INNOVATION AND TRENDS IN LASER MARKING

Anita Chandran explores the latest challenges facing manufacturers and users of laser marking systems

Since the mid-1960s, lasers have been used for mark-making, etching and cutting. The first laser marker was developed in 1965 with the aim of drilling holes in diamond manufacturing dies, and growth rapidly followed. The early introduction of CO_2 lasers for marking occurred in 1967, with the technology reaching maturity in the mid 1970s through a commercial, modern CO_2 laser system.

Laser marking systems have since gone on to become work horses across a wide range of industries, from aerospace to medical device manufacturing, pharmaceuticals and retail. Despite competing with other technologies, such as inkjet printing, lasers have demonstrated themselves as a robust, low-cost and repeatable mark-making technology. The process is also, importantly, ecologically friendly, requiring no consumables such as ink, cartridges and paper.

Now, laser marking systems no longer solely rely on CO_2 lasers, with other players such as fibre lasers and Nd:YAG solid-state sources providing routes to low-footprint, low-maintenance and highly efficient alternatives. The advancements in technological capabilities are also palpable. The fastest commercial laser markers can now process tens of thousands of parts per hour.

Though the developments in laser marking technology have been vast, manufacturers and users of laser marking systems are now looking for new routes to drive the development of marking technology forward, to combat new challenges and to improve processing outcomes.

Ceramic circuitry

Such challenges are arising from both new materials needing to be processed, as well as new applications needing to be served – each of which drives the need for growth and innovation, while shaping the market for laser systems development.

Ceramic, for example, is one of the fastest-growing materials in the field of laser processing, being vital in semiconductor parts and the manufacture of circuit boards. The printed circuit board (PCB), commonly referred to as the 'mother of electronic system products', is a type of component used in almost every electronic product. Small changes in PCB development have a large influence on market trends.

In recent years, there has been a shift in focus toward using ceramics in traditional printed circuit boards (PCBs), made from plastic epoxies such as FP4. In comparison to non-ceramic PCBs, ceramic circuit boards have excellent thermal handling, are easily implemented, and offer superior performance. However, many marking techniques, such as silk screen processing, are not well-suited for ceramics. Ink-based markings for ceramics are cumbersome, require several consumables and are not robust to wear and tear. The brittleness and hardness of ceramics also make them one of the more difficult materials to be marked.

Lasers have therefore risen as an alternative to ink-based printing techniques in recent years, with many laser firms having developed systems using sources particularly suited to ceramic marking – such as diode-pumped solid-state UV lasers, as well as traditional CO_2 lasers.
"There is definitely a trend towards miniaturisation here," says Andrew May, director of laser marking firm, ES Precision.

> "Another new and exciting area of growth in laser marking is data storage"

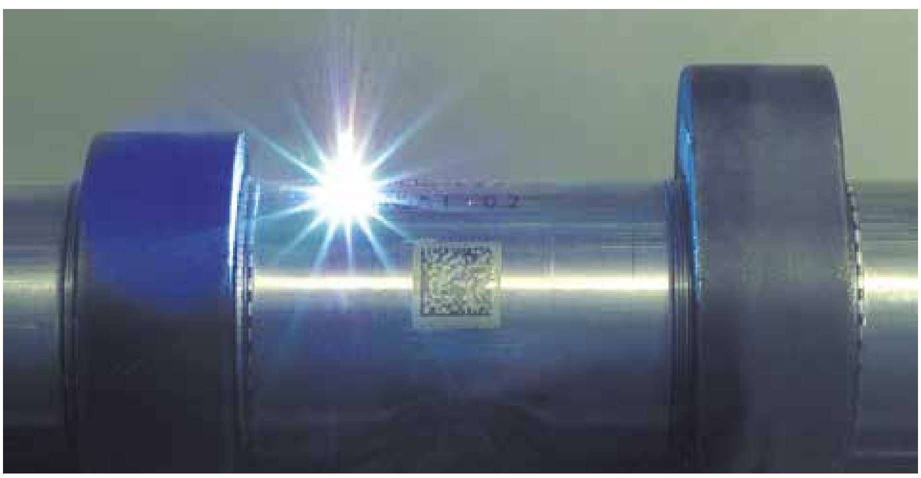
However, he stresses that the introduction of new trends in marking does take time: "Is there a new application week by week? No. But 15 years ago we'd never marked miniature ceramics and now we are."

Flexibility is key

However, despite being fast-growing, ceramic marking in electronics isn't currently ES Precision's largest market.

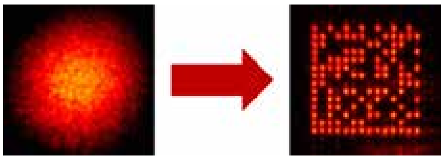
"The biggest industry for us is medical devices," states May, "then automotive, electronics and general engineering components. The sort of products required vary heavily from industry to industry, and the parts of those industries concerned."

The company, which has eight laser systems (five of which are galvo-driven) delivers marking services for a wide range of different application areas. Because of this, and because the company is always obtaining new clients with bespoke needs, May highlights that, for ES Precision, the ability to be flexible is vital.



ES Precision

Permanent laser marks can be made on curved metal surfaces



QiOVA's unique structured beam technology in action, showing a laser beam (left) being turned into a pattern (right) composed of individual beamlets, which can then be used to 'stamp' a data matrix onto a material in an instant

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The lasers it uses are therefore suited to marking varying materials, shapes and sizes, as well as varying batch sizes. The range of marks it can provide is also as diverse as its client base, with its lasers being able to produce everything from codes to graphics and data matrices – all at high speed and with high reproducibility.

Catering for such flexibility is therefore a must for laser marking machine manufacturers such as Bluhm Systeme, which constantly keeps an ear to the market and develops its products accordingly, according to Antoinette Aufdermauer, an editor for the firm.

Its marking systems include gas, fibre and solid-state lasers, including both CO_2 and YAG systems. The laser markers are all pulsed and operate at wavelengths ranging from 0.355μm to 10.6μm. Each laser has its specialty, with some overlap: the CO_2 lasers are useful for marking plastics, rubbers, papers and foils; the fibre lasers offer advantages when marking steel and certain plastics; and the YAG lasers are suited to marking metals and ceramics. "We test all of our customers' materials extensively in our laser laboratory in advance," says Aufdermauer.

Portability is also very important for ensuring flexibility, and is very desirable for industrial customers, according to Aufdermauer. As a result, Bluhm Systeme's newest product, 'Lightworx', features a 20W fibre laser in a compact workstation that can be easily moved in and out of production environments. The system is capable of making 'permanent, pin-sharp and forgery-proof' marks on both metals and plastics.

Rising to the challenges of traceability

Another important trend taking place in the field of laser marking is facilitating traceability – the individual identification of products via unique identifying marks on their surface. Such marks can take many forms, however of increasing popularity and importance is the use of data matrices such as QR codes.

By marking individual products with their own unique data matrix code, it is possible to easily identify key details such as their manufacturer, batch number and lifespan in a non-invasive way. This provides quality assurance: consumers and users can be sure of exactly where a product comes from. This type of quality assurance creates a direct link between consumer and manufacturer, and gives products added value, allowing them to compete with cheaper manufacturing industries.

Due to their incredible precision, lasers are well-suited to writing detailed codes down to 200μm in size – small enough that they can't be seen by someone in passing, but can be easily checked using a smartphone if a person knows their location. At such sizes, data matrices can be used for anti-counterfeiting purposes, making it easy to check the authenticity of a high-quality good in a non-invasive way. This has huge impacts on pharmaceuticals, as a way of ensuring that medicines such as pills are not made and distributed fraudulently.

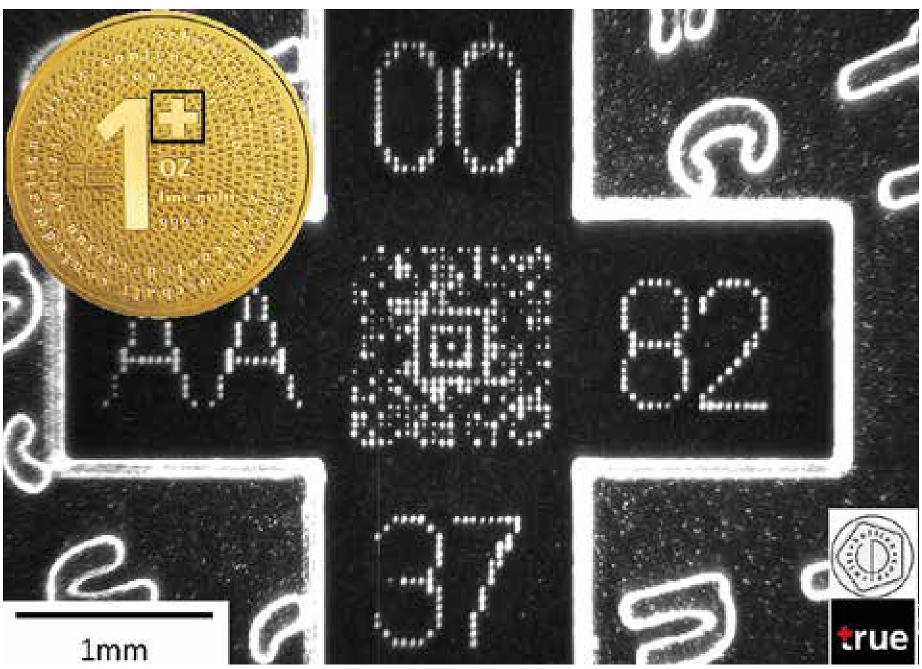
Component traceability also plays an important role in litigation. For example, if someone has a medical transplant, and that transplant fails, traceability gives them the power to know exactly what went wrong, where, and in which batch. This, of course, makes aspects such as product recall more efficient, but also gives more autonomy to customers. It may not be obvious, but as society becomes more interested in litigation, technology capable of facilitating it must also adapt to keep up.

"Standard marking solutions are not able to deliver one specific mark per product"

Traceability also facilitates another trend seen across the manufacturing community: increasing environmental sustainability and reducing ecological impact. By being able to trace a product, learning when it fails, or knowing when it reaches the end of its lifetime, manufacturers are better able to be proactive about replacement and recycling. This also means products can return for refurbishment in a scheduled fashion, and so fewer devices may end up in landfill.

However, there are numerous challenges that face current marking systems for data matrix marking. Certain materials pose difficulties, in particular glasses and polymers, as well as thin metals and foils. Marks also must be permanent and stable, and systems have to be able to adapt to a wide range of product sizes.

For certain laser markers, one challenge in particular is the marking of non-flat surfaces, an area where inkjet printers still routinely outnumber laser-based systems. Consequently, system engineers are working hard to overcome such challenges. Laser marking system manufacturer Laserax, for example, offers CO_2 and fibre lasers – with 20-500W average powers and varying cycle times – equipped with auto-adjusting focusing optics for 3D surfaces that adjust for object curvature. To account for surfaces of unknown geometry, Laserax's systems

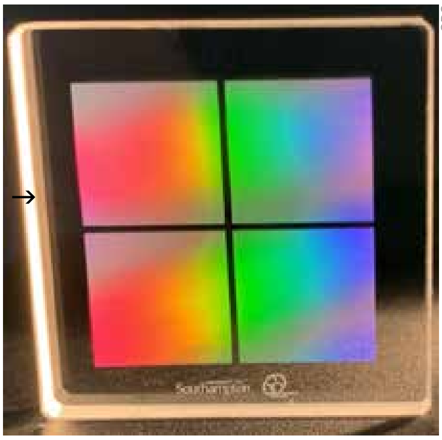


QiOVA

Micromarking on a gold dubloon for anti-counterfeiting purposes, made using QiOVA's structured light beam technology

use an autofocus vision system to first scan a 3D surface, then adjust the laser's focus during marking.

However, non-flat surfaces are not the only challenge facing manufacturers of laser marking systems. "There are many situations where the standard marking solutions globally – inkjet, standard lasers and such – are not able to cope with the needs required to deliver one specific mark per product," explains Dr Florent Thibaut, CEO of laser marking solution manufacturer QiOVA. "At the moment, typically you use a laser like you would use a pen: in a sequential approach. This is not fast enough – we need to find a solution that combines throughput and precision."



ORC

Ultrafast lasers can be used to encode data within silica glass, with a lifetime spanning eons

Sequential marking suffers because the laser mark has to change per product, so having a marking technology that is adaptable on a shot-by-shot basis is vital. Manufacturers require extremely high throughput – the mark must be adapted, and the rate of marking must be high – and this is without even considering the difficulties of machining certain materials, such as glass or polymers.

To address this, QiOVA has patented its VULQ1 technology – which won the Innovation Award for laser systems in industrial production engineering at the Laser World of Photonics this year – that does not use one beam in a sequential approach (as is the case for traditional marking systems). Instead, it uses hundreds of beams to create a stamp-like effect – producing a whole data matrix code in an instant. The method used to generate this unique stamp is dynamic beam shaping, achieved using components such as spatial light modulators (SLMs). The SLMs are able to adjust on a shot-by-shot basis to create a beam with a unique structure.

While other laser marking technologies might prioritise high repetition rate to achieve high-throughput, QiOVA instead uses higher pulse energies and parallel processing to great effect. "Stamp marking unleashes dramatic productivity potential for 2D barcode marking, combined with straightforward implementation," remarked Thibaut. For example, its technology can be used to mark PVC medical parts with 570μm-wide data matrix codes at a rate of 77,000 parts per hour. Other materials the system can mark include: aluminium coated with HDPE polymer; soda-lime glass; borosilicate glass; pure gold; and epoxy moulding compound. "The pattern size can be down to 100μm while conserving perfect readability, even when marking in-line, because all the dots are marked simultaneously," Thibault added. What's more, by not having to rely on high repetition rates, QiOVA can build its systems using off-the-shelf infrared and green Nd:YAG lasers – with repetition rates at around 20-30Hz – ensuring its systems can remain as cost-effective as possible.

Streamlining storage

Another new and exciting area of growth in laser marking is data storage, with researchers claiming they can produce highly efficient data storage systems by using ultrafast lasers to encode data into glass/crystal media. Data is stored in the form of micro ablations within the glass/crystal, which once produced has a staggeringly long lifetime – in the order of the age of the universe.

Hitachi announced its first quartz crystal data storage system in 2013, while in 2014 researchers at the University of Southampton's Optoelectronics Research Centre (ORC) announced their development of a femtosecond laser etched glass system. The ORC has since gone on to work with Microsoft Research on 'Project Silica', which promises zettabyte-level storage systems and a fundamental re-thinking of how large-scale storage systems are built.

However, writing on glass is not trivial, with standard pulsed UV or CO_2 laser systems producing microcracks – excessive heating at the material surface leading to damage at thermal hotspots. While this can be circumvented via reduced pulse energies, this isn't ideal when high levels of precision are required. This is why researchers are turning to ultrafast (femtosecond) laser systems to minimise the risk of thermal damage. The ultrashort duration of the high-energy pulses ensures just enough energy is delivered to the material to mark it with extreme precision, producing only a minimal heat-affected zone that avoids the creation of microcracks.

Currently, however, the limitation of this technique is the rate at which data can be written being extremely low, with the writing of terabytes of data potentially taking years to complete. Thankfully, ongoing breakthroughs are suggesting ways of improving the speed of data writing. Last year, the ORC researchers published in *Optica* an energy-efficient laser writing method that is not only fast, but can also store around 500 terabytes of data on CD-sized silica discs, which would make them 10,000 times denser than Blu-Ray optical disc storage technology (see page 37).

The researchers' new method involves using a 515nm fibre laser with a repetition rate of 10MHz and a pulse duration of 250fs to create tiny pits containing a single nanolamella-like structure in silica glass, measuring just 500 by 50nm. These high-density nanostructures can then be used for long-term optical data storage. The researchers achieved writing speeds of 1,000,000 voxels per second, which is equivalent to recording about 225 kilobytes of data (over 100 pages of text) per second.

The new method was used to write five gigabytes of text data onto a silica glass disc about the size of a conventional compact disc, with nearly 100 per cent readout accuracy. Each voxel contained four bits of information, and every two voxels corresponded to a text character. With the writing density available from the method, the disc would be able to hold 500 terabytes of data. The researchers say that with upgrades to the system that enable parallel writing, it should be feasible to write this amount of data in approximately 60 days.

Dr Anita Chandran is a writer based in Hamburg, Germany. She has a PhD in ultrafast fibre lasers and has worked in historical fiction, science pedagogy and AI ethics. She is also the fiction editor of *Tamarind*, a literary magazine looking at the intersections of the arts and sciences (Twitter: @tamarindlitmag). She has been awarded Imperial College's Sir Arthur Acland Prize for excellence in the humanities and was named overall winner of the Royal College of Science's 2019 writing challenge for her short story (Nothing but) Art.