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EXPERIMENTAL MICROMACHINING RESULTS USING A UV LASER WITH THE LASER MICROJET®

Paper M404

Alexandre Pauchard, Nandor Vago, Bernold Richerzhagen

Synova SA, Chemin de la Dent d'Oche, 1024 Ecublens, Switzerland, pauchard@synova.ch

Abstract

UV wavelengths are interesting for photothermal cutting of materials that have a low absorption coefficient or are transparent at 1064 and 532 nm wavelengths, such as copper, sapphire or glass. The high photon energy of UV lasers plays also a significant role in photochemical machining of polymer materials such as polyimide. In addition to the absorption coefficient, the optical penetration depth varies with wavelength, and different ablation results are expected for ultraviolet, green and infrared lasers. In many cases, the heat diffusion length should not exceed the optical penetration depth, in order to obtain high quality microstructures with clean edges and smooth surfaces. As a result, the duration of the laser pulses needed to be considered as well.

The objective of this investigation was to study the compatibility of a 355nm UV laser with the Laser MicroJet® and compare the results of processing difficult-to-machine materials with those obtained with other wavelengths (green and infrared) in terms of quality and throughput.

The following materials were tested: pure silicon wafers, low-k wafers, SiC wafers, sapphire wafers, wafers with polyimide coating and polyimide flexible circuits.

Introduction

The basic principle of the water jet-guided laser technology is to focus a laser beam into a hair-thin, low-pressure water jet. The water jet then guides the laser beam onto the wafer. One of the main advantages of this hybrid system – also called Laser-Microjet® – is to prevent heat damage to the material by cooling the cutting edges in between the laser pulses; simultaneously the water jet removes the molten material generated by the laser. Contamination is avoided thanks to a thin water film that covers the wafer surface during the cutting process. The particles, already cooled down by the water jet, cannot adhere to the wafer. The mechanical force of the water jet onto the wafer is negligible, due to the small jet diameter (75 to 23 microns) and the low water pressure (50 to 500 bar). The stable length of the water jet, corresponding to the process working distance, can be several centimeters long. Given the perfectly cylindrical shape of the water jet, kerf walls are highly parallel.

Because the water absorption coefficient is the lowest between 220 nm and 1100 nm (< 0.2 / cm), Q-switched Nd:YAG operating at 1064 nm and frequency-doubled Nd:YAG lasers operating at 532 nm are particularly adapted to the water jet-guided cutting technology. Cutting and grooving machines [2] based on both laser types have been widely deployed in a number of different markets over the last 10 years. Although frequency-tripled UV lasers operating at 355 nm are also within the usable optical spectrum of the water jet-guided technology, they have not yet been deployed because of the lack of optical fibers with high damage threshold at UV wavelengths, and to a lesser extent to the lack of experimental results. In this paper, we present new cutting and grooving results obtained with a UV laser.

Laser characterization

The 355 nm laser used in the following water jet-guided cutting experiments is a Q-switched diode-pumped frequency-tripled Nd:YAG laser [1]. The laser system consists of a laser head, power supply and water chiller. The water temperature of the chiller controls the temperature of the gain medium. Ovens control the temperature of the second and third harmonic generators crystals. The laser crystal is used in a side pumped geometry. A series of laser diode bars is mounted in a circularly symmetric pattern for side pumping the Nd:YAG rod.

Measured characterization data [1] are shown in Figures 1 to 4.

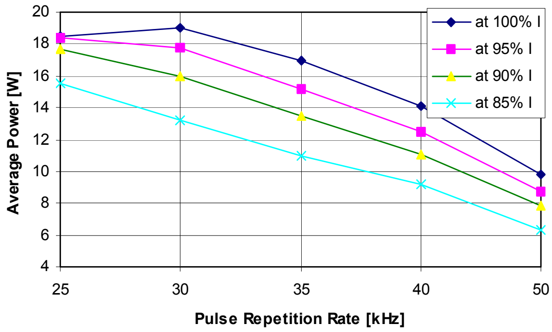

Figure 1: Average power vs. repetition rate

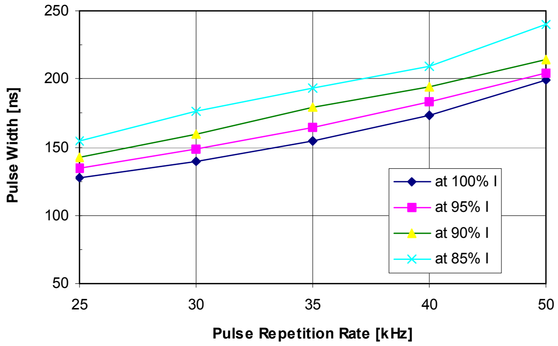

Figure 2: Pulse width vs. repetition rate

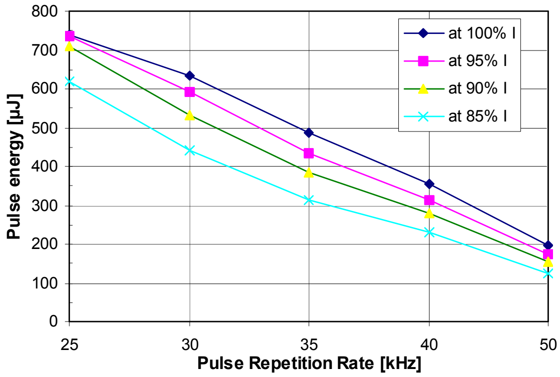

Figure 3: Pulse energy vs. repetition rate

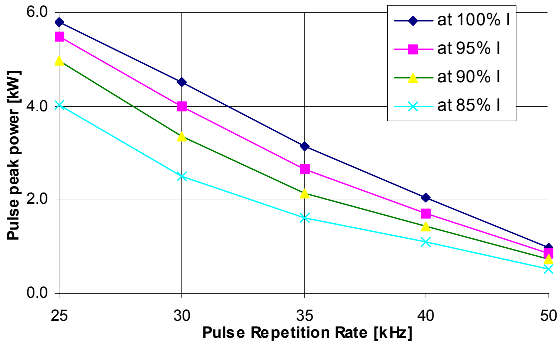

Figure 4: Peak power vs. repetition rate

Machining setup and configuration

The laser was used in an open setup on a dedicated R&D machine. It used a direct focusing scheme without intermediate fiber delivery for machining. A sketch of the setup is shown in Figures 5 and 6. The collimated laser beam has a diameter of 3.5 mm at the exit port of the laser head. The beam size is reduced down to 2 mm with a reverse beam expender (extraction factor 1.75). The light is then focused through a quartz window and a layer of pressurized water into the water jet nozzle by a 25 mm focusing lens. The calculated focus diameter in the water at the nozzle entrance is approximately 7.5 µm. The theoretical depth of focus (d = 2* zR, zR: Rayleigh length at the position of 50% power density reduction) is 185 µm.

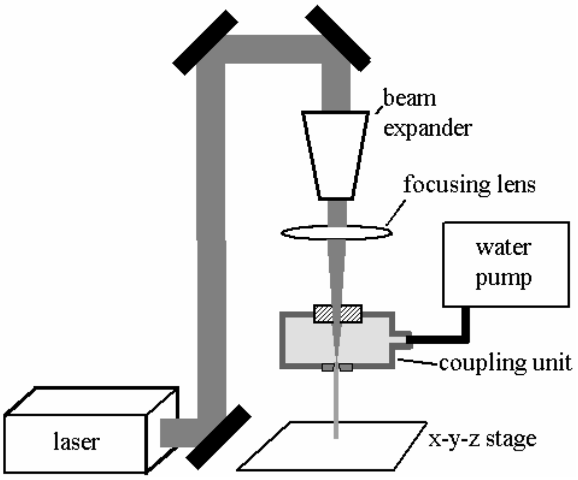

Figure 5: Schematic of the focusing setup used in these experiments

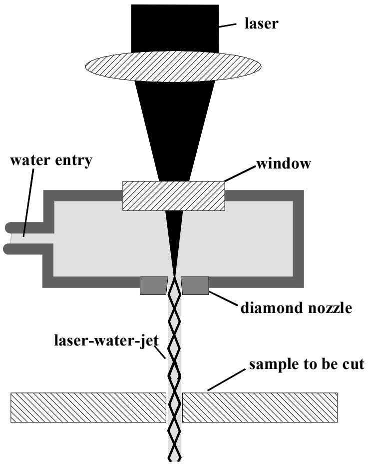

Figure 6: zoom of the coupling cell

The laser system was operated under Continuous Mode – Internal Trigger. The focusing head is fixed and an x-y table under the beam moved the sample. The distance between the cutting head and the work piece was 10 mm.

Machining results

Cutting bare silicon wafers

In terms of cutting thin silicon wafers, an effective cutting speed of 50 mm/s could be achieved when cutting 100 µm thick bare silicon wafers with the UV laser. It is similar to the cutting speed with IR fiber lasers or second harmonic Q-switched lasers. However, only 8 W output power was required in comparison to 30 W at 532 nm and 35 W at 1070 nm. Higher speeds could be possible if required. The high cutting quality, shown in Fig. 7, was comparable to that of fiber lasers. Note that the image was taken before the wafer was cleaned.

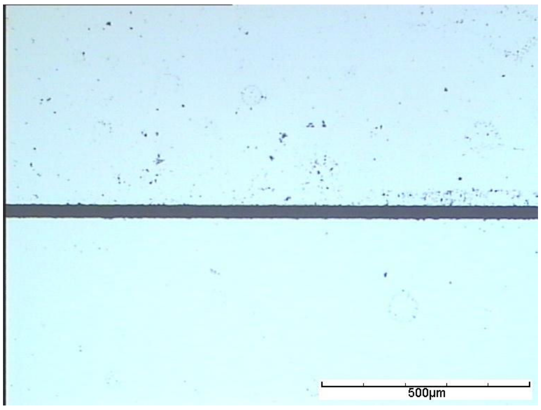

Figure 7: front side of bare Si wafer, 10x objective, bright field image

Cutting of 75 µm thick Si wafers with low-k layers

Results from previous tests with a 532nm laser showed that grooving and cutting through low-k wafers is possible with neither cracks nor chipping in various areas of the dicing street. However, in some places, lateral cracks and chipping of the low-k layer alongside the dicing kerf could still occur, especially in dicing streets with test pads and thick glass layers (about 5 µm).

Tests with the UV laser [1] showed cutting through metal pads without glass cracking and chipping, even on the most problematic regions of the dicing street. A single cutting pass with a 40 µm nozzle and a water pressure of 250 bar could separate the 75µm thick low-k wafer material. The cutting speed is 50 mm/s and is higher than that with the green laser. A typical cut is shown in Fig. 8.

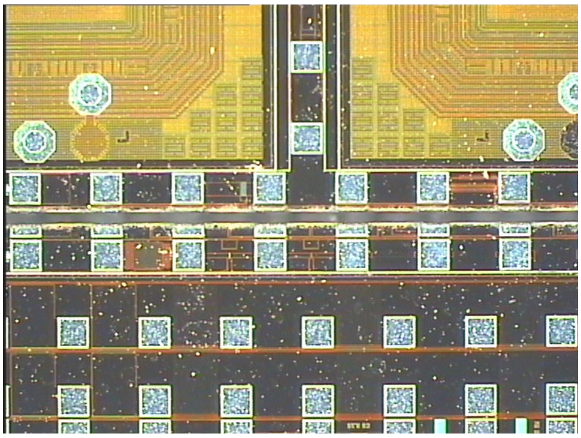

Figure 8: front side of 75 µm thick Si wafers with low-k layers, 10x objective, dark field image

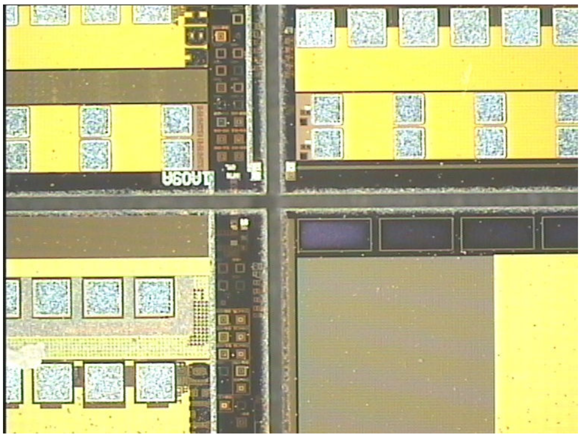

Figure 9: front side of 400 µm thick Si wafers with low-k layers, 10x objective, dark field image

Grooving 400 µm thick Si wafers with low-k layers

The objective of this experiment was to groove low-k wafers with a kerf width between 35-40 µm, without chipping alongside the kerf edge due to cracking in the glass-like layer. The grooving depth target was 8 to 10 microns at a high machining speed. An abrasive saw in a consecutive process step dices the wafers.

Single-pass cutting was performed at a speed of 75 mm/s, with a 40 µm nozzle and a water pressure of 250 bar. The pulse frequency was 35 kHz and the average power 11.2 W. The good cutting quality is shown in Fig. 9.

Grooving & cutting SiC wafers with SiN top layer

SiC wafers are made for the manufacturing of LEDs emitting at different colours. Some of them have nitride layer as active ingredients such SiN, GaN or InN. Although this type of active layers is very thin (below 1 µm), it has sometimes an enormous influence on the result of the laser dicing.

SiC wafers (95 µm thick) with a SiN top layer (170nm thick) were cut using 30 µm nozzles and a water pressure of 450 bar. The repetition rate was 40 kHz. The cutting speed was 80 mm/s. Figure 10 shows the result after 3 cutting passes. The measured kerf width was 28-30 µm. The scribing result is free of burrs and heat damage. In comparison to previous cutting tests with 532nm lasers, higher finishing quality and material removal rate (hence higher dicing speed) was observed. The dicing process was carried out with a laser output power of 7.5 W, slightly less than the power of previous green experiments.

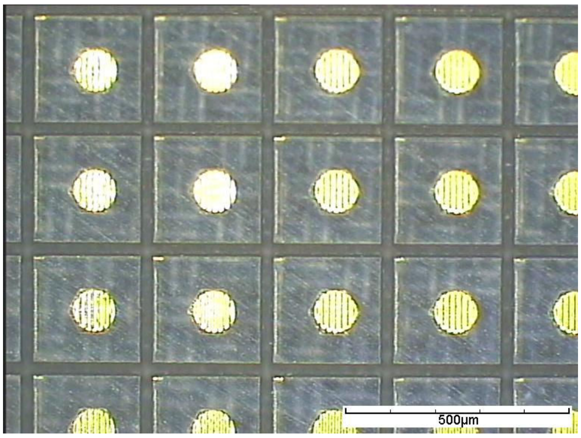

Figure 10: front side of SiC wafers with SiN top layer, 10x objective, dark field image

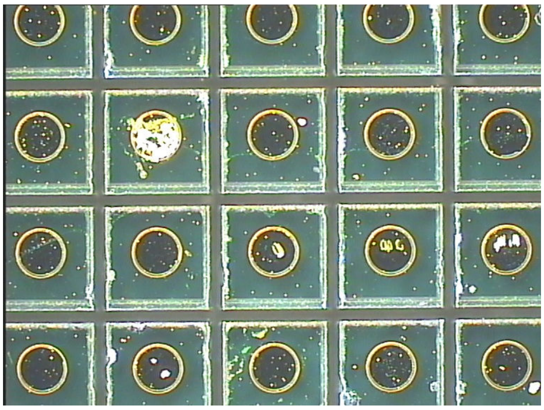

Figure 11: front side of 250 µm thick SiC wafers, 10x objective, dark field image

Using the same cutting parameters as above but 25 passes with a cutting speed of 60 mm/s, 250 µm thick SiC wafers were cut into individual LEDs with a die size of 250 x 250 µm, as shown in Fig. 11. A high amount of debris was observed. The dicing quality and speed are comparable to those of a green laser but lower than those of an infrared laser. Applying a water film during laser dicing and a subsequent high pressure cleaning process after laser dicing shall improve the results.

Saphire wafers

A six-inch 220 µm thick saphire wafer with chip structures was grooved using a 40 µm nozzle and a water pressure of 420 bar. The laser repetition rate was 25 kHz and the average power 13.6 W. The measured kerf width of the groove at the surface was about 46-48 µm. The grooving depth, measured by cross section evaluations, is shown in Figure 12 as a function of the number of passes.

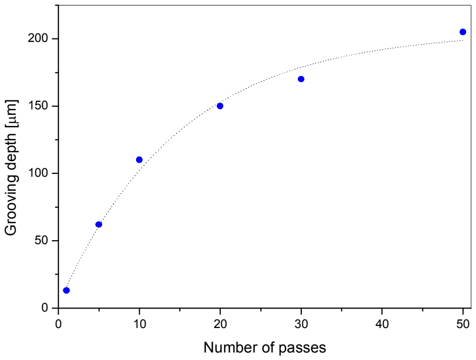

Figure 12: Grooving depth vs. number of passes

Only 7 to 8 passes were required to achieve a target grooving depth of 75 µm. The overall cutting speed was 7.5 mm/s. The effective grooving speed with UV laser is higher than the 2 mm/s grooving speed obtained with a 140 W green laser. The cutting quality was good, as shown in Figures 13 and 14. The UV laser is clearly a better choice for machining sapphire.

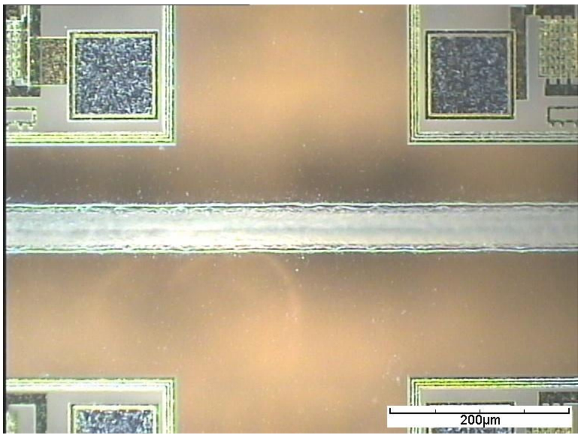

Figure 13: 1 pass over 220 µm thick saphire wafer, 20x objective, dark field image

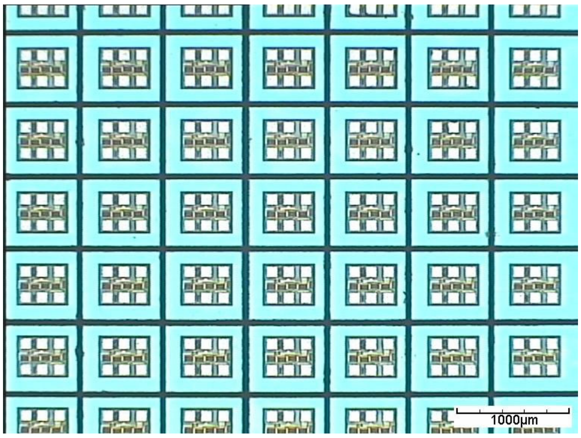

Figure 14: 220 µm thick saphire wafer, chip pitch 750x650µm, 2.5x objective, bright field image

Cutting of Si wafers with 4µm polyimide coating

The cutting of 75 µm thick Si wafers with 4 µm polyimide (PI) coating was tested with the UV laser. The objective of this test was to investigate the one-step cutting process with the UV laser. The nozzle diameter was 30 µm and the water pressure 450 bar. The laser repetition rate was 50 kHz and the average power 4 W. The cutting speed was 25 mm/s, and only 2 passes were necessary. The measured kerf width is 28-30 µm. A typical cut is shown in Fig. 15.

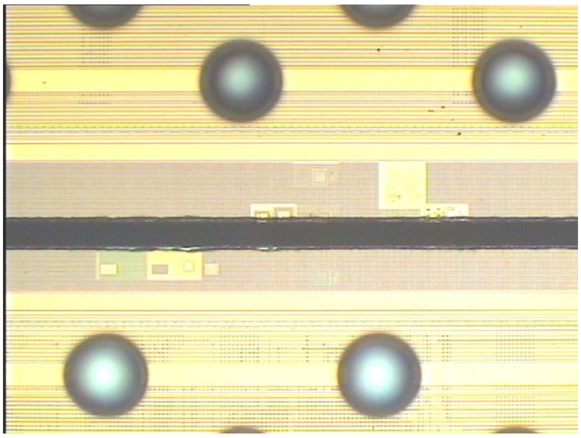

Figure 15: Si wafer w/ 4 µm polyimide (PI) coating, 20x objective, bright field

Two avoid delamination of the PI layer at critical areas, for example areas with metal pads, not only UV wavelengths are favourable due to the enhanced absorption and the photochemical ablation effect, but a high overlapping is also necessary. In the current test, the ablation depth per pass was about 40 µm. The ratio of the ablated volume of PI to Si per pulse is about 10:90. A high pulse-overlapping rate can be realized by either reducing the translation speed or by increasing the pulse frequency. A high pulse-overlapping rate generates only a small ablation volume, as a consequence there is a small spatial temperature gradient between the PI layer and the substrate during every laser pulse. This consideration is very useful at critical areas, as the metal pads in the dicing street will negatively influence the lateral heat conduction. As the heat extension coefficients of PI and Si are different, the larger the heat affected area of the PI, the larger is the thermal stress between them. A pulse overlap of 88% was seen with the shallow grooving (mostly to remove the PI layer only), while 98% was necessary for the multiple pass cutting.

PI with copper and adhesive in flexible circuits

Polyimide with copper plating is frequently used as flex board material. The lamination of flex is subject to cold rolling, heating and hot rolling to compress the adhesive. Delamination may occur if the flex is subject to too much heating by laser or by mechanical impact of the water jet. Figure 16 illustrates the lamination of a common flex used for flexible circuits.

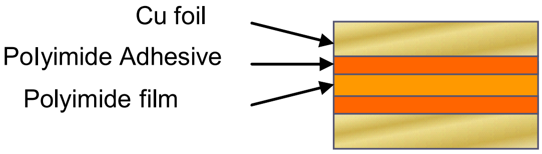

Figure 16: Layout of a common flex

Flexible Printed Circuits (FPCs) were cut using the Laser MicroJet technology and the UV laser [1]. The first layer consist of 25 µm Polyimide (PI), or 85 µm solder of Sn alloy in some areas. The second layer consists of 43 µm copper foil over 25 µm PI. The third layer consists of 50 µm of PI and cured adhesive. The last layer consists of 25 µm precure adhesive. The nozzle diameter was 30 µm and the water pressure 450 bar. The laser repetition rate was 40 kHz and the average power 9.5 W. The cutting speed was 320 mm/s and 4 passes were necessary. The measured kerf width was 28-30 µm.

The results demonstrated the feasibility of cutting FPCs with good quality, without slag or burr at the cutting edges, at high processing rates. In the majority of cutting regions, delamination, chipping or thermal damage of the PI could be prevented. A glass transition on the surface (skin effect) as well as a change of color (bleaching effect) of the PI did not take place. A typical cut is shown in Fig. 17.

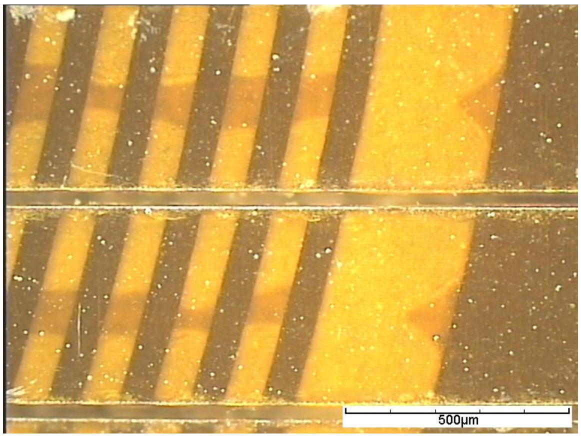

Figure 17: cut through a PI/Cu layer of a FPC, 10x objective, dark field

Conclusion

UV lasers operating at 355 nm are well adapted to the Laser MicroJet grooving and cutting technology. The UV laser beam can be guided with a water jet for machining a variety of materials with good quality results and satisfactory throughput. In many cases, the obtained throughput is on par with high power green and IR lasers. No nozzle damage due to high peak powers occurs, even with the smallest nozzle diameter of 30 µm. Pure silicon wafers, low-k wafers, SiC wafers, sapphire wafers, wafers with polyimide coating and polyimide flexible circuits were cut with the UV laser. When combined with the Laser MicroJet, UV lasers are superior to green or IR lasers for cutting materials that have a low absorption coefficient or are transparent at 1064 and 532 nm wavelengths, such as sapphire.

The availability of UV fibers with sufficient laser damage thresholds would greatly facilitate the deployment of UV lasers with the water jet-guided technology.

References

[1] AVIA ThorTM laser from Coherent Inc.
[2] www.synova.ch

Meet the Authors

Alexandre Pauchard is R&D Manager at Synova SA. Before that he held positions as VP of Engineering at id Quantique in Geneva, Director of Engineering at Nova Crystals in California, Visiting Scholar at the University of California in San Diego and Invited Research Scientist at the Delft University of Technology. He holds a M.S. in Physics from ETH Zurich and a Ph.D. in Microengineering from EPFL. He has published over 30 papers and has been awarded 6 international patents.

Nándor Vágó received his MS degree in engineering physics from the Budapest University of Technology in 1999. With a Swiss federal scholarship he began his PhD at the Swiss Federal Institute of Technology in Lausanne in a joint research program with Synova SA in 2001. He took part in the development of the water-jet guided laser technology used for cutting purposes and surface treatment. He is R&D engineer at Synova SA from 2006.

Bernold Richerzhagen received his M.Sc in Mechanical Engineering from Aachen Polytechnic in Germany. During his PhD in Microtechnology at the EPFL in Lausanne, he proved the feasibility of guiding laser light in water. Starting with an engineering office in 1996, which enabled him to realize the first industrial prototype, he successfully achieved the commercialization of the Laser-Microjet with the foundation of Synova SA in 1997, to which he is today the CEO & President.