The Best of Both Worlds – Laser and Water Jet Combined in a New Process:

The Water Jet Guided Laser

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Abstract

The advantages of laser material processing have now been combined with those of water-jet cutting for the first time, yielding a radical new process available today for industrial applications. This revolutionary principle involves bundling and guiding a laser beam (Nd:YAG) in a laminar water jet with a diameter of only two mils (50 microns). “Microjet®” (as the process is called) can be used for the cutting, drilling, ablation and surface structuring of metals, ceramics, plastics, composites and semiconductor materials with an outstanding degree of quality. Its ample working distance of up to 4 inches makes the laser unarguably suitable for countless new applications in the field of micro processing – applications which cannot be realized with conventional laser systems on account of their beam geometric and the requisite focusing on the work piece. What’s more, the potential applications are further expanded by the fact that the thermal influence of Microjet is quite negligible and the process results in extraordinarily precise cut edges. It’s no wonder Synova reports the industry showing a keen interest in the Microjet, within the fields of microelectronics and surface treatment, the watch-making industry, aerospace and automotive industries in particular, all harboring high hopes for the new technology.

“Microjet” is based on an internationally patented material processing technology that has already received numerous awards: a laser beam is guided onto the work piece inside a water jet, with the wave being conducted in the water jet via the total reflection that takes place at the interface between water and air, in a manner similar to conventional glass fibers. The water jet can thus be referred to as a variable-length fluid optical wave-guide.

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 by it's inventor, "Laser Microjet" or more simple “Microjet”.

The Principle

By this method, a pulsed-laser is focused into a water jet nozzle. The laminar water jet functions as an optical fiber, leading the light onto the work piece located between 1 to 4 inches beneath the nozzle. The total reflection on the water/air surface allows the maintaining the high laser intensity and small beam size, which is normally found only in the laser focal point, over a very long work distance useable for material processing.

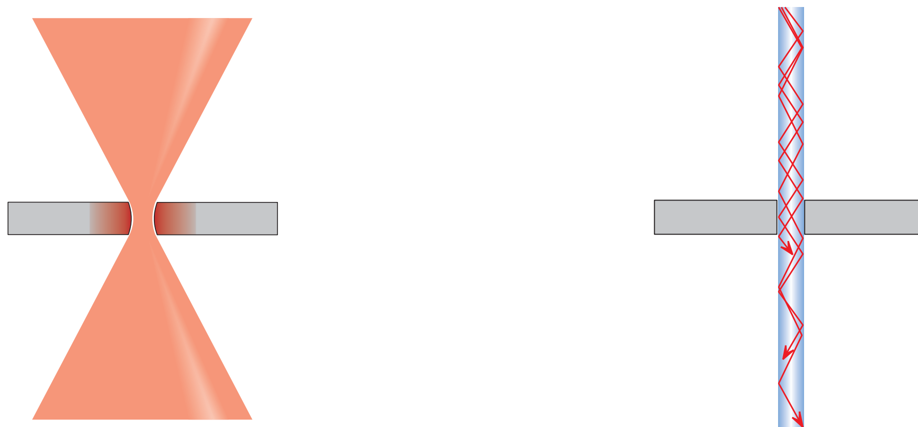

Fig 1: *Left: Conventional laser cutting, the work piece must be placed precisely in the focus. The heat influx into the work piece is considerable.*
Right: Laser Microjet, with the same focus diameter the working distance is farther away.

The Advantages in Processing Sensitive Materials

The water jet completes the laser cutting in an ideal manner. Firstly, it acts as a cooling element for the material between laser pulses precisely where it's necessary, in the cutting kerf. Furthermore, remaining melting is removed out of the kerf and is cooled simultaneously. The cooling of the ablated products is paramount in the prevention of melted material adhering to the substrates. In numerous applications, the parallel cutting plays a leading roll. In contrast to conventional laser cutting, the Laser Microjet can produce high precision, parallel kerfs, even in thicker material.

In the following tables, the two separated processes, (high-pressure) water jet and (CO_2) laser cutting, are compared with the combined process.

Fundamental differences

	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**
Energy medium	Water	Light 10.6 µm (far infrared)	Light and (a little bit) water 1.06 µm (near infrared) water jet guided laser beam
Energy source for ablation	High-pressure pump 3000 to 4000 bar	Gas laser	Solid-state laser (water jet does not ablate!)
Energy transmission	Rigid high-pressure hoses	Beam guided by mirrors (flying optics); fiber-transmission not feasible	Light conducted by fiber transmission, resulting in high degree of flexibility
Material expulsion	High-pressure water jet	Gas jet, thus necessitating additional gas	Water jet; system operates without gas
Distance between nozzle and material and maximum permissible tolerance	Approx. 3 mm ± 1 mm, distance sensor, regulation and Z-axis necessary	Approx. 0.5 mm ± 0.1 mm, distance sensor, regulation and Z-axis necessary	0 – 100 mm; distance sensor, regulation and Z-axis dispensed with

Tab 1: *The LASER-MICROJET combines the advantages of cutting by water jet (cold, large working distance) and laser cutting (precise, fast).*

Machine

	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**
Machine set-up	Working area and pump can be located separately	Laser source always located inside machine	Working area and laser and/or pump can be located separately on account of fiber transmission
Typical table size	2500 x 1250 mm to 4000 x 2000 mm	2500 x 1250 mm to 6000 x 2000 mm	300 x 300 mm to 1000 x 600 mm
Typical beam/jet output power at work piece	4 kW – 17 kW (4000 bar)	1500 kW – 2600 kW	100 W – 500 W

Tab 2*: The Laser-Microjet is a flexible, modular processing system with medium laser output and a generally small table size.*

Applications

	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**
General applications	Cutting Ablation Structuring	Cutting Drilling Engraving Ablation Structuring Welding	Cutting Drilling Engraving Ablation Structuring
3D cutting	Only partly possible due to problem of destruction of residual energy behind the work piece	Difficult on account of rigid beam guidance and distance regulation	No problem thanks to fiber transmission and long working distance
Materials that can be cut	All materials	All metals (excluding highly reflective metals), all plastics, glass, wood, ceramics	All metals (excluding highly reflective metals), various plastics, ceramics, semiconductor materials

	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**
Material combinations	Possible without exception	Materials with different melting points can barely be cut	Possible if absorption is sufficient
Sandwich structures with cavities	Limited	Not possible	Possible up to a distance of 50 mm
Cutting materials with impaired access	Limited due to short distance between nozzle and material	Rarely possible due to short distance and large cutting head	Possible in many cases thanks to long working distance
Material properties influencing the processing	Material hardness	Absorption characteristics of material at 10.6 µm	Absorption characteristics of material at 1.064 µm
Material thickness at which processing is economical	10 – 50 mm	1 – 10 mm, depending on material	0 – 3 mm, depending on material
Most frequent applications	Cutting of ceramics, stone and metals of greater thickness	Cutting of flat sheet steel of medium thickness for sheet metal processing	Precision cutting of sensitive, thin material with negligible thermal influence

Tab. 3: *The LASER-MICROJET is particularly suitable for high-precision processing of thin materials (0 – 3 mm), with its specific characteristics (long working distance and negligible thermal influence) leading to new applications*

Costs (approx.)

	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**
Wear parts	Water jet nozzle, focusing nozzle, high-pressure components (valves, hoses, seals, etc.)	Protection glass, gas, nozzles, dust and particle filters	Flash lamp, water jet nozzle, protection glass, filter for cutting water
Average consumption of complete system	20 kW pump: Electr. power: 22 – 35 kW Water: 150 l/h Abrasive: 36 kg/h Disposal of cutting waste	1500 W CO_2 laser: Electr. power: 24 – 40 kW Laser gas (CO_2, N_2, He): 2 – 16 l/h Cutting gas: (O_2, N_2): 500 – 2000 l/h	200 W Nd:YAG laser: Electr. power: 15 kW Water: 6 l/h

Tab. 4: *The investment costs for the LASER-MICROJET are comparable to those for conventional cutting systems. The operating costs are in general lower.*

Processing precision

	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**
Minimum cutting kerf width:	0.5 mm	0.15 mm, depending on cutting speed	0.05 mm, independent of cutting speed
Appearance of cut surfaces	Like sand-blasted, depending on cutting speed	Striated structure	Like sand-blasted, independent of cutting speed
Parallelism of cut edges	Good; “tailed” effect in curves in the case of thicker materials	Good; occasionally conical edges	Very good
Processing accuracy	Approx. 0.1 mm	Approx. 0.05 mm	< 0.01 mm
	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**

Burring	No burring	Partial burring	Virtually no burring
Thermal stress of material	None	Deformation, tempering and structural changes may occur	Very slight: no deformation or tempering and virtually no structural changes
Forces acting on material in direction of jet during processing	High: thin, small parts can thus only be processed to limited degree	Gas pressure of up to 20 bar poses problems with thin work pieces ("fluttering"), distance cannot be maintained	Very slight, e.g. < 80 mN at 100 bar and diameter 0.1 mm, thus also allowing problem-free processing of very fine work pieces

***Tab. 5**: The LASER-MICROJET is particularly suitable for high-precision processing of work pieces sensitive to deformation and heat.*

Operating environment

	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**
Personal safety requirements	Protective glasses, ear protection, protection against contact with water jet	Laser protection glasses not absolutely necessary	Special laser protection glasses necessary (high transmission of sunlight: < 80%), water jet not dangerous
Smoke and dust generation	Water splashes, contaminated with particles	Occurs; plastics and certain metal alloys produce toxic gases	Slight, as no cutting gas is used and the majority is absorbed by water
Noise pollution	High	Low	Low
Soiling of machine	High	Low	Very low
Cutting waste	Large quantities of cutting waste occur on account of mixing with abrasives	Cutting waste, predominantly in the form of dust requiring vacuum extraction and filtering	Cutting waste mainly absorbed by water

***Tab. 6:** The LASER-MICROJET is the most non-polluting working method.*

Chronology

	Water jet cutting	**CO_2 laser**	**LASER-MICROJET**
Inventor	Dr. N. Franz (McCartney, USA), 1970	Laser: T.H. Maimann (USA), 1960 Laser processing: 1963 CO_2 laser: 1968	Dr. B. Richerzhagen (Switzerland), 1994
First industrial machine	1971 – Ingersoll-Rand, USA, 1985 with abrasive water jet	1965, USA	1997, Synova, Switzerland
Future developments	Virtually no new developments expected as potential virtually exhausted	Virtually no new developments expected as potential virtually exhausted	Major development potential, e.g. with laser diodes as pump light source or as direct laser source
Extension of existing machines with water-jet guidance (LASER-MICROJET®)		Not possible due to unsuitable wavelength	Simple to realize with Nd:YAG laser

***Tab. 7:** The LASER-MICROJET embodies a new, modern technology with an enormous potential for further developments.*

The combined advantages of both processes allow the Laser Microjet to resolve certain applications, otherwise unresolved for each separate process. Hereafter, examples of applications

will be mentioned, namely those with which the water-jet guided laser can be carried out successfully.

Application Example 1 - Wafer Dicing: Diamond Saw versus Laser Microjet

The cutting of Silicon wafers is an indispensable process in microchip production. The established process is a saw with diamond blades, which have become in the last few years a perfected high-tech tool. The limits of the saws appears to be nevertheless reached in what is concerning industries' demands of speed, quality and capabilities (thin wafers). In the future, the demands will increase, and the search for alternatives is long underway. In addition, dicing experts from large companies cite the problems of saws in their conventional applications: no consistency in the cutting quality (chipping), constant wearing out of saw blades, and high operational costs.

With the Laser Microjet, an alternative to diamond sawing has been found. The Laser Microjet already fulfills today the high demands that will be placed on the dicing machines. Current trends in microelectronics are leading to thinner wafers and smaller chips, thus increasing the value of the Laser Microjet. The technology has an enormous development potential, particularly in the miniaturization of the water jets (below 50 microns) and the utilization of new laser sources.

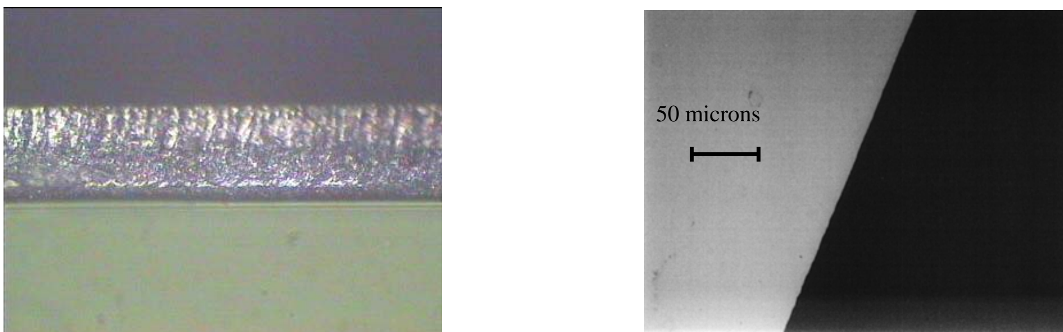

Fig 2: *Edge quality with the Laser Microjet –cut Silicon chips. Left: View of the edge (thickness 200 um). The increased roughness from the thermal ablation does not lead to lower fracture strength. Right: View from the backside. (No chipping)*

An important problem, now solved, is the holding in place of the chips during the separation process. In the case of the Laser Microjet, tape will be used as by sawing, and the tape will be applied onto the wafer. This special tape, called LaserTape®, is not cut by the laser and it allows the water jet to pass through. The LaserTape fulfills the same function as the conventional tape, hence allowing for production to continue without changing the handling process.

Application example No. 2: Cutting of round Silicon chips: Conventional laser versus Laser Microjet

Silicon will not only be cut in its classical right-angular form as material for integrated circuits, but will also be used in the form of round chips. Thyristors or diodes are a typical application of these chips, which are currently cut out with conventional lasers. The quality of the cut by conventional laser is poor (burrs, cracks, deposit material), which is also the reason why the conventional laser is not used for the dicing of wafers mentioned in the application example no. 1. The heat induction into the silicon by conventional laser cutting produces cracks and undesired structural changes in the material. Besides this, burrs occur and deposits of ablated material remain on the wafer surface. These hot deposits can adhere to the substrate, thus requiring the application of a protective coating beforehand and a chemical removal of the coating together with the deposits thereafter.

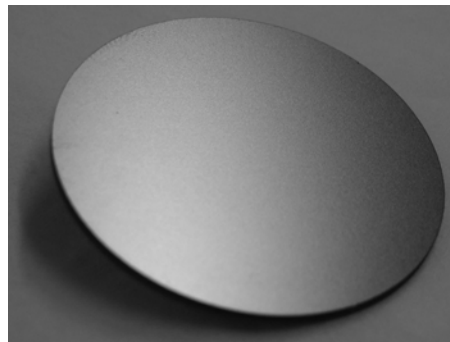

Fig 3: *With Laser Microjet cut round Silicon chip*

With the Laser Microjet, a much better process is available. Due to the efficient cooling of the cutting kerf, burrs and cracks will be avoided. In addition, the surface is much cleaner and protective coating application beforehand is no longer required. Lastly, an important advantage is the higher cutting speeds that can be reached with the very small kerfs.

Application example No. 3: Cutting of an air gap in ferrite cores, breaking and bonding versus Laser Microjet

Ferrite cores are used in many compact, radio frequency components, for example, in cellular phones, digital subscriber lines (high speed modems) etc. The demands concerning the precision of the air gap are extremely high, particularly when it comes to parallelism of the cutting edges and the heat affected zone. A too large heat affected zone has a negative influence upon the attainable performance of the radio parts. The conicity of the cutting kerf increases the electrical dispersion field and therefore influences the tolerance data of the components.

Until now, two methods were used for the fabrication of air gaps: The first with the use of a diamond saw. However, the use of a saw creates the same problems already mentioned in application example no. 1. Above all, the variations in the rate of saw blade wear, resulting in a high tolerance, and a slow cutting speed make this method undesirable. The second technique is the breaking and then re-bonding of the cores. Here again, reduced productivity and reproducibility in a very time consuming process leave a lot to be desired.

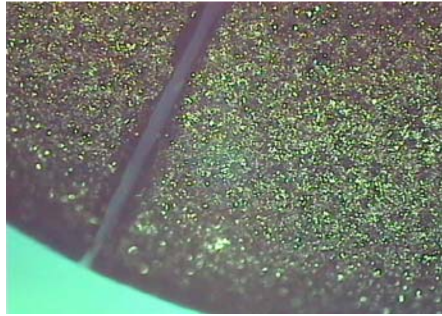

Fig 4: *Ferrite cores with air gap cut by the Laser Microjet.*

The Laser Microjet in terms of speed and precision surpasses both techniques. The argument of speed speaks for itself, which is also a synonym for productivity. Even more important is the precision of the Laser Microjet technology, making it possible to produce Ferrite cores with a precision of +/- 3% in contrast to +/- 20% by conventional fabrication. Lastly, the Laser Microjet allows further miniaturization of the size of the components.

Application example no. 4: Vacuum grips and Nozzle fabrication, EDM versus Laser Microjet

In certain cases, the Laser Microjet can replace the EDM machine, for example when very precise holes or slits in conductive material have to be made. Such slits are made in a vacuum grips for lifting and handling of very sensitive parts. The slits are used to control and model air flows.

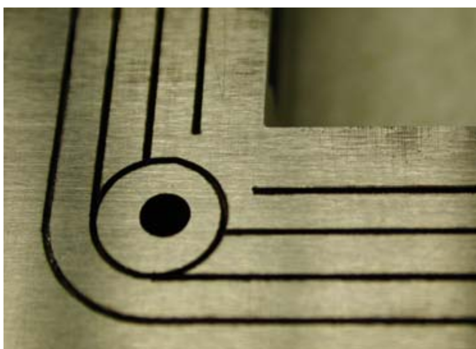

Fig 5: *Left: with Laser Microjet cut vacuum grip. Right: Holes (0.9 mm) in the side of a pipe, drilled with the water guided laser.*

EDM machines allow the required forms and precisions, but they have the disadvantage of slowness and quite high costs, because for every work piece, a new eroding electrode has to be made. For a realistic calculation of the manufacturing time, the time required for the electrode production and the cost of the electrode material has to be taken into account.

Thanks to the parallelism of the cutting edges and the high processing speed of the Laser Microjet, it's all the more possible to finish the shown work pieces in a quarter to one-fifth of the earlier required time. In other words, an increase in productivity of between 400 and 500 percent is achievable.

Resume

The water jet guided laser has established itself in the precision processing of sensitive materials. Thanks to it's cold cutting, the possible edge parallelism, and the processing speed; the Laser Microjet finds more and more applications and replaces less precise and slower processes. The three principal qualities of the Microjet are clearly illustrated in the application examples. In general, all three qualities together allow the replacement of previous, less efficient technologies, but sometimes, either the coldness of the cut, the processing speed, or the parallelism of the edges is the most important advantage.

New Developments and Overview

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 Laser Microjet for dicing of Silicon wafers. This version has a standardized cassette-handling module (with cleaning and handling of the wafer).
The Laser Dicing system has been shortly presented to the public this year at an international trade show.

Fig. 6: *Laser Dicing System*

Until now, the Laser Microjet Systems have been put into operation with YAG laser of different power and pulse lengths, as well as CW YAG Laser. The utilization of other

wavelengths is naturally possible and is also very interesting from a material processing point of view. New developments in the domain of double frequency YAG lasers will in the short-term be commercially available. A key advantage of the green laser is the extremely low absorption in water. An additional advantage is the increased absorption of green light compared to infra-red light, for example in the processing of copper, gold, polyimide, materials widely used in the field of microelectronics.

Author’s biography:

Bernold Richerzhagen (born 1964 in Cologne, Germany) 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 is the inventor of the water jet guided laser technology. Since this invention in 1994, he has published a great number of articles on combining laser and water jet for which he has received several awards. He is the CEO of SYNOVA SA, Lausanne, an incorporated company manufacturing high precision laser machines, which he has founded in 1997.