ADVANCED SCANNING SOLUTIONS FOR MICROMACHINING

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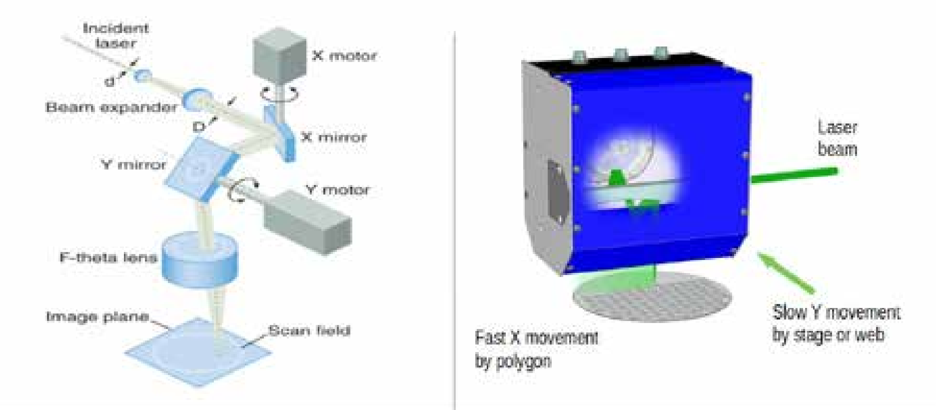
For laser material processing in general, and particularly laser micromachining, achieving maximum throughput with high precision is essential to compete with established techniques such as mechanical milling or drilling, chemical etching or electrical discharge machining. Currently, there are a number of industrial lasers available that provide pulse repetition rates in the megahertz (MHz) range – nanosecond fibre and DPSS lasers along with the latest class of picosecond and femtosecond ultrafast lasers operating at pulse rates of up to 8 MHz.

Unfortunately, with lasers operating close to, or in excess of, one million pulses per second, traditional beam delivery techniques such as a fixed beam with linear stages moving the substrate or 2D-galvanometer beam scanning do not have the velocity to match these pulse rates and the requested precision. Innovative optical technologies like polygon scanning and dynamic 5-axis laser beam deflection allow more efficient and more precise micromachining due to new and optimised overall system solutions.

These holistic solutions and their robust design, with optimal interworking of optics, mechanics, thermal concepts and especially the control of laser beam deflection, offer easy-to-use technologies for industrial applications even in serial production. For large scan fields and highest throughput the polygon technology achieves amazing results. For machining of high aspect ratios (small width at high depth) galvo-based 5-axis micromachining allows dynamic and precise generation of desired shapes, for example negative or zero tapered cross sections of elliptical shaped bore holes.

In this article a new polygon optical scanning system from Next Scan Technology is presented that has proven to operate with all major high pulse rate laser types, along with a highly integrated 5-axis micromachining sub system, named precSYS, from SCANLAB. This is ideally suited for dynamic micromachining of high aspect ratios with defined precision.



Speed	: max 10 - 15 m/s	Speed	: 10 - 100 m/s (constant)
Scan field*	: often limited to 50-80 mm	Scan field*	: up to 300 mm without stitching

* Full telecentric processing

Figure 1: Galvanometer and polygon scanning techniques

Highest speeds with polygon scanning

A rotating polygon mirror spins at a constant speed and writes one line at a time (raster scanning) of a bitmap image, while the substrate is moving underneath the beam. In contrast, two galvanometer axis as commonly found in laser marking systems use two servo controlled mirrors that turn back and forth and can be used in both raster and vector scanning (see Figure 1 left).

Whereas laser scan heads use lenses to focus the beam, the system described here uses exclusively reflective optics. The laser beam is reflected off one of the flat faces of the rotating polygon onto the primary mirror, which in turn reflects the beam onto the secondary mirror that delivers the beam to the substrate (Figure 1 right). Depending on the timing of the laser pulse in relation to the polygon mirror position, the beam can hit the primary mirror anywhere across its face, which determines where along the scan line the laser exposure occurs on the substrate.

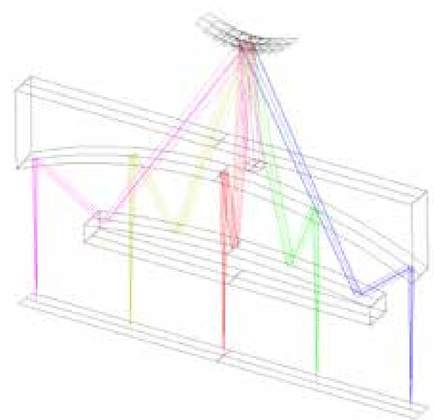


Figure 2: Polygon scanner optical schematic using non-spherical focusing mirrors

The primary and secondary mirrors are non-spherical in design providing diffraction limited performance (see Figure 2). For practical purposes, this optical design permits very small focal spot sizes (down to 5 µm), maintains beam roundness and is fully 'telecentric' where it preserves a perpendicular beam across the entire scan area. Much like the largest telescopes, the non-spherical mirrors are economically scalable compared to glass refractive optics. It is possible to have a 300 mm field of view in the scan direction for large substrates such as a 12 inch semiconductor wafer or web-based processing while still maintaining spot size and beam quality.

One of the advantages of polygon scanners is that they are extremely stable. When simply gating the laser where the laser uses its internal clock frequency, there will always be an uncertainty or timing jitter when the laser pulse is on, in relation to the angle of incidence onto the mirror face. This can result in a one spot radius displacement on target from scan to scan. In applications such as percussion drilling or precision cutting, where many tens if not hundreds of overlapping pulses are required to pierce or mill the material, precise repeatable spot placement is necessary. Here, a 'Master

Controller' reads the encoder to determine the polygon facet location and synchronises the firing of the laser on a pulse by pulse basis

Not all applications are suitable for polygon scanning. In fact, the vast majority are not. As such, they are considered in the industry as a complimentary technology to a 2- or 3- axis galvo-based or a fixed beam approach where they are typically limited to 10 m/s. Polygon scanning provides speeds of up to 100 m/s or more at high accuracy. Polygon scanning is a bitmap or raster scanning option only.

Typical applications for polygon scanners

Although operating in a niche market, polygon scanning is enabling lasers to address large markets in targeted applications. In general, these markets and applications require extremely high throughput, utilising the high pulse rates of the lasers, high accuracy and repeatability whether over small areas such as 50 mm or large areas in excess of 1 metre.

2.5D Surface shaping

There is a great deal of interest in using lasers to modify the surface of a material to change its inherent characteristics (Figure 3), requiring high density laser pulses to be delivered over large areas, e.g. to make a surface hydrophobic on headlights and windshields of automobiles where water sheds off easily. Also, in making high precision tooling for security printing polygon scanners play a role.

Figure 3: Topography of Switzerland (process development and processing by Bern University of Applied Sciences)

Thin film patterning

An ideal application for MHz lasers is patterning the transparent conducting oxide (TCO) on the glass of smart phones, with over 800 million units sold last year. In addition, larger format glass in tablets, computer monitors and televisions are increasingly offered with touch screen capability. Pulse energies of only a few micro-Joules are sufficient, but high write speed is vital to compete with the standard process of using chemical etching.

Polygon percussion hole drilling

With advanced controls on speed and pulse timing, polygon scanning can be applied in percussion hole drilling. The scan rate, ranging from 200 up to 400 lines per second, delivers a percussion drilling-like process by multipass

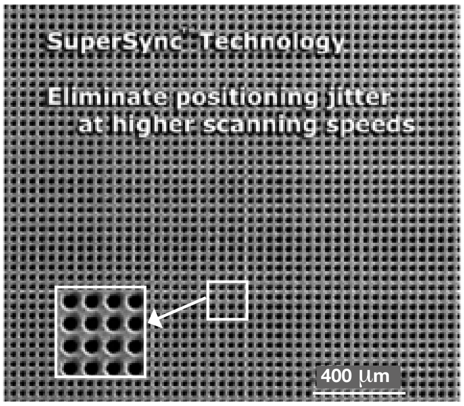


Figure 4: High density hole pattern by SuperSync Technology

operation. With its high spot repeatability thousands of holes per second can be applied challenging legacy processes such as Through Silicon Vias and high density hole patterns for filter applications (Figure 4).

Scribing, grooving and dicing

High precision laser scanning used for high end markings or cutting of brittle materials often requires high pulse overlaps and multiple passes. However, even when using ultrashort pulsed lasers such as pico- and femtoseconds the processed material might receive a damaged surface caused by localised heating. Managing this inter-pulse temperature effect can be solved through an interleave scan strategy.

precSYS: 5-axis scanning sub system

Drilling straight walls with high aspect ratios is not feasible if the laser beam impacts specimens at a normal perpendicular incidence angle. The beam caustic affects hole corners and limits the maximum aspect ratio – that is why 5-axis solutions and process strategies like trepanning or spiral drilling with superimposed non perpendicular attack angle of the laser beam (called precession drilling) are needed. A novel 5-axis technology allows beam inclination and enables straight walls, as well as negatively tapered holes.

The simplified principle of operation is achieved via five galvanometer axes that results in a beam inclination and/or a lateral shift of the beam and/or a shift of the focus position in the z-direction within a range of ±1.0 mm after the focal lens (in the working area). The angle of incidence (maximum AOI ±7.5°) can be adjusted within a 2.5 mm image field for precession processing (Figure 5). The superimposed movements of all five axes (x, y, z, α, β) are factory calibrated at SCANLAB and can be easily programmed in the precSYS' own DrillControl software directly in metric units within precSYS' Cartesian image field coordinate system, which enhances ease of use and repeatability.

Pre-calibration allows defined and precise machining in the whole image field, so it is possible to drill even lateral shifted holes (out

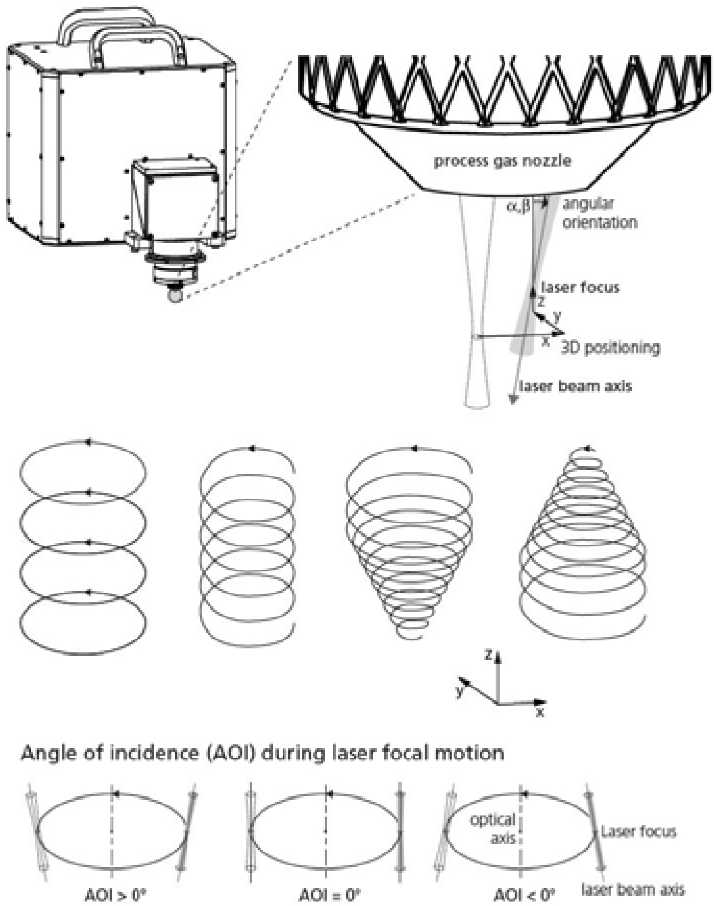


Figure 5: precSYS System design for flexible 5-axis laser processing in the µm range

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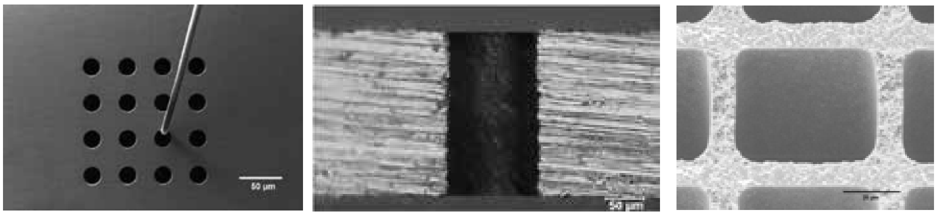

Figure 6 left: array of bore holes machined in the precSYS's image field without xy-stage, middle: cross section of a zero tapered 100-µm bore hole, right: square hole array with aspect ratio 10 (Image, process development and processing by Posalux SA)

of the optical axis) arranged in an array without moving the workpiece (no xy stage is needed).

High-end scan technology with small mirror deviations and low moving masses ensures highly dynamic processing, with precession frequencies up to 500 Hz (30,000 rpm). precSYS is specifically conceived for USP laser precision processing (typically 300 fs – 10 ps / typical laser pulse energy 250 µJ). The system allows highly dynamic and contour-true processing with maximum accuracy. It is constructed to be robust and thermally stable.

The software facilitates management of one or several systems for serial production. The standardised interface for XML data exchange allows straightforward remote connectivity to PLCs, and thus integration into modern automated manufacturing environments. Hence, it is fully open to all requirements of factory automation and modern IoT (Internet of Things) architectures.

5-axis micromachining results

precSYS achieves impressive 3D processing results, with sharp, burr-free and molten-free bore hole entrances and exits. Figure 6 (left) shows an array of 200-µm-bore holes in steel machined in the image field without moving the workpiece. Figure 6 (middle) shows a zero tapered cross section of a 100-µm bore hole in 200-µm steel. This bore hole has been machined with an angle of incidence AOI < 0° (process time 1s). Figure 6 (right) shows a result of a zero tapered square hole array with squares edge length of 50 µm x 50 µm in a 500 µm thick ceramic workpiece. A reproducible and accurate geometry has been machined without destroying previous shape and remaining wall thickness of 10 µm in between of the square holes. Also this array has been machined without an xy-stage. The measured deviation is about 1 µm. Process time per square was less than 15 seconds.

Outlook

To allow the applications of ultrafast laser sources to develop, solutions which combine throughput and precision are most critically important. A lack of suitably fast and accurate scanning heads has limited the deployment of ultrafast lasers to date in large scale production systems.

Using proven engineering concepts of 5-axis galvo-based technology, or polygon scanning systems together with novel all-mirror focusing optics and high speed synchronisation, the solutions described here may unlock the potential for both already-existing sources and new ultrafast pulsed lasers in a range of innovative applications.

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OBSERVATIONS

HIGH POWER MICROPROCESSING USING INNOVATIVE OPTICAL DEVICES

Arnold Gillner

This is a very timely article which deals with current approaches at ILT Fraunhofer to speeding fabrication using high average power ultrafast lasers with ps/fs temporal pulse lengths. Detrimental thermal effects can be minimised with ultrashort pulses provided fluence is limited to a few times ablation threshold while combined with low pulse overlap leading to precision laser machining of solar cells, batteries, injection mould tools and electronic components. However, current systems typically use only 1-10 W average power. Various approaches to increasing throughput with high average powers are discussed and demonstrated.

Firstly, high rep rate, multi-MHz systems are combined with ultrafast beam scanning at speeds >100 m/s using a rotating polygon mirror. This also requires challenging laser beam modulation at several MHz synchronised to the laser cycle and position on the workpiece. Thus, every pulse can be used with low pulse overlap for melt free ablation and high speed, micro-structuring of metals at 1064 nm, with 10 ps pulses is clearly demonstrated.

Secondly, lower repetition rate, high energy systems are combined with a static diffractive optic element (DOE) and galvo scanner for parallel beam micro-structuring at required fluence per beam. The splitting of a laser beam into 196 beamlets was successfully demonstrated in an optical set up and integrated into a laser processing machine. Multi-beam drilling of filter foils and thin film ITO is demonstrated nicely.

Finally, a liquid crystal Spatial Light Modulator (SLM) dynamically addressed with appropriate phase masks can produce a Programmable DOE (50Hz bandwidth) used for dynamic, parallel beam and beam shaping applications. Average powers approaching 100W combined with high peak powers can now be handled, making this approach attractive for the future. I agree whole heartedly that the long-term goal of using multi-hundred-watt ultrafast lasers for large area micro structuring is not far off, making these approaches economically viable.

Walter Perrie, University of Liverpool

GREEN BEATS UV: NEW CUTTING SOLUTIONS FOR DEPANELING & PCB CUTTING

Christian Hahn et al.

It is certainly true that for many precision machining applications, the growth in use of UV lasers has eclipsed green lasers over the past few years. The factors which used to be seen as negatives against UV lasers – crystal lifetimes, regular 'hands-on' intervention for best performance, higher-cost optics and much higher capital cost – have largely been overcome and this has led to massive adoption of UV lasers in markets such as the PCB industry. However, as this article points out, the technical results which can be achieved with modern pulsed green lasers can match those of UV for certain applications so the question is what are the drivers for choosing green vs. UV lasers.

The examples cited in the article do not rely on ultra-high resolution machining and so the larger spot size from green lasers is not such a big problem in the cases presented. The case which is made seems to promote the higher peak power of the BLIZZ 532-30-V as being the factor which allows for efficient results for PCB cutting.