquid waveguide, contacting directly the material. During the coupling of a laser beam into a water jet, the laser is focused through a chamber filled with water into a nozzle; the laser light is then trapped inside the jet by total internal reflection at the water/air interface. The spot diameter is constant on the stable length of the jet, which can be up to several centimeters long, depending on the jet diameter. With a diameter ranging from 23 to 60 µm, the laminar water jet conducts the laser beam perfectly focused to the surface of the work piece and through the cut (see Figure 1).

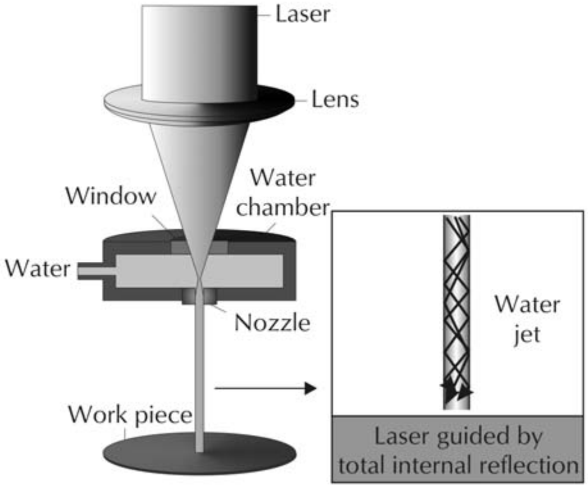

Figure 1: Basic principle of the water jet guided laser

Because of the low-pressure of the jet (50-500 bars), the force applied to the work piece is negligible (less than 0.1 N), but still the pressure is sufficient for efficiently removing all molten material while cooling the edges, preventing the development of a heat affected zone (HAZ). Heating effects, such as oxidation or micro-cracks, are inexistent.

Conventionally, multimode Q-switched lasers, operating at 1064 nm (infrared), 532 nm (green), or 355 nm (UV), are being used as a source for water jet guided laser processing. Regarding the water jet, pure de-ionized and filtered water is used. As the jet is only "hair thin", the water consumption is very low – about 1 liter per hour at 300 bar water pressure. The nozzles are composed of sapphire or diamond in order to generate a long, stable water jet.

Water-Jet-Guided Fiber Laser

Fiber lasers provide a very attractive option for integration with the water jet guiding technique, because of their beam quality and other advantages, such as their compactness (i.e. small installation footprint).

The combination of the fiber laser and the microjet (see Figure 2) is very interesting. The microjet acts as a liquid fiber extending the fiber laser, hence elongating the waveguide directly on to the work piece. Thanks to the exceptional beam quality available in fiber lasers, thinner water jets can be used.

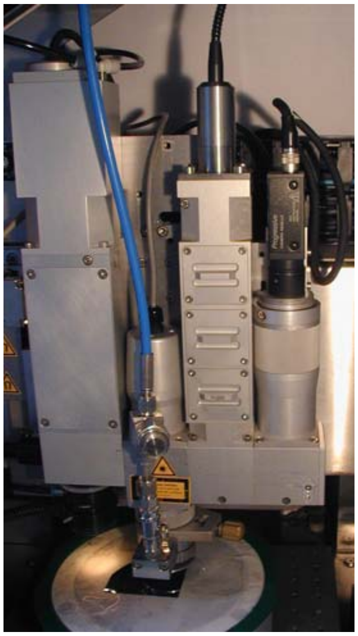

Figure 2: Coupling head equipped with a fiber laser

Mask Cutting

The application of solder paste onto PCB to SMT-component pads requires a type of mask called "stencil"; stencils are usually made out of thin sheets (thickness ranging from 50 to 200 µm) of stainless steel, but also of nickel, molybdenum and polyimide. A stencil contains a large number, typically between 1,000 and 10,000, of small openings.

Stencil production is a demanding operation: precision, quality, and speed are paramount. As the number of holes increases, achieving a high speed becomes very important. Since it is necessary to ensure that the solder paste can detach easily from the stencil, the tapered angle of the openings must be controlled. It is also necessary for the volume of solder paste in each bump to be very precise and consistent; for this reason, burrs and particle deposition should be avoided while a high cutting precision is ensured. Finally, when thin metal foils are being cut, applied forces and the heat affected zone (HAZ) should be reduced as much as possible. Stainless steel expands by 16 to 18 mm per meter of length, per °C, as the material is heated. As a result, stencils measuring 500x500 mm need to be cut with an average temperature as stable as ±0.6 °C to achieve a ±5 µm tolerance.

The water jet guided laser is well suited for stencil cutting as the process is fast, accurate and clean. There is no thermal load thanks to the water jet, and no mechanical damage.

Examples

Usually, the Laser-Microjet is not used in percussion drilling. By moving the Laser-Microjet head and table, any kind of shape is possible, resulting in high opening quality and high cutting rates (trepanning).

The three following photos show different openings produced by the Laser-Microjet in thin stainless-steel sheets. For all three samples, an infrared fiber laser has been used, coupled with a 40-µm nozzle generating a 35-µm jet. Figure 3 shows a series of 60-µm wide slots (material thickness: 50 µm, cutting rate: 20,000 per hour). Figure 4 shows 250-µm wide rounded squares (material thickness: 50 µm, cutting rate: 12,000 per hour). Figure 5 shows the ability to cut arbitrary shapes (material thickness: 30 µm).

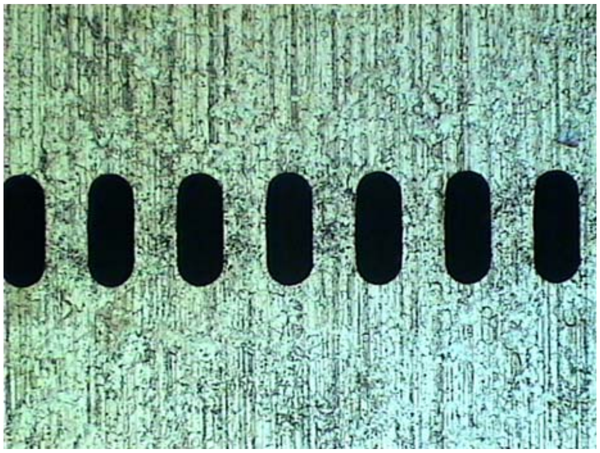

Figure 3: 60-µm wide slots in 50-µm thick stainless steel; cutting rate 20,000 / hour

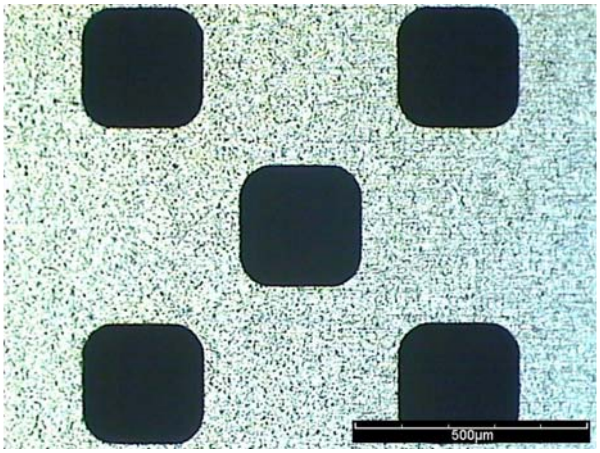

Figure 4: 250-µm wide rounded squares in 50-µm thick stainless steel; cutting rate 12,000 / hour

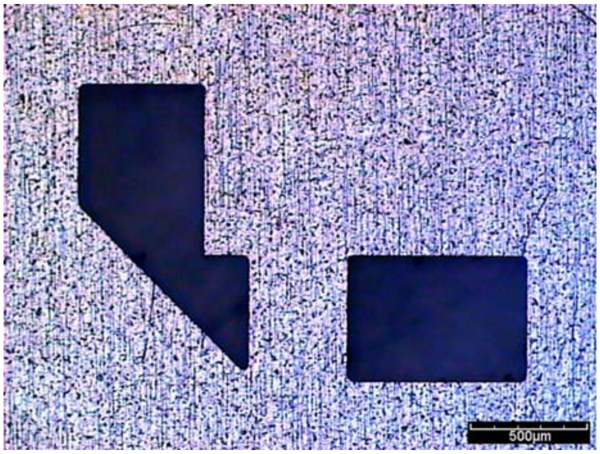

Figure 5: Free-shape cutting in 30-µm thick stainless steel

Conclusions

In combination with the water jet guided technology, fiber lasers obtain outstanding results, especially in applications such as mask cutting, which require high speed and accuracy. The water-jet-guided fiber laser provides high flexibility, high speed and the ability to cut small apertures with clean edges. It avoids dross and slag and the material is free from mechanical and thermal stress. This new method for cutting stencils is fast, clean, and cost efficient. The water-jet-guided fiber laser is also currently used for other precision applications, such as wafer dicing for the semiconductor industry.

References

[1] B. Shiner (2003) High-power fiber lasers impact material processing, Industrial Laser Solutions.

[2] M. Hatcher (2003) Fiber sources target automotive industry, Opto Laser Europe, 24-25.

After receiving his M.Sc in mechanical engineering from Aachen Polytechnic in Germany (RWTH) and his PhD in micro-technology from the Swiss Federal Institute of Technology Lausanne, Bernold Richerzhagen founded Synova SA in 1997 to develop the water jet-guided laser technology he had invented during his PhD.