RECENT ADVANCES IN PRECISION MACHINING OF VARIOUS MATERIALS WITH THE LASER MICROJET®

Paper #M704

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Abstract

Laser micromachining employs ultra short pulsed or UV lasers to overcome problems of thermal damage and debris formation. However, the main obstacles in using these types of laser are notably, low ablation rates and high running costs. This paper describes some recent advances made in the precision machining of industrial materials, using the unique capabilities of the Synova Laser Microjet® technology. Tests carried out with the water jet-guided laser, for industrial customers show superior results in terms of high precision cutting quality, combined with high speed, as well as negligible heat damage, or contamination problems. The tests, prove this technology is highly suited for materials that are otherwise, difficult to process, or that yield poor results with today's conventional methods. The results presented are for precision dicing and cutting of 900µm moulded wafer and mould compound, cutting optical elements from 250µm silicon wafer and cutting and grinding of 700-830µm silicon wafer, all for the semiconductor industry, cutting 200µm brass watch hands, cutting of 200µm Nitinol for medicinal stents, cutting 5mm stainless steel tubing for medicinal use in endoscopy and cutting of up to 8mm PCD/WC or CBN/WC materials for the machine tool industry.

Introduction

The purpose of this paper is to bring to the attention of the listeners some of the distinct processing advantages now being made possible using the Laser Microjet® technology, the principle for which has been extensively described in earlier papers [1,2].

The principle advantages of the Laser Microjet® are its high cutting speeds, ability to cut thin items as well as to penetrate deep into thick target materials, producing perfectly parallel kerf walls, with no heat affected zone (HAZ) damage, as the water jet provides a continuous cooling effect and leaves no back surface chipping of the material. The water jet also provides an effective medium for cleaning the kerf of ablated material whilst exerting minimal mechanical forces, and simultaneously provides a protective film to prevent any deposition on the work piece surfaces.

This unique ability of the Laser Microjet® water jet-guided laser to penetrate deep into the target material is based on the physical property of the kerf width being a few microns wider than the water jet itself, as depicted below in Figure 1. This leaves an air gap surrounding the jet, allowing for a loss-less guidance of the laser beam to the bottom of the kerf.

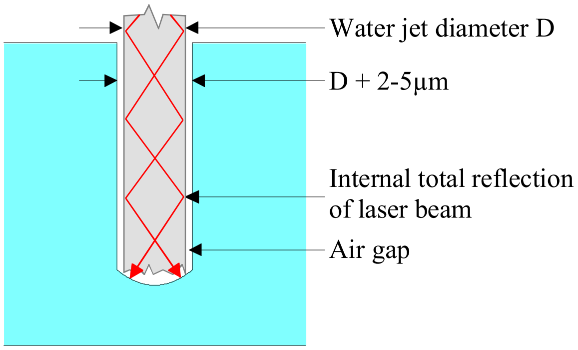

Figure 1 Illustration of the water jet-guided laser material penetration

This extraordinary effect means that cutting thick materials is perfectly possible, maintaining the already added LMJ advantage of perfectly parallel kerfs. The maximum cutting depth is only limited by the size of the jet nozzle, which in turn determines the point at which break-up of the jet occurs (~1000 * D).

The examples given in the following sections cover a broad range of materials, which are now being regularly processed in industry, or are the results of detailed application testing on behalf of external clients.

Semiconductor Applications

An example of the capability of the LMJ is the cutting of Ø100mm 1770µm thick silicon wafer. For a conventional dry laser the material thickness limit is ~200µm, due to diffraction of the beam, which would with thicker material, result in angular kerf walls and a corresponding poor cut quality. Using the LMJ, thick silicon wafer can be processed with excellent results as is documented in Figure 2. For this operation, a pulsed 532nm Q-switched green laser, operating at 22kHz, with an average power of 31W, with the final through cuts made at 35kHz, 33W. The nozzle diameter used was 50µm and the water pressure 200bar. The cuts were made in 24 passes at 120mm/s for the initial cuts and 4 passes at 100mm/s for the finishing cuts. This gives a 257mm/min overall speed for the cutting operation.

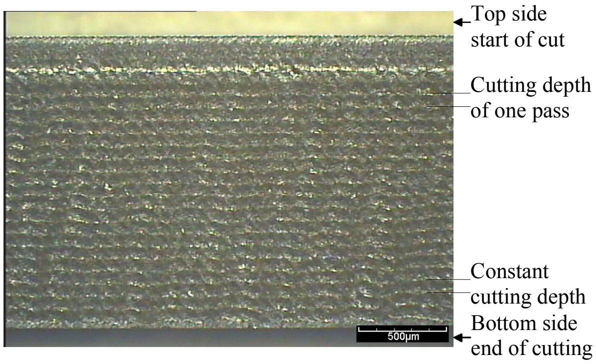

Figure 2 Image of sidewall of 1770µm thick wafer, cutting passes are clearly visible

The ripple in the wall face in Figure 2 amounts to <2µm.

A second example is the cutting of long “comb” like shaped structures from Ø300mm, 250µm thick silicon wafer, as shown in the sample in Figure 3. The cutting consisted of 40*400µm wide and 125mm long “fingers”.

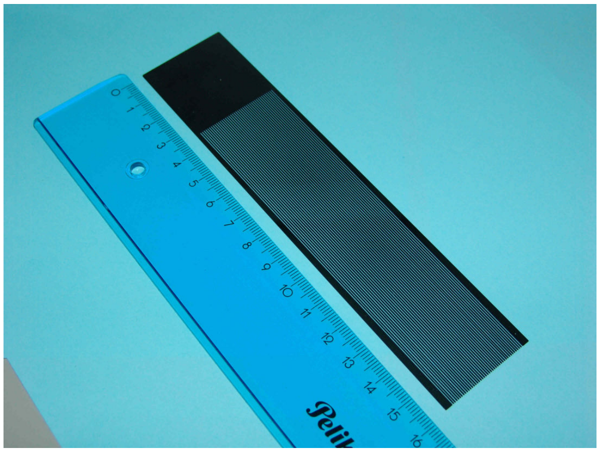

Figure 3 "Comb" structure cut from 250µm silicon wafer

The material was cut using a pulsed 532nm Q-switched green laser, operating at 40kHz, with an average power of 32W. The nozzle diameter used was 50µm and the water pressure 150bar. Each cut was made in 4 passes at 100mm/s.

The quality of the chip free cutting is shown in Figure 4, which shows the “comb finger” tips after separation. The resulting parts exhibited no micro cracking, no thermal deformation and demonstrated high fracture strength.

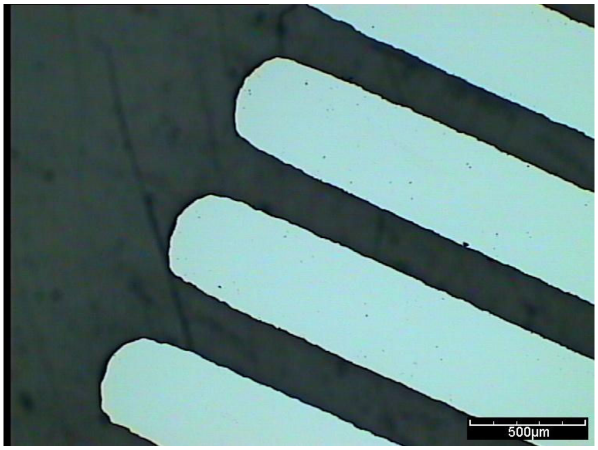

Figure 4 Image of back surface after separation

A final example of the capabilities is the cutting and grinding of 45° chamfered edges on Ø300mm polished (700µm) and ground (830µm) thick silicon wafer.

The following steps were carried out using a pulsed 532nm green laser, operating at 15kHz, with an average power rating of between 7 and 10W. The LMJ was fitted with a 50µm nozzle and the water pressure was 180bar.

The first step is the preparation of the wafer to have sharp edges, by implementing a straight cut in three passes. The grinding operation to produce top and back surface 45°chamfered edges was then carried out as depicted in Figure 5.

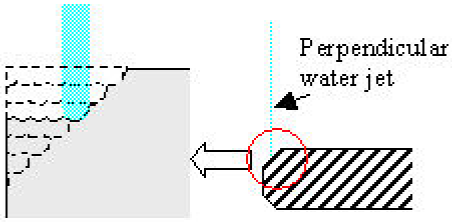

Figure 5 Chamfering in multiple passes

Each layer is removed using a number of adjacent cutting scans with a 20µm overlap, starting at the outside and moving inwards. With optimised parameters, the required different chamfers widths were produced on both sides as listed in Table 1 and shown in Figure 6 and **Figure 7**.

Table 1 Processing times for different chamfer widths

Nr. passes/side	Chamfer width [µm]	Chamfer height [µm]	Total Process time [s]
15	130-135	135	189
66	340	380	829
36	250-275	260	452

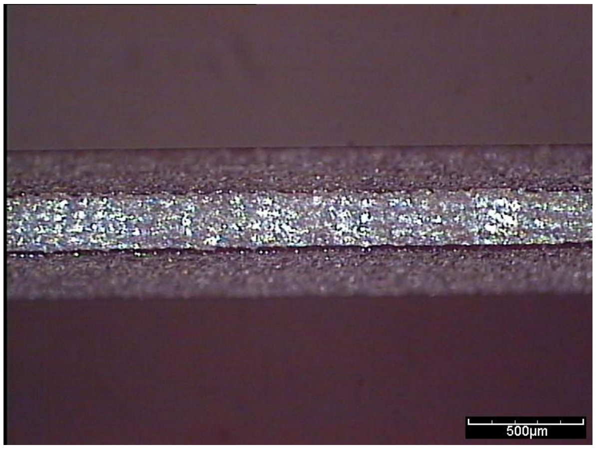

Figure 6 Microscopic image of typical wall cut with chamfers

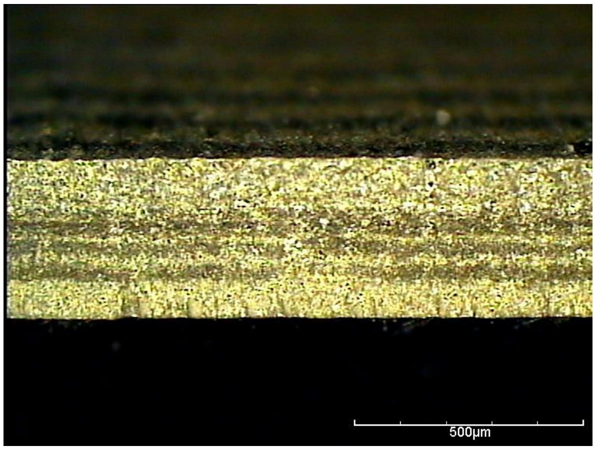

Figure 7 Microscopic image of the chamfer surface

The above examples demonstrate the capabilities of the LMJ, which no conventional dry laser can achieve. With this come the added advantages of little or no post processing, as ablated material is flushed away with the water jet and the protective water film stops any deposition on the material surfaces.

Watch Applications

The hands on today's watch mechanisms, either pure mechanical or battery driven, place demanding requirements on the manufacturers, especially for items destined for the luxury market. Cutting such fine mechanical parts, which are normally made from brass or steel, with conventional dry lasers does not produce good results, due to the resulting heating effects, burrs and deposition of ablated material. These in turn require additional processing steps, before the part can finally be used.

Using the Laser MicroJet$^{®}$ as a cutting tool for watch hands from 200µm brass has been demonstrated, with excellent results. For the tests, a LSS800 stencil cutting machine was employed, using an Nd:YAG 532nm pulsed laser, operating at 15kHz and average power of 40W. The Laser MicroJet$^{®}$ was equipped with a 40µm nozzle, operating with a water pressure of 280bar.

One of the main goals was to demonstrate a high cutting speed and achieve a time of <8 seconds/hand in continuous operation. Figure 8 shows the results of a short sample test run. The following two images, Figure 9 and Figure 10 show magnified views of the watch hand surfaces immediately after cutting.

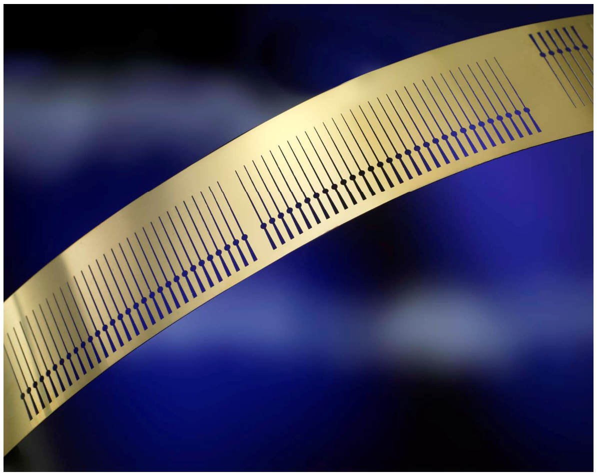

Figure 8 Result of continuous cutting of watch hands

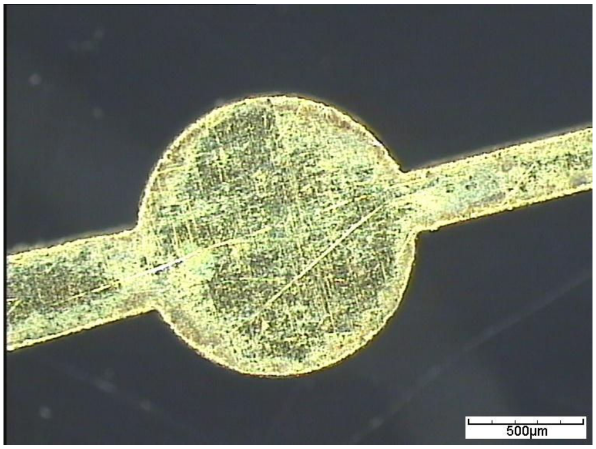

Figure 9 Microscopic image of front side of brass watch hand

Figure 10 Microscopic image of back surface of brass watch hand

Medical Applications

The Laser MicroJet® has also proved itself in the manufacturing of medical devices, especially stents. These devices, which are essential for today's increasing use of non-invasive surgery practices, are used extensively for counteracting localised constrictions in bodily organs, such as arteries which have been cleared after angioplasty. The stent is installed on a balloon catheter in a collapsed state, moved to the affected area and then expanded by inflating the balloon, the stent then locks into place in the artery, forcing it to remain open.

Since the stent will remain inside the human body, and is crucial to the patient's long-term health, the finish is paramount, requiring a high level of quality control during fabrication, i.e., clean smooth surfaces with no attached dross or burrs.

The devices require the cutting out of intricate patterns in the metal sheet or tube to obtain struts, the shape of which together with the type of material employed, determine it's expansion characteristics. The main materials used are flat or tubular stainless steel, titanium, or Nitinol (NiTi) of varying thickness or diameter. Of these three materials, 316L stainless steel, which is non-ferrous, is the most commonly used. For flat sheets, which are later bent to form a tube and welded; the material thickness can vary between 100 and 200µm. For tubular stents, the diameters typically vary from 1 to 5mm and the tube wall thickness from 30 to 600µm.

Conventional cutting using an Nd:YAG laser, characteristically leaves an oxide layer on the surface of the stent, and remelt on the sides of the struts due to diffusion of the laser beam as shown in Figure 11. These unwanted artefacts must then be removed, typically using a closely controlled micro blasting process, to avoid weakening the strut joints, which could subsequently lead to premature device failure. Besides these additional processing steps, other factors such as cutting speed and the degree of automation required, all contribute to a limited throughput in stent production.

Figure 11 Microscopic image of a conventionally cut 316L stainless steel stent, directly after cutting

In comparison, the LMJ provides excellent and fast cutting quality (parallelism and smoothness) and especially no thermal damage. Stent materials exhibit excellent absorption properties at infrared (IR) and so efficient machining with lasers operating at this wavelength is possible. Using a diode pumped pulse 1064nm IR laser operating at 1.5kHz, with 23W average power, and a cutting speed of 9mm/s. The nozzle diameter was 30µm and the water pressure 300bar. A clean, remelt-free cut was achieved and the continuous water jet immediately cools the material. The results are a very narrow burr-free cut, with parallel kerfs, little or no thermal penetration and no oxidation as shown in Figure 12. As no remelt is created during the cutting, micro blasting can be significantly reduced or even eliminated. The LMJ process increases the quality of the manufactured item and removes the danger of stent failure due to weakened struts, eliminating possible future legal liability issues.

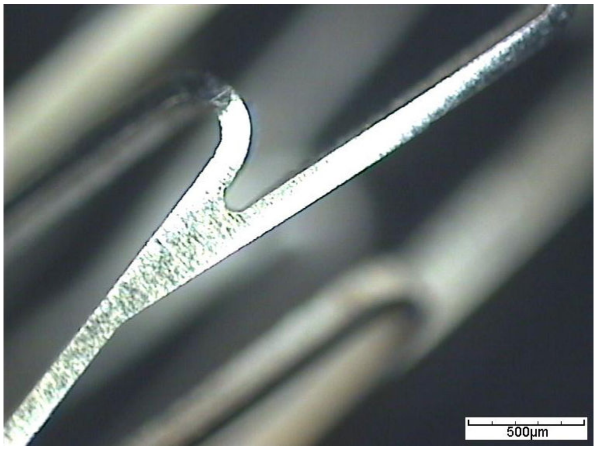

Figure 12 Microscopic image of stent made from 200µm Nitinol directly after LMJ cutting

A further example of medical devices, which can be cut using the LMJ, requiring exceptionally high quality, is for stainless steel tubing used in endoscopy. When cut using conventional dry lasers, the devices require considerable post processing to produce an acceptable finished product. The same devices when cut with the LMJ produce an almost perfect finished product, requiring only a minimum of post process cleaning.

The partial view of the article shown in Figure 13, was cut from Ø5.2mm tubing, wall thickness 350µm, with a pulsed 532nm green laser, operating at 25kHz and an average power of 60W. The jet nozzle diameter was 50µm, water pressure 400bar and the cutting speed 25mm/s. Processing time for the complete part was ~140 seconds.

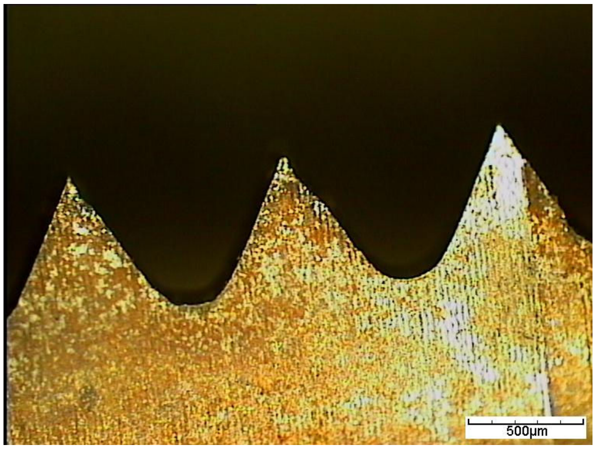

Figure 13 Microscopic image of back surface of Ø5.2mm 316L stainless steel tube directly after LMJ cutting

The apparent discolouring of the material in the above image is from a previously applied protective film, and not as a result of the LMJ cutting process.

Tooling Applications

The machine tool industry is being faced more and more with producing tooling for manufacturing parts made from hard or difficult to process materials. The tools themselves have to be made from super hard materials to ensure an economical lifetime for the part. These tools are now often made from pure Diamond (C) also in it's PolyCrystalline Diamond (PCD) form, cubic Boron Nitride (cBN), or Silicon Nitride (SiN), three of the hardest materials previously known to mankind, only now being overtaken by newly discovered and still exotic materials such as Aggregated Diamond NanoRods (ADNRs) and Ultrahard Fullerite (C_{60}).

The presently accepted machining methods involve the use of lasers, grinding and Electrical Discharge Machining (EDM). All of these methods, however, have their own distinct disadvantages. Dry cut lasers cannot be used to cut thick materials without leaving behind a heat affected zone (HAZ) around the cut area, thereby lowering the quality and usefulness of the finished article. Grinding is an accepted method, but is costly in terms of grinding media, also leaves a damaged area, and is not suited to complex shapes. EDM is a proven method, but will only work with electrically conductive materials, is slow and leaves an oxidised surface at the cut edges.

The Laser MicroJet® offers a tool where the laser beam can cut into, cut through and even cut complex 2-D shapes in ferrous or non-ferrous materials, producing clean perfectly parallel kerf walls, with no burrs, no contaminants, no re-deposition, and is not reliant on electrical conductivity of the work piece. For cutting these hard materials, machine processing tables of 300*300mm are available, with axis speeds of up to 1000mm/s, absolute precision of ±3µm and repeatability of ±1µm.

For cutting complex layered tooling made from CBN/WC material, two recent applications demonstrating the use of the LMJ are described below.

A "Christmas tree" shape was cut from a 5mm WC disk with a 5mm thick CBN insert, using a pulsed dual cavity Q-switched 532nm green laser, operating at 8kHz, with an average power of 140W. An 80µm nozzle used was, with a water pressure of 400bar. The cutting was made at 10mm/s with 220 passes, giving an overall speed of 380s/insert.

A view of the tip of the resulting article top surface is shown in Figure 14.

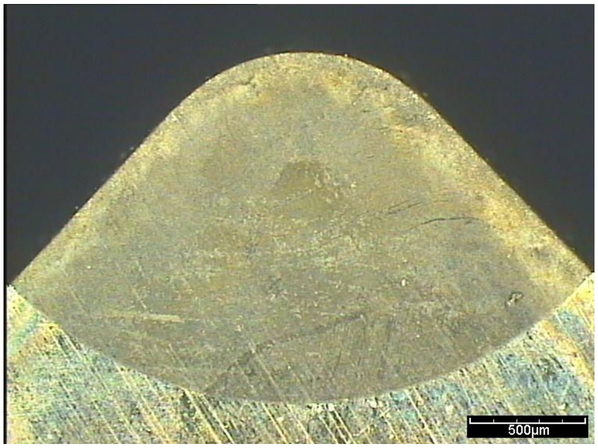

Figure 14 Microscopic view of front side showing the CBN insert

The second example was to make a chamfered cut through a Ø13.4mm cylinder composed of a 1.0 – 1.5mm thick CBN layer on a 6.5 – 7mm WC backing. Cutting parameters were as for the previous example. The cutting speed was 20mm/s requiring 700 passes, giving an overall speed of 600s/insert.

The following Figure 15 depicts the direction of the cut made through the CBN layer into the WC backing material.

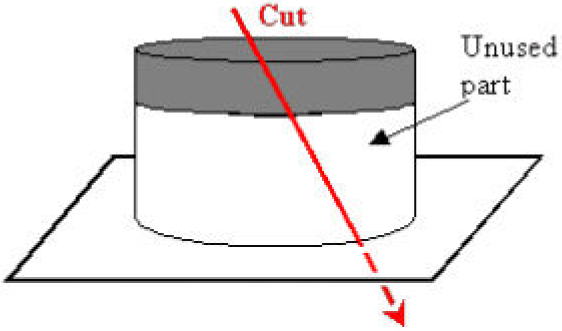

Figure 15 Sketch showing the cutting requirements

The last image, Figure 16, shows the topside surface of the CBN material immediately after cutting.

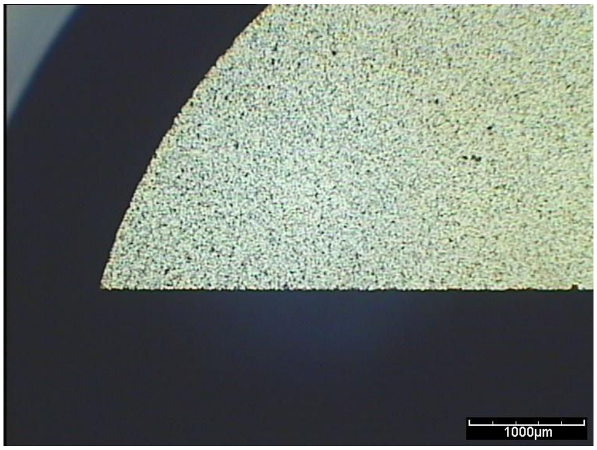

Figure 16 Microscopic image of topside of CBN material

Conclusion

As noted at the beginning of this paper, this series of results is presented to give insight into the potential capabilities of the Laser MicroJet®. The results show that the LMJ is an appropriate machining technology for many material-processing applications. The cuts are clean, reliable, accurate, and show negligible heat damage. In particular, the cutting of complicated shapes such as stents provide excellent results, achieving a consistent pattern transfer. The wide range of materials, suitable for processing with the LMJ, make this tool a worthy challenger to any other form of micromachining.

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Meet the Authors

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Tuan Anh Mai received his Dipl.-Ing. in mechanical engineering at the University of Ilmenau (Germany) and his Dr.-Ing. at the University of Hannover (Germany). Dr. Mai has been working in the field of optics and laser materials processing, especially in developing and customizing laser micromachining processes and systems since 1984. He worked at the Laser Zentrum Hannover and Singapore Institute of Manufacturing Technology as a research scientist and project manager. Before joining Synova in 2005 as an R&D Manager, he worked in the Netherlands for a laser wafer dicing company as Process Development and Application Manager.

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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 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, Ecublens, a Swiss company manufacturing high precision laser machines, which he founded in 1997.

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