Industrial applications of the water-jet guided laser

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Microjet® combines the advantages of laser material processing with water-jet technology, yielding a radical new process for industrial applications. By bundling and guiding a pulsed Nd:YAG laser beam in a laminar water jet with a diameter of only 50 µm, Microjet® can cut, drill, ablate and surface structure metals, ceramics, plastics, composites and semiconductor materials with an outstanding degree of quality and over a working distance of up to 100 mm. These unique features make Microjet® suitable for many applications in the field of micro processing that are not suited to conventional laser processing due to limitations imposed by the need to focus the beam onto the workpiece. Moreover, the thermal influence of Microjet® is quite negligible and the process yields precise cut edges. Applications in the fields of microelectronics and surface treatment, the watch-making industry, aerospace and automotive industries are particularly suited to this new technology.

The capability of laminar water jets to guide light was exploited as early as the European Renaissance in water-fountain shows where the light was coordinated with music. In literature, one can find research work on a light-guiding water jet by Prof. Colladon of the University of Geneva in 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 by it's inventor, "Laser Microjet" or more simple “Microjet”. A laser beam is guided onto the work piece inside a water jet by the total internal reflection at the interface between water and air, in a manner similar to the way light is guided in a conventional glass fibre. The water jet can thus be referred to as a variable-length fluid optical wave-guide.

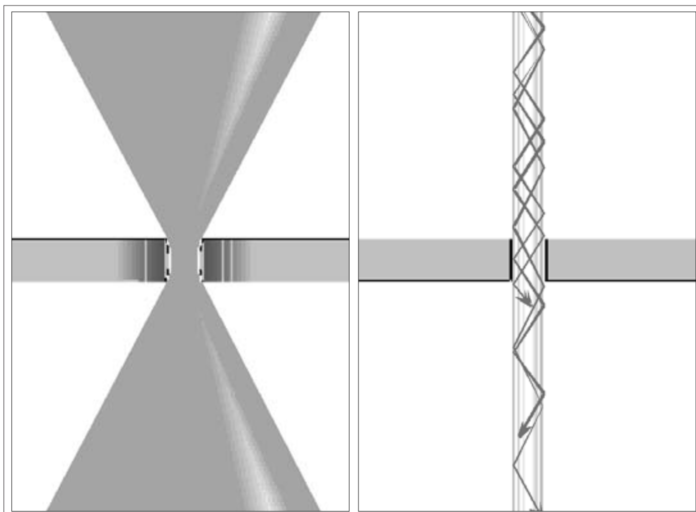


Fig 1: (left) Conventional laser cutting, the work piece must be placed precisely in the focus and the heat influx into the work piece is considerable. (right) Laser Microjet, a pulsed-laser is focused into a water jet nozzle , providing the same focus diameter over a greatly extended working dis-

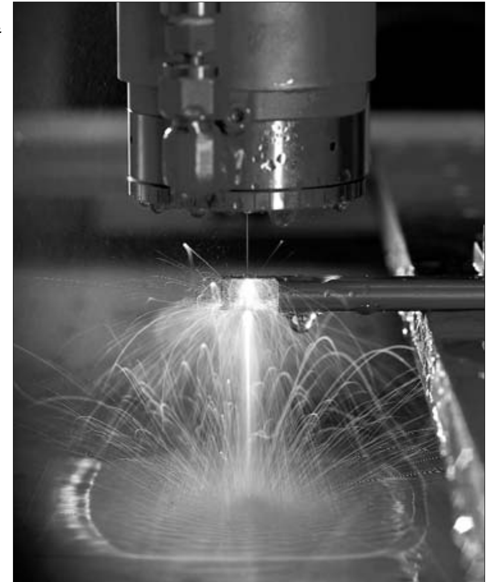


Figure 2. The water jet acts as a cooling element for the material between laser pulses precisely where it is most effective, in the cutting kerf. Furthermore, waste material is removed from the kerf and is cooled simultaneously. The cooling of the ablated products is paramount in the prevention of molten material adhering to substrates.

Comparison of processes

Figures 1 and 2 illustrate some of the unique features of the Microjet®. The laser is typically a pulsed Nd:YAG, average power 100 - 500 W, which ablates the material. The water jet guides the beam, cools the processed material, ejects surplus material and provides a precise parallel kerf even in thicker materials.

As a result of the long working distance of Microjet®, and distinct from either laser or water jet cutting alone, sandwich structures with cavity layers can be processed up to a depth of about 50 mm and cuts can be made where access is impaired. The investment costs for the Microjet® are comparable to those for conventional cutting systems and the operating costs are in general lower.

Precision cutting of sensitive, thin (less than 3 mm thick) material with negligible thermal influence is the most frequent Microjet® application. Cuts have highly parallel edges, smooth (‘sand blasted’ texture) sides and kerf widths as small as 50 µm. Also, the force on the workpiece by the Microjet® is tiny (e.g. less than 80 mN at 100 bar water pressure and 0.1 mm jet diameter) compared to the much larger forces imposed by water jet or assist gas used with laser cutting alone, thus also allowing problem-free processing of very fine work pieces.

Safety considerations are the same as for Nd:YAG lasers with regard to the laser radiation hazard, but fume hazards are greatly much less than for laser processing (since most fume is absorbed in the water) and the water jet itself is not dangerous.

Applications

The main application areas are cutting, drilling, engraving and surface structuring. All metals (excluding highly reflective metals) can be machined with the Microjet®, as can various plastics, ceramics and semiconductor materials, providing they are absorbing at 1.064 µm.

Cutting of Silicon Wafers

The cutting of Silicon wafers is an indispensable process in microchip production. The established process is to use high speed diamond blade saws. The limits of these saws appears to have been reached and alternative solutions are required to provide higher speed, better cut consistency (with no chipping) and a capability to process smaller chips on thinner wafers and with more elaborate designs (eg in the case of Multi Project Wafers (MPW), several designs from different customers and/or projects are combined onto one wafer and this involves a number of 'T-Cuts').

Figure 3 illustrates the performance of Microjet® laser cutting. The Microjet® already fulfils the high demands that will be placed in future on the dicing machines and the technology has an enormous development potential, particularly in the miniaturisation of the water jets below 50 µm and the utilisation of new laser sources.

The chips are held in place during the separation process by the application of LaserTape® to the wafer. This special tape is not cut by the laser and allows the water jet to pass through.

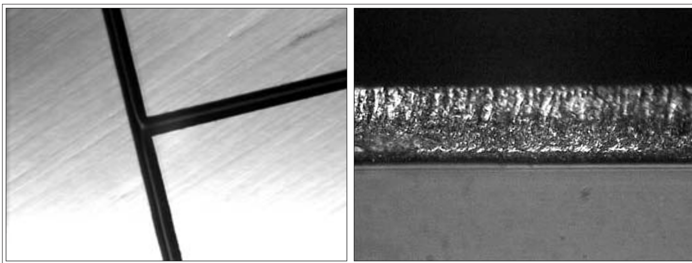


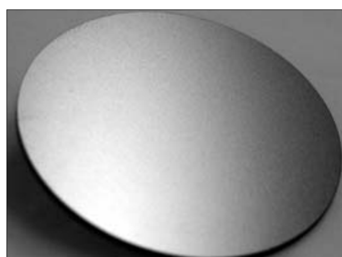
Figure 3. Microjet® laser cutting of silicon wafers. (left) Illustration of a T-cut, where the use of a short pulse laser provides a burr-free, clean cut with an average kerf width of 40 to 50 µm and no chipping. (right) Edge quality on a 200 µm thick wafer.

Another major application in this area is the production of power semiconductor devices (including thyristors and diodes used as rectifiers and switches in electrical power transmission). The elements of these devices are cut out of silicon wafers: typically circles of diameter 5 mm to 70 mm and thickness 200 µm to 1500 µm.

Such devices are currently cut out with conventional lasers, but the cut quality is poor (burrs, cracks) due to heating, and deposits of ablated material remain on the wafer surface, which is also the reason why conventional lasers are not used for the dicing of wafers described above. To prevent these hot deposits from adhering to the substrate, a protective coating is applied beforehand, requiring chemical removal thereafter.

With the Microjet®, efficient cooling of the cutting kerf prevents burrs and cracks from forming and a protective coating is not required, see Figure 4. In addition, a higher cutting speeds can be achieved with a very small kerf.

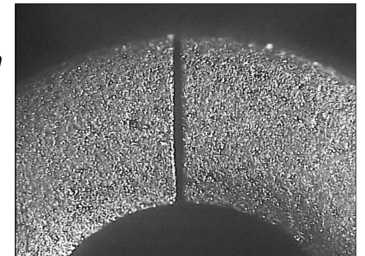
Figure 4. A round silicon chip cut by laser Microjet.



Cutting air gaps in ferrite cores

Ferrite cores are used in many compact, radio frequency components, including cellular phones, digital subscriber lines (high speed modems) etc. The requirements for the air gap in the core are extremely high, particularly when it comes to parallelism of the cutting edges and the heat affected zone. If the heat affected zone is too large it adversely affects the attainable performance of the radio parts. The conicity of the cutting kerf increases the electrical dispersion field, which influences the tolerance data of the component specification.

Figure 5. A ferrite core with air gap cut by the Laser Microjet. More than 50 standard 1.2mm thick cores can be cut per minute , each requiring a 3mm long cut. The core shown in the pictures was cut in only 3 seconds.



Other techniques used for producing air gaps, including use of diamond saws and the breaking and re-bonding of cores, suffer from poor reproducibility, cause overheating of the core and are slow. As illustrated in Figure 5, the Microjet® surpasses both techniques in terms of speed and precision. The increased speed translates into increased productivity, whilst the precision of ±3% contrasts with ±20% for ferrite cores cut by conventional means. The Microjet® also allows further miniaturisation of the size of the components.

Precision holes and slots

In certain cases, the Microjet® can replace the EDM machine, for example making precise holes or slits in conductive material. EDM machines are slow and costs are high because a new eroding electrode has to be made for every workpiece. In Figure 6 and 7 the Microjet® produced the parts in a quarter to one-fifth of the time required for EDM.

Figure 6. Slits made in vacuum grips for lifting and handling of sensitive parts. The slits are used to control and model air flows.

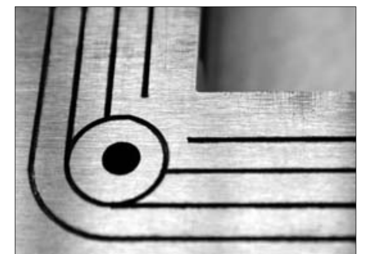
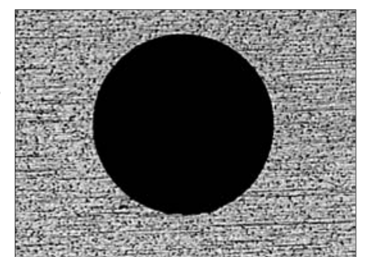


Figure 7. Holes (0.9 mm) in the side of a pipe, drilled with the laser Microjet.

Figure 8. The Laser-Microjet® can cut between 60 and 100 apertures per minute in a standard 150 micron thick stainless steel stencil. Excellent quality is not achieved at the expense of speed.



Other example where the Microjet® is now finding application include the manufacture of solder mask stencils, typically stainless steel or polyimide foils 50 to 200 µm thick, which are used to apply solder paste onto printed circuit boards. A large number of small square or round apertures have to be drilled at slight angles to allow the paste to detach from the mask. Precision, quality and speed are critical.

Using a short pulse laser, a burr-free, clean cut can be achieved but the water jet avoids any thermal damage and eliminates oxidation. An example of a hole in such a stencil is shown in Figure 8. The backside of the mask is left completely burr free, requiring no post-treatment. In comparison with the conventional laser, the difference is at the very least, quite remarkable.

Conclusion

The water jet guided laser has established itself for precision processing of sensitive materials. Thanks to it's cold cutting, the high edge parallelism and processing speed; the Microjet® is finding an increasing number of applications, replacing less precise and slower processes. The three principal qualities of the Microjet® are clearly illustrated in the application examples. In general, a combination of all three qualities leads to the replacement of existing less efficient technologies, but sometimes either the coldness of the cut, the processing speed, or the parallelism of the cut edges becomes the dominant advantage.

The many advantages offered by this new process can also be exploited in a clean room environment. Synova Inc., together with it's partners in Switzerland and Germany, have developed a compact, clean room capable version of the Microjet® for dicing of Silicon wafers. This version has a standardised cassette-handling module that provides cleaning and handling of the wafer.

Until now, the Microjet® Systems have been operated with pulsed Nd:YAG lasers over a range of powers and pulse lengths and with cw Nd:YAG. Other wavelengths can be used including frequency doubled Nd:YAG. A key advantage of the green laser beam is its extremely low absorption in water and increased absorption (compared to infra-red light) in the processing of copper, gold, polyimide; all materials widely used in the field of microelectronics.

Bernold Richerzhagen received his MSc in mechanics from the Technical University of Aachen, Germany, and his PhD in micro-technology from the Swiss Institute of Technology, Lausanne, Switzerland. He invented the water jet guided laser in 1994 and has received several awards for this work. In 1997 he founded SYNOVA SA, Lausanne, manufacturing high precision laser machines.

QUESTION AND ANSWER

E-stop requirements

We are a laser system manufacturer and have two power supply/control unit that we want to connect. One of them has an emergency stop which we want to use turn off both units when pressed. The only problem is that the emergency stop is wired in series with the mains.

Is it possible for us to power the second power supply/control unit from the first using a cable between the two? The cable will carry the mains supply from the first unit to the second, so that the emergency stop will cut the power to both units.

The relevant international standards are either:

a) IEC 60204-1 Safety of machinery Electrical equipment of machines general requirements;

b) IEC60950 Safety of information technology equipment;

or

c) IEC 61010-1 Safety requirements for electrical equipment for measurement, control and laboratory use: general requirements;

together with ISO 13850 (EN418), which gives the Principles of Design for Emergency Stop equipment.

Most equipment can be assumed to fall into one of these standards and there is a wide diversity of interpretation since the scope of each may not exactly cover the application being considered. The standards should be considered as indicators of good practice.

Without reviewing the total configuration or requirement, there is definite benefit in having a single a.c. power source. If the a.c. power disconnection device is also the E-Stop then compliance with the requirements of 60204-1 removes any potential problems.

In my view it is generally unacceptable to use machine tool type E-Stops (the mushroom headed push button) directly connected to the incoming a.c. mains. It is certainly unacceptable on anything but the simplest of machines. The switch would rarely have sufficient rating (either operating current or fault current capacity) to be a suitable component. There is also an expectation that this sort of device would normally be connected to some lower control voltage.

IEC60204-1 has the following relevant Clauses: 9.1.1 (requires transformers to be used for the supply of control circuits.), 5.1 (recommends that, where practicable, the electrical equipment should be connected to a single power supply and that the supply conductors are terminated at the supply disconnecting device), 5.3.2, 5.3.3 and 5.3.4 (give the requirements for the disconnecting device if it is to be used as the Emergency Stop and requires prevention of unexpected start-up), 9.2.5.4.2 and 9.2.5.4.3 (requirements for an Emergency stop device i.e. override all other functions and operation, remove power from devices causing hazardous conditions, not initiate a restart when reset and be accessible to the user).

IEC60950 has the following relevant Clauses: 2.8 (requirements for safety interlocks), 3.2 (requirements for connection the a.c. mains supply, 3.4.6 (requirements for the isolating device), 3.4.8 (requirements for switches when used as the disconnection device), 3.4.11 (requirements when using multiple power sources).

In IEC61010-1, 6.12 (requirements for disconnection from the supply source) and Clause 15 (requirements for protective interlocks) are the relevant clauses.

Mike Barrett Pro Laser