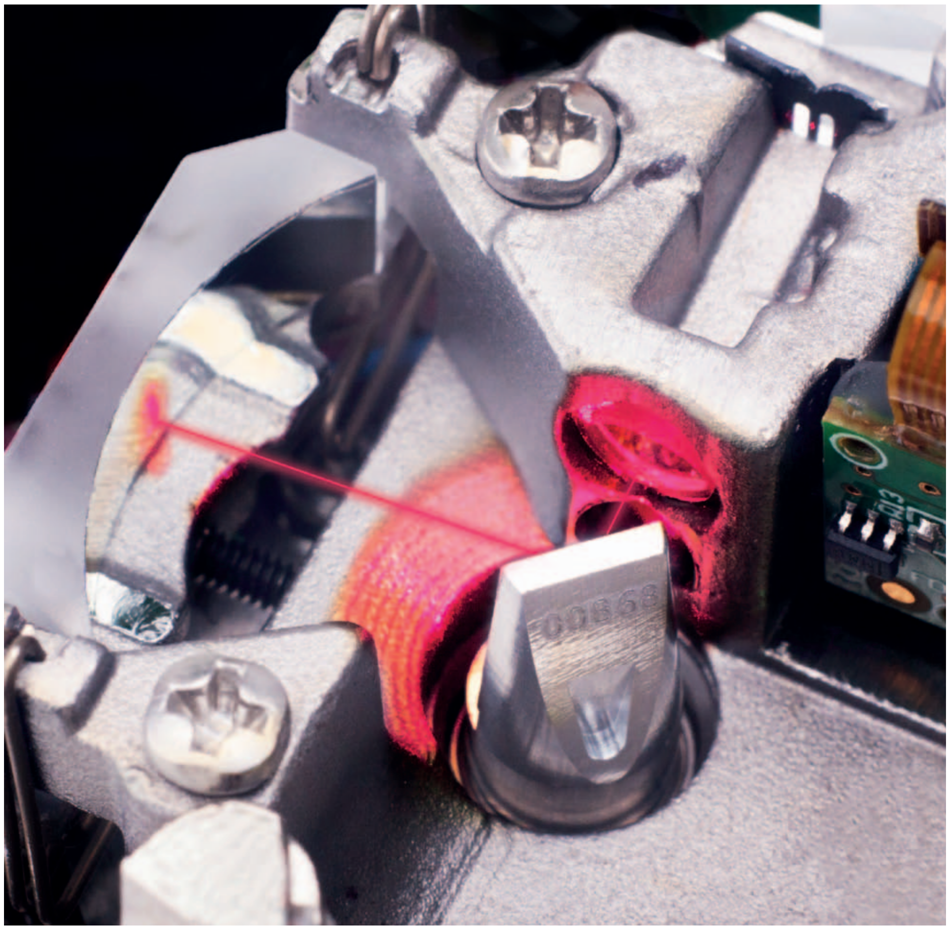
ALL IN THE DELIVERY

With new fibre delivery options now available, along with advances in scanning solutions, ultrafast lasers are becoming a much more practical tool for industrial machining, as **Rachel Berkowitz** discovers


Scanlab

Scanlab's digital encoder technology in a galvanometer scanner, enabling it to meet future market needs

Ultrashort pulsed lasers are now an established industrial machining tool, but delivering such picosecond and femtosecond pulses of light to the workpiece can still present challenges. By moving away from solid-core fibres and toward hollow-core fibres for beam delivery, updating tried-and-true techniques for scanning the beam onto the target, and developing lenses that focus faster than ever before, technology is meeting these challenges.

An alternative to solid-core

More than 75 per cent of macro laser applications employ beam delivery methods using solid-core fibres. That's because they're straightforward to integrate with existing systems for companies using YAG, diode, disk and fibre laser beams in applications such as cutting or welding.

But while solid-core fibre optics have become the norm for lasers that pulse at nanosecond timescales, they're not suitable for delivering high power lasers that pulse at picosecond to femtosecond timescales. 'This is now changing with the availability of so-called anti-resonant fibres,' said Duncan Hand, professor of applied photonics at Heriot-Watt University in Edinburgh, Scotland.

Anti-resonant fibres have a hollow core and allow the delivery of much higher peak powers than earlier designs. They can deliver 100W average power and high energy (>100μJ) picosecond pulses. Current research focuses on evaluating whether different designs are truly single mode or have some level of guidance for other modes, and on understanding how this might affect transmission efficiency and bend sensitivity.

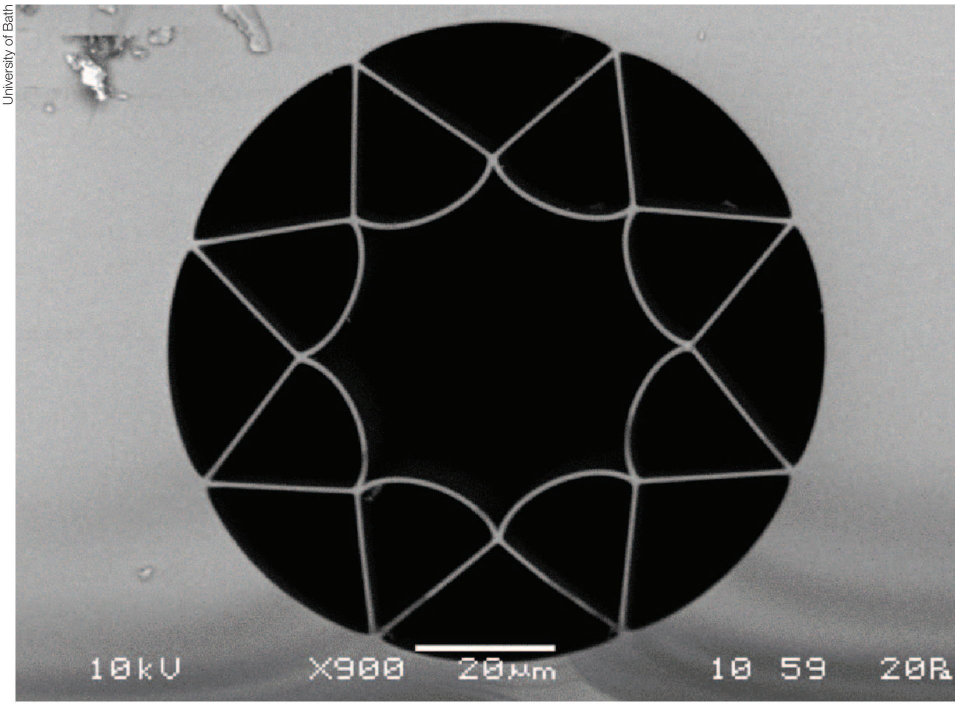
Hand is optimistic about this technology's future. 'Fibres for single-mode delivery of high power, ultrashort pulses are becoming available commercially, and so I would expect these to become standard in the next few years.'

Commercial hollow-core fibres

Solid-core fibres are plagued by beam dispersal and damaged fibre materials when used to deliver high-power laser light. To address these issues, Germany-based Photonic Tools has introduced a fibre with a hollow core through which to guide the beam. This means the light travels through 'nothing', a vacuum.

'It's possible to deliver ultrafast lasers in free space, but it's more complicated to maintain and to service. And you have stability issues,' said Bjorn Wedel, Photonic Tools co-founder. Typically, ultrafast lasers have been guided by complicated optical systems that must be assembled piece by piece. Hollow fibres offer a free-space solution within a stable, sheltered cable.

Guiding the beam through a hollow region at the fibre's centre results in a flexible medium with minimal dispersion, reduced nonlinearity, and less laser-induced damage. To make this work,



University of Bath

An SEM image of an anti-resonant fibre made by the University of Bath. The parts that appear black are air, and the rest is glass. The core guiding region is in the centre. The curved 'walls' surrounding the core are less than 1µm thick

the fibre's Eigenmode has to match the fundamental mode of the laser beam. Therefore, a single mode beam can be maintained over a fibre's length, while higher order modes are suppressed.

Wedel explains that 'using the optical fibre output, people have a perfect reference for the laser beam'. Photonic Tools offers a product that includes a beam launching system, easily adaptable to any laser source, fibre type, and processing head. 'If you deal with ultrafast components, you have to pay more attention to preserving all parameters of the beam. This must be engineered into the processing head as well.'

Clients can therefore use the technology to integrate any kind of laser within their machining, welding, or micromachining system. New interface software will allow for greater ease in using hollow fibres for a variety of applications.

'We look forward to introducing this technology to a wide laser manufacturing base,' Wedel concludes.

Integrated ultrafast systems

In France, Amplitude Systèmes offers a fully coupled ultrafast laser with hollow core fibre output, which can be directly integrated in a micromachining station and coupled to a scanner. 'Imagine that, until now, when machine manufacturers wanted to integrate an ultrafast laser, had they been using a standard fibre laser, they would have had to redesign the machine completely to integrate free-space optics,' said Vincent Rouffiange, vice president of sales. 'Free space optics would be a nightmare, in terms of design, for a scanning head installed on a rotating axis.'

With fibre delivery, design is simplified and there's no need for cleaning optics or a covered beam path. A scanning system can be mounted on a rotation or translation axis; and the laser itself can sit outside of the machine, if so desired.

'Fibre delivery in ultrafast is a real revolution. It can open new machine design and new applications, for example, using an ultrafast laser with a robot.' Rouffiange tells of one company with a machine designed for a CW fibre laser. This company had a request from a customer to integrate an ultrafast laser in order to achieve better ablation quality, reduce the heat affected zone, and increase accuracy. This company purchased Amplitude's Satsuma fibre-coupled solution, removed the old connector, and their customer was set to go.

> **"I would expect these [fibres for ultrashort pulse delivery] to become standard in the next few years"**

Faster scanners

Ultrashort pulsed lasers make possible applications unfeasible with longer pulses, providing high precision in micromachining. Here, ultrafast lasers remove a small quantity of material per pulse. To achieve industrial-scale throughput, scanners that deflect and position the beam need to work at high rates. Hence, it's also essential to have very high speed beam scanning to prevent damage from thermal effects.

Galvanometer or 'galvo' scanners have long been the primary scanning tool. They use one or more reciprocating (elements move back and forth to drive motion) servo-controlled galvo motors with mounted mirrors to deflect and position a beam. But they can't keep up with more powerful and faster-pulsed lasers. The alternative is polygon scanners, which use a multifaceted or polygon mirror to deflect the beam to its target. Polygon scanners operate at a fast, constant speed, as opposed to a galvo's reciprocating motion and its non-linear effects on position. They can achieve scan speeds an order of magnitude greater than traditional galvo scanners.

Lightweight mirrors help to increase speed in modern galvo scanners, but offer minimal heat sinking, creating problems for high-power lasers. Another issue is that galvo scanners use an analogue or digital encoder to determine mirror position. However, flexing of the motor shaft and mirror, when scanning at high speed, causes the mirror to point in a different direction from that indicated by the encoder.

In contrast, polygon scanners do not use encoders to determine mirror position. Rather, a 'start of scan' detector triggers a timer when the beam approaches the target. Since the polygon rotates at a constant speed, beam location is determined by elapsed time, with a new timer triggered for each passing facet of the rotating polygon. The mirror's hefty mass helps maintain speed stability, while serving as a heat sink and improving the laser damage threshold.

Polygon scanning technology was originally investigated by Xerox in the mid-1970s. The company needed to scan a line very rapidly, and so became Lincoln Laser's first customer for polygon scanners, which became commonplace in laser printers. While polygon scanners for laser printers don't need to be able to handle high energy beams, the technology is still a possible option for the higher powers found in materials processing.

'Polygon scanners are for brighter beams,' says George Helser, president of Precision Laser Scanning in Arizona. That includes high power lasers that need to scan rapidly to avoid thermal damage to the target, such as drilling holes in a thin film while removing minimal material.

Helser points out that materials processing system engineers might be aware of polygon scanners, but not how to implement them. When making the transition from galvo to polygon, his

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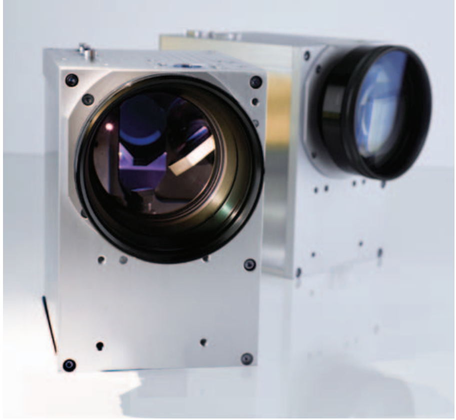

The IntelliScan III 20 is ideally suited for a wide range of large-image field applications

company guides the client in choosing components such as beam expanders and shapers that alter the beam for particular applications.

Traditional markets for polygon scanners have included lithography and lidar mapping systems, as well as confocal microscopes that illuminate one spot at a time, rather than a whole field, thus requiring the illuminated spot to move quickly. But the need for faster scanning in material processing drives today's market.

Syncing ultrafast lasers with polygon scanners can be challenging, as the polygon and the laser compete to serve as the master clock. Higher internal laser clock rates help this situation. 'People are using polygon scanners with ultrafast lasers, but many more will benefit from polygon speed when they understand how to implement it,' explained Helser.

Real-time, active stabilisation devices, such as those from MRC Systems that combine a fast closed loop controller with beam position detectors and piezo-driven mirror actuators, can also be necessary to minimise undesired beam fluctuations caused by vibrations, moving optics or thermal drift. These devices are designed to give greater accuracy and more reliable beam delivery in precise laser processing.

Modern scanners for new applications

Despite the advent of polygon scanning and ultrafast lasers, Germany-based Scanlab sees galvo scanners as their basic technology to meet current and future market needs, according to business development manager, Holger Schlueter.

Modern digital optical encoder technology allows galvo scanners to operate more accurately at higher speeds, by converting motion into digital pulses used for position measurements. An innovation by Scanlab lets them remove inertia-increasing components, improving dynamic performance for a galvo scanner that relies on this kind of feedback mechanism.

Scanlab's IntelliScan series brings this advantage to customers requiring scanners that don't drift. Their encoder makes the scanner ideal not only for micromachining, but also for industrial 3D printing, where a laser beam has to deflect rapidly onto the workspace for jobs such as hardening powder into a desired shape. This technology is becoming increasingly favoured in micromachining because of high accuracy and throughput, but also for a growing market in 3D printing, which requires long-term stability.

Scanlab's head of product management, Michael Breit, is also optimistic about the future of their product: 'There's a huge trend toward higher throughput and increasing the field of view to print larger parts.' This requires multiple scanners to operate together, and therefore an intelligent calibration procedure to match the scan fields perfectly. This will be key to bringing the technology into widespread industrial use.

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Still, system designs push the limits of scanner speeds, largely because of the high repetition rates of ultrafast, and power capabilities in areas such as micromachining. To increase speed, Scanlab uses a forward-looking servo algorithm called ScanAhead, implemented in the ExcelliScan scan head and RTC 6 control board. 'We're free of tracking error with this system; what you see is what you get,' added Schlueter.

Now, Scanlab is increasing its stake in the polygon scanner market by acquiring Next Scan Technology. This Dutch/Belgian company has made a name for itself as manufacturer of the Line Scan Engine product family. The two firms together create a team with complementary system approaches to ultrashort pulsed laser processing.

Focus on speed

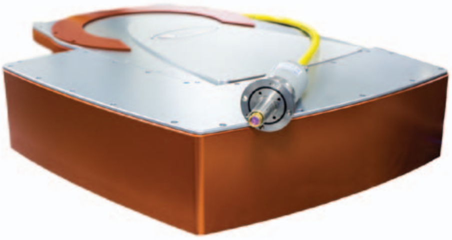
Galvo and polygon scanners position laser beams more accurately and faster than ever before. 'These allow you to move a beam in X and Y space, but to deal with Z, you have to deal with focus,' explained Craig Arnold, co-founder of New Jersey-based Tag Optics. That involves integrating a lens upstream of the scan head, to focus the beam as it moves across its target. Tag Optics develops custom lenses to meet the challenge of focusing the beam fast enough to keep pace with its X and Y movement.

Using a speaker, the company's computer-controlled adaptive optics system generates sound waves from 50kHz to more than 750kHz to induce density variations and therefore refractive index changes in a liquid, thereby changing the focus of the lens. That leads to a tuneable, liquid-based lens, whose focus can be changed on a sub-microsecond timescale.

'The main differentiating factors that our lens has over other liquid lenses or tuneable lenses is speed and optical quality,' said co-founder Christian Theriault. And it's no problem to integrate with an ultrafast-pulsed laser, as long as power density remains under 100W/cm^2. That makes Tag's adaptive lens suitable for marking, small-scale cutting, and welding, in markets that include computer chips, silicon wafers, and glass etching.

As lasers make their way into every manufacturing application from fabric to car parts, technologies are limited by how fast the beam can move. Along with speed comes the need for accuracy: it's difficult to ensure that the beam is positioned precisely in systems based on mechanical moving parts.

Theriault points out that 'you can't break Newton's laws of physics. An object in motion keeps wanting to move: the faster something moves, the harder it is to stop at a precise location.' With no mechanical parts, Tag's lens makes sure that the laser will be focused continuously throughout the Z range.



Amplitude Systèmes

Ultrafast laser with hollow-core fibre delivery

Innovation driven by power and pulse rate

Future industrial applications will require even higher scanning speeds than are currently available. These needs will drive innovation for yet higher power lasers with higher pulse rates.

Current research looks for ways to synchronise fast laser pulses with polygon mirrors in scanning systems. And specially designed coatings for optical components can play an important role in increasing power delivery.

Perhaps most important, however, is visionary work to convince customers that new technologies are accessible. Speed, precision, and accessibility will all play important roles in future beam delivery systems.