Polygon Laser Scanning

A need for speed in laser processing and micromachining

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Throughput is key to enable the advent of high powered lasers sources. However, their deployment in large scale production is limited by the lack of adequately scaled scanning systems. Based on proven engineering concepts a polygon scanner system has been introduced in the market place. Together with novel all-mirror focusing optics and high speed synchronization features a solution is discussed to unlock the potential for both legacy and ultrafast pulsed lasers in a range of applications.

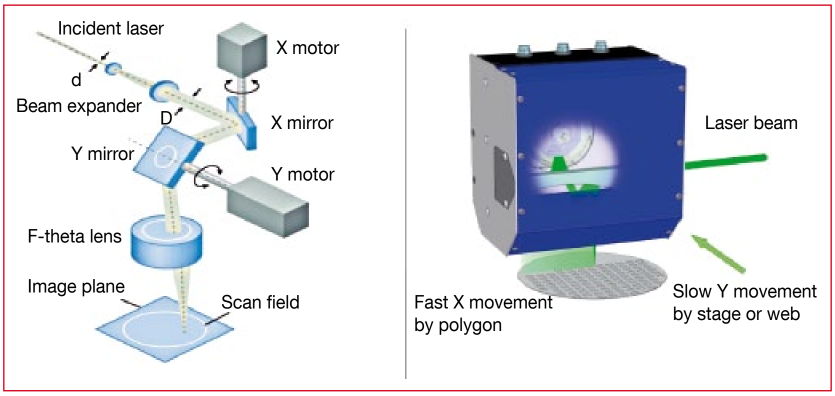

Fig. 1 Galvanometer and polygon scanning techniques.

For laser materials processing in general, and particularly laser micromachining, achieving maximum throughput 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 range – nanosecond fiber 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 at either approaching 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 galvanometer beam scanning do not have the velocity to match these pulse rates. A new polygon optical scanning system has proven to operate with all major high pulse rate laser types commercially available in industrial applications. We will describe the technology, its benefits and limitations and present selected applications.

Polygon scanning

Polygon scanning of laser beams is not new having been introduced in the mid 1970s in the first commercially available laser printers. 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 moved underneath the beam. In contrast, galvanometers as commonly found in laser marking systems use two servo controlled mirrors that 'wobble' back and forth and can be used in both raster and vector scanning (see Fig. 1).

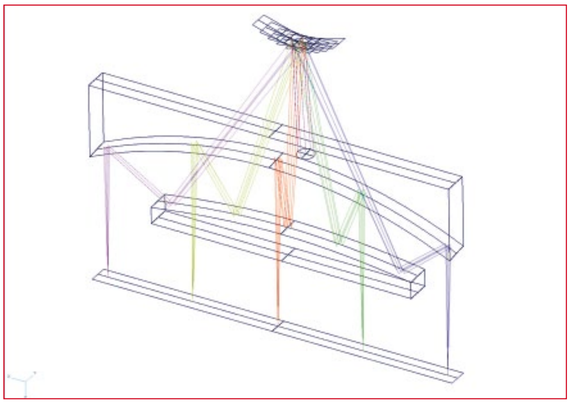

Fig. 2 Polygon scanner optical schematic using non-spherical focusing mirrors.

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 (Fig. 2). 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.

The primary and secondary mirror are non-spherical in design providing diffraction limited performance. Think of it as similar to a Cassagrain telescope in reverse. 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-

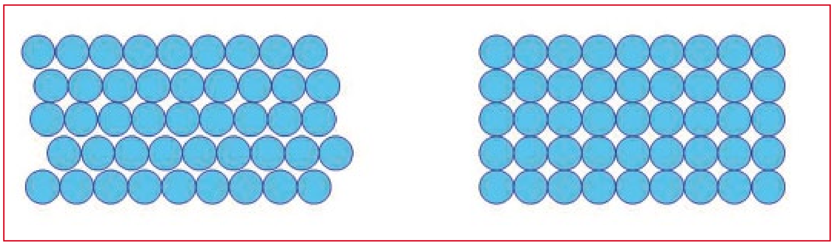

Fig. 3 Left image: No synchronization of laser & polygon; Right image: Synchronized.

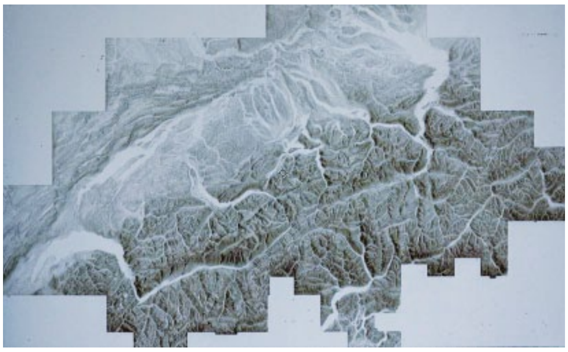

Fig. 4 Topography Switzerland (Process development and processing by Bern University of Applied Sciences – Dr. B. Neuenschwander/B. Jäggi/M. Zimmerman – supported by the FP7 project APPOLO).

based processing while still maintaining spot size and beam quality.

One of the advantages of polygon scanners is once the polygon mirror reaches constant rotational velocity, it is extremely stable. When simply gating the laser where the laser uses its internal clock frequency, there will always exist an uncertainty or timing jitter when the laser pulse is on in relation to the angle of incidence onto the mirror face. This results in approximately a one spot radius displacement on target from scan to scan as shown in Fig. 3a). In some applications, such as scribing or cutting applications, this is insignificant.

However, in applications such as drilling or surface patterning 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 synchronizes the firing of the laser on a pulse by pulse basis, Fig. 3b.

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 galvo-based or a fixed beam approach where they are typically limited to 10 m/s. Polygon scanning however provides speeds of up to 100 m/s and more at high accuracy.

For instance, general laser marking of parts, a galvo with a 30–100 kHz laser covers most all requirements. If on the other hand, you have a high speed line for laser marking or paint stripping as in the aeronautics industry, polygon scanning offers a throughput benefit.

Polygon scanning is a bitmap or raster scanning option only. As such, they are optimal for percussion drilling. However, they do not provide the smooth wall profiles of vector scans for cutting the circumference or trepanning large holes, greater than 50 – 150 µm (depending on wavelength). Picture a hole where there is small a saw-toothed profile on the inner diameter. In some applications where open area is the criteria factor instead of wall smoothness, polygon scanning may be applicable.

Percussion drilling, where the laser beam diameter defines in large part the hole diameter, the hole quality is less dependent on the laser delivery technique. Throughput is defined by the hole density and substrate size. Sparsely placed holes in a large area are best served by galvos. The rule of thumb is if you need to process less than 15 % of the substrate, alternative techniques are typically more cost effective. However, utilizing large field mirror optics can avoid time consuming stitching by traditional glass f-Theta lenses and their limited telecentric field of view.

Applications

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 utilizing 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 meter.

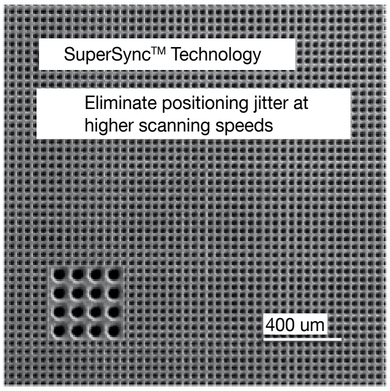

Fig. 5 High density hole pattern by SuperSync™ Technology.

Here are some of the most interesting applications where polygon scanning has enabled laser technology to address industrial applications.

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 requiring high density laser pulses 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. The laser must process 80 % or more of the entire surface requiring high pulse rate and high scan speed. In the example shown in Fig. 4, multi-passes are used where each layer is processed with a different bitmap. Using a 4.1 MHz laser (Time Bandwidth) at a line scan speed of 60 m/s results in a 14.5 µm (1.750 dpi) spot spacing and requires only 24 seconds per layer (dimensions 108 × 65 mm)

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 sold last year. In addition, larger format glass in tablets, computer monitors and televisions are increasingly offered with touch screen capability. Only a single laser pulse per location is required whereby the laser is not machining the TCO layer but attacking the interface of the TCO and glass lifting off the thin film. 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 etch.

Hole drilling

With advanced controls on speed and pulse timing, polygon scanning can be applied in percussion hole drilling. If the laser is set on a 'low' PRR like 200 kHz the scan speed separates the laser pulses fired. The scan rate, ranging from 200 up to 1400 lines per second for the LSE50 (Line Scan Engine by NST), delivers a percussion drilling-like process by multipass 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. An additional benefit is the range of laser sources that can be incorporated from CW and nanosecond pulsed fiber lasers, modulated by NST GateMaster to ultrafast lasers equiped with NST SuperSync Technology.

Scribing, grooving and dicing

For cutting applications, multiple passes are required regardless of galvo or polygon scanning. For a 1 MHz UV laser with a 15 µm spot the minimum resolution is approximately 25 µm to meet the minimum polygon speed of 25 m/s (LSE170) which would result in a spot separation of 10 µm. This simply requires a different way of thinking about how you approach scribing applications.

The beam can be delayed slightly to subsequently fill in the unexposed areas. The more passes to cut through or scribe to a certain depth, homogenizes the exposure across the line such that you can achieve a uniform depth.

Although polygon scanning is not new there is limited information available on material processing efficiency. Research by Dr. Neuenschwander of Bern University of Applied Sciences [1] has proven the importance of dosed pulse energy. Polygon scanning might be an advantage to avoid plasma absorption and localized heating compared to repetitive pulses overlapped along a slower moving line scan. For thin film patterning where a single round pulse can remove the top layer, overlap of pulses is required to avoid scalloped edges. Multipass processing is an acceptable technique without any throughput penalty or compromise in quality.

New developments

September, 2013 saw the kick-off of a new EU consortium, the Appolo Project (www.appolo-fp7.eu) All partners selected a few directions for validation of novel laser technologies, including equipments: the ultra-short pulse laser scribing for monolithic interconnects in CIGS solar cells: from laser to pilot line; use of lasers in smart surface texturing for automotive and printing/decoration industries and for the real-3D flexible electronics.

November, 2013 saw the kick-off of a new EU Consortium, the Ultrafast_Razipol Project (www.razipol.eu) with a first goal of developing a 500 W, 20-40 MHz laser for high speed manufacturing off large area substrates. Polygon scanning will be vital in delivering these high pulse rate laser beams over large areas. When there is a need for speed in laser micromachining, polygon scanning is enabling unprecedented throughput.

[1] *B. Neuenschwander, B. Jaeggi, M. Schmid, V. Rouffiange* and *P.-E. Martin*: Optimization of the volume ablation rate for metals at different laser pulse-durations from ps to fs, Proc. SPIE 8243, Laser Applications in Microelectronic and Optoelectronic Manufacturing (LAMOM) XVII, 824307 (February 9, 2012); DOI:10.1117/12.908583

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Company

Next Scan Technology (NST)

Evergem / Belgium; Silvolde / The Netherlands

Next Scan Technology (NST) was founded in 2010 as a Dutch/Belgium privatly owned company. Based on a 20 year track record in the development of optical scanning devices NST developed a new to the world polygon scanner system including large area optics and advanced control features.

Through a Sales & Marketing office in The Netherlands and R&D/Production plant near Ghent, Belgium NST offers the laser material processing community these high throughput scanning solutions for both legacy and ultrafast lasers. With a steady growing team we provide our global customers in high end manufacturing industries such as semicon, display and medical devices with products and services to leverage throughput and reduce their manufacturing costs in applying small features onto any substrate.

www.nextscantechnology.com

Author

Ronny De Loor, CTO Next Scan Technology, studied electronics at the Ghent University. His first job was with a start-up Belgian company DISC, active in the Graphic Arts industry, where he designed professional laser printer equipment for the printing and printed circuit board industry. With the introduction of many successful laser writing based products DISC became a leading company in the packaging printing market. DISC was acquired by BARCO end of the eighties, and further developed in to a world-wide company with 1800 employees. At BARCO Graphics Mr De Loor later acted as director of hardware engineering and was involved in the development of all the laser writing equipment. On the technical side he focused on the optical designs and (co-) authored several patents in the field of laser writing equipment.
Since 2003 Mr. De Loor started his own engineering company, focusing on product design and projects in the photonics area.
In 2010 he and Lars Penning founded Next Scan Technology with a mission to bring the laser writing know how of the NST team to the laser material processing market.

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