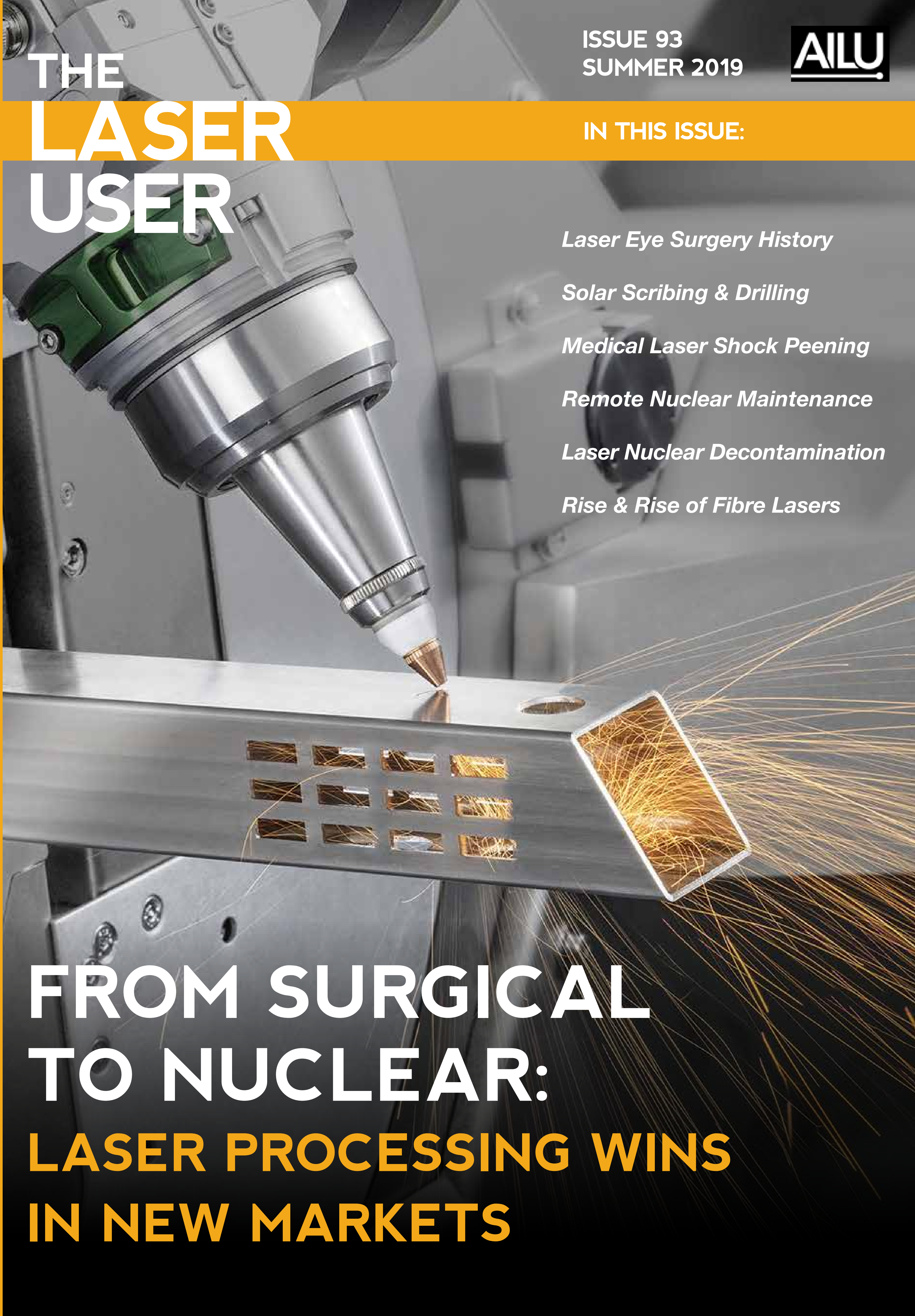
ISSUE 93
SUMMER 2019

AILU

THE LASER USER



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FROM SURGICAL TO NUCLEAR: LASER PROCESSING WINS IN NEW MARKETS

THE LASER USER

Editor: Dave MacLellan
Sub-Editor: Catherine Rose

ISSN 1755-5140

The Laser User is the house magazine of the Association of Industrial Laser Users. Its primary aim is to disseminate technical information and to present the views of its members. The views and opinions expressed in this magazine belong to the authors and do not necessarily reflect those of AILU.

The Editor reserves the right to edit any submissions for space and other considerations.

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WELCOME TO NEW AILU MEMBERS

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KTN
Matthew Wasley
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Cover image: BLM's LT7 fibre laser system designed for the processing of tube, whether round, square or open profile.

Courtesy of BLM

AILU STEERING COMMITTEE 2019-20

President:	Jon Blackburn (TWI)
Vice President:	Adam Clare (University of Nottingham)
Exec. Director:	Dave MacLellan (Anode Marketing)

Elected until 2022

Richard Carter	(Heriot-Watt University)
Hollie Denney	(II-VI)
Matthew Wasley	(Knowledge Transfer Network)

Elected until 2021

Derrick Jepson	(Aerotech)
Arina Mohammed	(University of Hull)
Krste Pangovski	(University of Cambridge)
Mark Thompson	(IPG Photonics)

Elected until 2020

Shireen Khanum	(GF Machining)
Anke Lohmann	(Anchored In Ltd)
Mike Poulter	(SPI Lasers)

Co-opted

Jonathan Lawrence	(Coventry University)
Mark Millar	(Essex Laser)
Tony Jones	(Cyan Tec Systems)

Past presidents and founder members are also able to attend committee meetings. Anyone wishing to join the AILU Steering Committee please contact the Executive Director.

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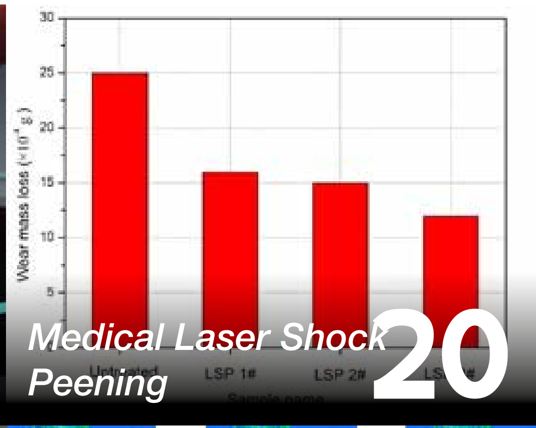

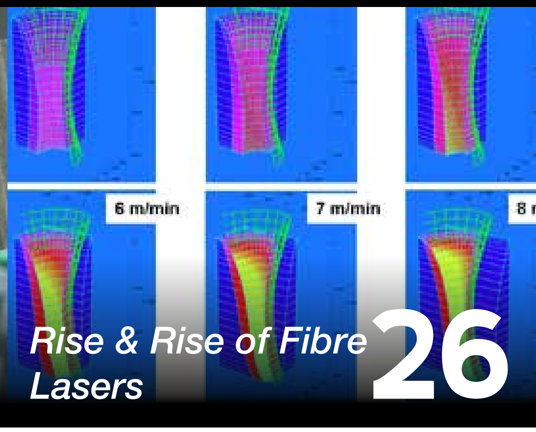

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ASSOCIATION NEWS

FIRST WORD

This year we are stepping up our profile at Advanced Engineering 2019. I have supported this show for the past few years with AILU. If I had to sum up, what I like about it is that it bucks the trend of UK trade shows. It gets three things right in my view.

Firstly, it is short – keeping it to 2 days means exhibitors and visitors are pushed together in a busy and buzzing show. Most 5-day shows are topped and tailed with low attendance.

Secondly, it attracts the right kind of audience: buyers, manufacturing engineers, business owners and decision makers. Too many shows are filled with people trying to sell to the exhibitors and not buy from them, not this one.

Finally, it works closely with Trade Associations, pulling groups of similar companies onto zones or hubs which help visitors navigate the show. Although we have had a Laser Manufacturing Hub for several years now, this year we are offering "pods" so our members can "turn up and go" at the heart of the hub and next to a sizable networking area. This is an efficient way of "doing" exhibitions and is very small-business friendly.

If you need to book a stand or a "pod" act fast – the show is at the NEC from 30-31 October and promises to be another great event. There is more information elsewhere in this issue.

Dave MacLellan
dave@ailu.org.uk

PRESIDENT'S MESSAGE

AILU is an organisation I first became aware of around the mid 2000s, when I was a Research Engineer with the University of Manchester, based at TWI, Cambridge. Paul Hilton and Lin Li, both former AILU Presidents, encouraged my involvement, and I've been an active member of the Steering Committee since 2013. It still feels a bit surreal to be AILU President. This despite being the Vice President for the past two years, and the AILU tradition of the Vice President succeeding the President. May need to work on my listening skills.

When describing the role to colleagues, I flippantly describe it as 'Chief Volunteer', but the reality is very different. The role is an opportunity to provide leadership to the Association, which in turn represents a large, diverse and successful industry sector. Lin has provided a great example of how this can be done, working with Dave, Liz and Cath in the AILU office to ensure a successful two years under his leadership. With the support of Adam Clare (AILU's Vice President), the Steering Committee Members, and the Early Career Researchers Committee, I'm confident this success can continue.

The overall ambition over the next two years is simply to provide further benefits to AILU members. With this, AILU should continue to prosper, and become increasingly recognised nationally and internationally for its sector building activities. Key goals relate to the new website to improve member engagement, collaboration with other associations (UK and overseas), and initiatives which will support AILU accessing grant funding opportunities to increase its activities. Feedback on other activities/initiatives we should be considering is most welcome.

AILU has a busy few months coming up, organising a workshop on Advanced Laser Fabrication in the Transportation Sector (Belfast 19/09/19), the Annual Job Shop Business Meeting (Oxford 03/10/19) and hosting the Laser Hub at the Advanced Engineering show (NEC 30-31/10/19).

Things move on apace in 2020 - it's AILU's 25th Anniversary which will be celebrated at a special conference, ILAS 2020, held in Daventry on 20th and 21st May. The programme will follow the normal ILAS format and include contributions by special guests who have played key roles in the formation and development of AILU over the years. It promises to be a fantastic event so put it in your diaries!

Jon Blackburn
jon.blackburn@twi.co.uk

RIC'S RAMBLINGS

One small step for man, one more amazing application for laser technology…

Dear Readers, as I write this we are 50 years and one day away from the moment Neil Armstrong and Buzz Aldrin stood on the moon for the very first time. I am old enough to have been placed in front of a TV screen at that moment, but not quite old enough to remember what I saw! What an incredible feat of engineering, science, technology and human endeavour. Mind blowing really when you think about it. But for me, what is really cool about the whole thing is that part of the precious payload that went with them was a set of optics (corner-cube reflectors) that were subsequently set-up on the moon so that we could fire a laser beam up and very accurately measure and monitor the earth-moon distance – something we still do today.

The laser, with its ability to remain tightly collimated was the obvious choice of instrument of course. Even so, the beam typically spreads to about 7 km in diameter at the moon and on to 20 km by the time it gets back to earth – so very weak signals. However using this system we are able to measure the earth-moon distance (some 385,000 km on average) to an accuracy of 3 cm or so – pretty impressive stuff. We also now know that the moon is receding from the earth at a rate of 3.8 cm per year – interesting to think of the consequences of that!

All this got me thinking about the other uses of lasers in and for space exploration and earth observation - spectroscopy, communications, data transfer, environmental and remote sensing, maybe space debris mitigation (if you have a big enough laser), gravity wave detection and even good old photon thrusters – ok Laser Propulsion Systems to give them the official non-Star Trek name.

But you know for me the really important message behind the moon landing is that if we as humankind set our minds on solving a challenge, we can. Kennedy said that by the end of the 1960s we would put a human on the moon, and we did. This took enormous quantities of money and highly skilled resources, but it happened and the challenge was met and solved. That makes me feel good for the future and some of the huge challenges we all face on this planet – we have shown that where there is a will there is a way –so let's get on and get solving.

Ric Allott *ric.allott@stfc.ac.uk*

LASERMET TO SUPPLY JAGUAR LAND ROVER

Lasermet has been selected as the supplier of new laser safety enclosures to be used by Jaguar Land Rover as part of its UK investment in manufacturing new vehicles.

Lasermet manufactures its laser safety enclosures at its plant in Haydock. These form an integral part of the laser protection environment designed to keep workers safe from the potentially harmful effects of exposure to laser radiation. Looking after the health and safety of its workers is paramount for Jaguar Land Rover especially when working with high powered welding lasers.

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ROFIN-SINAR UK REBRANDS AS LUXINAR

Rofin-Sinar UK has rebranded as Luxinar, marking a new chapter in the company's 20-year history.

The move will allow the company to further strengthen its portfolio of market leading sealed CO_2 lasers and new, cutting-edge femtosecond lasers, as well as maintain the company's growth which has gone from strength to strength in recent years.

Continuing to operate from its purpose-built manufacturing facility in Kingston upon Hull, UK, Luxinar employs more than 180 people – both in the UK and overseas, with operations in China, South Korea, Germany, Italy and the USA.

Contact: Joanna Houldridge
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ES PRECISION WIN HEALTHCARE AWARD

ES Precision won the Medilink UK Healthcare Business Awards Engineering Award for the ingenuity of their CO_2 laser perforating process.

This process contributes to a better, more comfortable experience for amputees when wearing artificial limbs. Judges identified an impressive use of a specialist manufacturing technique to improve patient comfort and recognised that the company has developed an efficient and effective way of manufacturing prosthetic silicone inserts by laser drilling.

ES Precision Team with award presenter Adam Kay, author of 'This is Going to Hurt'

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AILU MEMBERS JOINS FORCES ON ADDITIVE MANUFACTURING PROJECT

The NEWAM (New Wire Additive Manufacturing) project builds on and exploits the UK's substantial lead in wire-based directed energy deposition (DED) technology, with a vision to transform large-area metal additive manufacture, by pioneering new high build-rate wire based processes with greater precision of shape and microstructure.

Cranfield University, the lead university in the project consortium, has joined forces with other AILU members - the University of Manchester and Coventry University - and Strathclyde University to deliver this ambitious research program over a five year period.

SPI Lasers are supporting Cranfield University with their first placement of a 10 kW QUBE CW Fiber Laser. The flexibility of the laser for use in the project is enhanced through the use of an integrated 4-way beam switch unit and by having beam delivery fibres of 150 μm, 200 μm and 400 μm core diameter. To further enhance the capability of the laser processing cell at Cranfield University, two further QUBE Cabinet lasers, each of 6 kW output power and with 100 μm delivery fibres are also part of this project.

Professor Stewart Williams, the Principle Investigator on the NEWAM Program Grant, commented,'We are delighted to continue our long established collaboration with SPI Lasers through the NEWAM project. NEWAM is fundamentally based around high power fibre lasers so the involvement of SPI Lasers is a very important contribution towards the success of the research programme.'

Dr Mark Greenwood, CEO of SPI Lasers, commented "SPI Lasers and Cranfield University have worked together on many developmental projects over the years, and we are very pleased to continue that association as we place our first 10 kW QUBE CW Fiber Laser at Cranfield. We look forward to seeing how the results shape the manufacturing strategies of the future".

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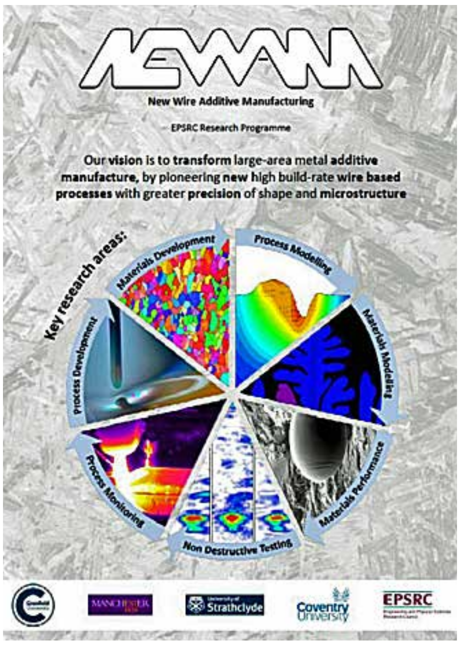

Contact: Jack Gabzdyl
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BUSINESS NEWS

BLM ANNOUNCES DATES FOR TWO-WEEK INTUBE 19

BLM Group has announced dates for its in-house INTUBE Expo event, which brings together the wide range of tube and flat sheet processing from across the group's diverse portfolio. The event will take place at its ADIGE and ADIGE SYS facilities in Levico Terme, Italy, and runs from Monday 30th September through to Saturday 12th October.

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STEELSCOUT EXPANDS METAL TYPES SUPPLIED

SteelScout has diversified into offering stainless steel, yellow metals and aluminium on its online buying platform. With the addition of copper, bronze, brass and aluminium, SteelScout is seeking to establish itself as a multi-metal platform, bringing buyers better value and greater convenience across a broader range of metals.

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TRUMPF PRESENTS ITS NEW BUSINESS FIELD

The creation of TRUMPF Photonic Components, with its focus on the vertical-cavity surface-emitting laser (VCSEL), gives the company access to a new market segment that will complement its existing high-power diode laser business.

In VCSEL technology, the diodes emit light perpendicular to the surface of the semiconductor device, unlike conventional edge-emitting diodes where the laser light is propagated horizontally to one or two end faces of the device. These laser diodes are used in smartphones, in digital data transfer applications and in sensors for autonomous driving.

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HAMAMATSU EXPANDS IN JAPAN

Hamamatsu Photonics will construct a new factory building at the Shingai Factory, Hamamatsu City, Japan, to cope with increasing sales demand for opto-semiconductors, X-ray image sensors and X-ray flat panel sensors.

The new factory building will be completed in August 2020.

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SUCCESS AT MOTION CONTROL AWARDS FOR PI

Physik Instrumente (PI) enjoyed a successful Motion Control Industry Awards, reaching the finals of the Technical Innovation of the Year award for its newly developed PIRest active shims. The company, which was also a runner up in the Manufacturer of the Year category, impressed judges with a ground-breaking solution that offers design engineers a simpler, faster and more practical option for precision, long-term alignment of components.

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NOVEL LASER SOLUTIONS FOR THE CONSERVATION OF STONE STRUCTURES

Across the globe, initiatives are being taken to conserve historical sites threatened by contamination from biological growth, such as algal biofilms, and carbon deposits from air pollution. However such projects are expensive. For example, in the UK the restoration of Piece Hall in Halifax, Yorkshire, cost £19 m. A substantial portion of masonry cleaning costs go into the recovery of environmentally hazardous substances used, such as biocides sprayed onto stone surfaces. Due to its toxicity, the excess liquid must be recovered from the environment to mitigate far-reaching ecological damage.

The limits of traditional stone cleaning methods

Environmentally friendly policies for restorative work are increasingly being sought worldwide as conventional masonry conservation methods are coming under scrutiny. Conventional methods are proving inadequate - for example where buildings have a variety of algal species contaminating the surface. Biocides are typically organism-specific and so multiple biocides are required in order to remove all offensive organisms. Since organism susceptibility varies, copious volumes of biocide can be required to target just a small fraction of biological species distributed over a wide area.

Natural biocides such a copper are alternatives to solution-based biocides. Copper metal is physically installed in strips into the mortar and oxidises over time to produce a natural biocide which, despite being prone to leeching from buildings, is more environmentally benign. However, incorporation of foreign structures into the mortar can compromise the integrity of the masonry. Moreover, the characteristic bluish-green of copper (III) oxide, can cause staining which in some cases is not aesthetically pleasing.

Abrasive methods like bristle brushes and pressurised water can attack both carbon and biological staining but have been known to damage the stone surface, making it rough. This creates a larger surface area, making the stone prone to an accelerated build-up of biological growth after cleaning because incoming spores have more places to settle. This can undermine the effectiveness of the cleaning process and the economic argument for performing the cleaning. Abrasive methods are by necessity time intensive since they are performed relatively slowly in the hope of making the cleaning process gentler and to limit damage to the parent stone. However, this results in long project durations, increasing management time and associated running costs.

Novel laser solutions

In response to challenges faced by conservationists, high average power lasers offer a new solution. Laser cleaning of masonry simultaneously cleans both carbon deposits

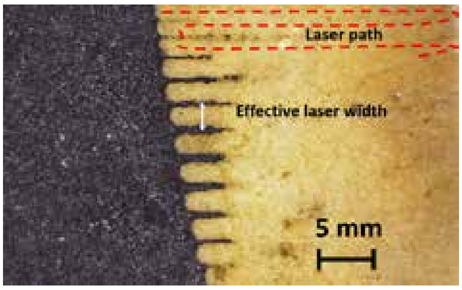

Figure 1: Concentrated carbon deposits on marble stone cleaned with a Vulcan 1600 infrared laser.

and biofilms. Moreover, the volume of residue produced during laser cleaning is considerably reduced, most of which is airborne ablation by-products which can be captured and contained by deploying standard air extraction systems.

The versatility of laser cleaning solutions offered, for example, by Powerlase Vulcan systems, allows laser parameters to be adjusted to optimise performance on different masonry surfaces - such as marble, sandstone and granite - without damaging the stone surfaces. Key parameters include laser average power, the energy of the beam and laser scanning configurations, such as spacing between laser beams lines. Laser cleaning acts locally at the surface of the stone, hence avoiding the destructive probing observed with abrasive methods or insertion of copper implants which can compromise their mechanical integrity.

The ability of lasers to remove both carbon deposits and biological growth has significant implications for cleaning speeds and ease of processing. Hazards involved such as laser light (visual) and ablation products (airborne) can be reliably controlled and quantified. This makes laser cleaning solutions simple to regulate and means users can confidently operate according to government policies.

Figure 1 shows the results of cleaning a concentrated carbon deposit from marble. The laser beam is rastered from side to side to create an effective 'line of laser' which is evident from the interface between the soiled and clean region. The spacing between the 'lines of laser' has been adjusted to be wide enough to reveal the trailing edges of carbon deposit at the soiled interface for illustrative purposes. Therefore the cleaned region in between the trailing edges provides the width cleaned by a single line of laser, the 'effective laser width'. The spacings inbetween can be brought close together to remove all residue and reveal a sharp interface. Biofilms are also effectively removed by laser cleaning as shown in Figure 2.

Carbon deposits and biofilms can be removed indiscriminately from stone because of the large difference in the ablation threshold and thermal capacity of stone compared to surface contaminants. This means that as the laser interacts with the surface of the stone, the contaminants strongly absorb the laser light, heating up faster than the stone and become so hot they rapidly degrade from solids to gas by sublimation.

Laser cleaning solutions are becoming increasingly sought by conservationists as their rapid cleaning capabilities offer a convenient and controllable method to preserve valuable structures. Laser cleaning is setting the standard for masonry cleaning solutions of the future.

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Osas.Omoigiade@andritz.com
www.powerlase-photonics.com

Full article available on the blog page at the above website - 'The High Power Laser Blog'.

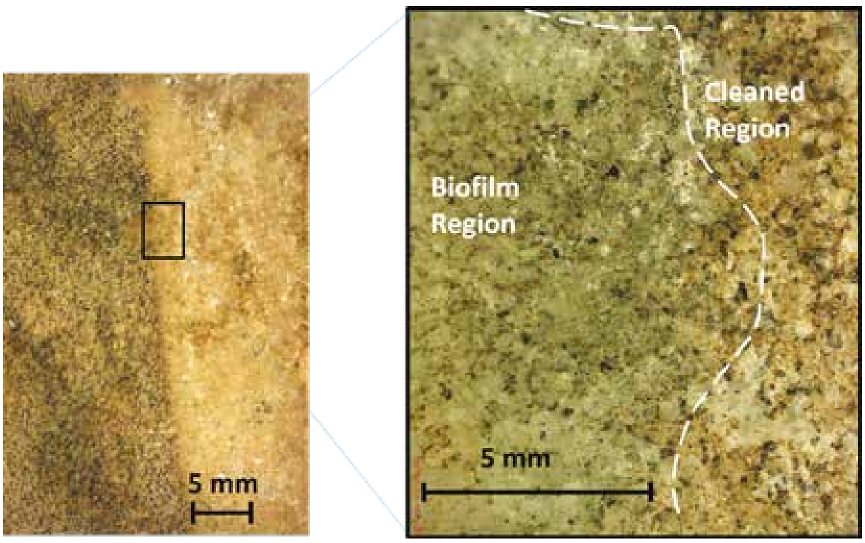

Figure 2: Biofilm coated marble stone with one side cleaned with a Vulcan 1600 infrared laser. One region of the biofilm and cleaned region interface is focused in on to show the difference in surface contamination in the two regions.


ADVANCED ENGINEERING 2019
30 & 31 October 2019 | NEC, Birmingham
The UK's largest annual gathering of engineering supply chain professionals
"I found the event a great networking opportunity to meet industrial professionals from different backgrounds with different products."
Kat Clarke, Wing Manufacturing Engineer, Airbus
15,000 engineering professionals in attendance
500+ exhibitors showcasing their products/services
Over 200 hours of free-to-attend industry content
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AUTOMOTIVE ENGINEERING
PERFORMANCE METALS ENGINEERING
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SPOTLIGHT ON ECRs

Name: Tara Murphy

Nationality: British

Academic history:

I studied for my Bachelor's degree in Physics at the University of Bath and graduated in 2011. I had completed a project on non-linear optics using Hollow Core Photonics Crystal Fibres.

That same year, I began working in an Applications lab, specialising in nanosecond pulsed fibre lasers for materials processing. I spent 4.5 years working as an Applications Engineer, before returning to Photonic Crystal Fibres at Fianium Ltd in 2016, now NKT Photonics.

I spent 2.5 years working in Technical Support for Supercontinuum laser sources, troubleshooting, training customers and assisting with bespoke scientific and industrial applications. I then established NKT Photonics' first Applications Lab for ultrafast lasers where I am now working again in materials processing. I process a range of materials using pico and femto second lasers. I work closely with our R&D team to assist in new product development and attend international conferences.

I think the laser industry is very exciting as there are always new materials and new applications emerging. I enjoy meeting people in this industry and understanding how and why they are using lasers.

Hobbies: In my spare time I like to watch live music and travel. I am also training for a charity race at the end of this year.

Name: Xiaojun Shen

Nationality: Chinese

Academic History:

I gained my Bachelor's and Master's degrees in China, majoring in Mechanical Design and Laser Engineering. My Master's degree was focused on improving the mechanical properties of aerospace engine components which I completed in 2013.

In 2017, I received a fully-funded scholarship from the Institute for Future Transport and Cities, Coventry University to undertake a PhD in the field of Laser Shock Peening of Titanium Alloys. In particular, the PhD research is focused on examining both the mechanical and biological properties of laser shock peening bio-grade titanium alloy for medical applications. To date, the results have shown that the operational life of prosthetic grade titanium alloy was prolonged with induced residual stresses from the laser shock peening process. This in turn will ensure that the patients endure only one surgical process (rather than multiple operations as it currently stands).

I joined the Early Career Researchers Committee in 2017. This keeps me up to-date with the latest developments in the laser industry, as well as extending my networking opportunities in the UK laser community.

Hobbies: I am huge fun of basketball and badminton. I also like to travel and I take a keen interest in different history and national cultures.

See Xiaojun's article on laser shock peening the medical sector, page 20

ULTRAFAST LASERS FOR MEDICAL DEVICE MANUFACTURING

The advent of lower cost, robust ultrafast lasers has enabled the manufacture of a number of medical devices and decreased the overall manufacturing costs of others. Ultrafast laser micromachining has been proven to simplify manufacturing processes and reduce costs, particularly by eliminating post-processing steps.

The most common medical devices fabricated with laser micromachining are used for surgical control, cardiovascular and orthopaedic interventions and drug delivery. Since laser machining became a viable option for medical device manufacturing (MDM), fine laser welding, marking, drilling and cutting of metals, glass and polymers has found application in the fabrication of a wide variety of medical devices and instruments.

Ultrafast laser-material interactions boast a range of advantages; The ultrashort pulse durations provide an exceptional peak power which enables marking of a wide range of materials without delivering heat to the material. The laser-material interaction enters the 'cold' or 'athermal' ablation regime and the machining quality significantly improves, which is imperative for the medical industry. Lasers excel in creating small and precise features where conventional methods cannot compete to achieve these intricate details. Also, higher precision manufacturing means less waste.

At NKT Photonics we have developed the Origami XP laser which is the first all-in-one, single-box, microjoule femtosecond laser on the market. With its OptoCAGETM technology it provides high level beam pointing stability, low pulse noise and less sensitivity to ambient temperature fluctuations, making the laser well suited for medical device manufacturing.

All of the examples shown below have been processed using ORIGAMI XP femtosecond laser.

Contact: Tara Murphy
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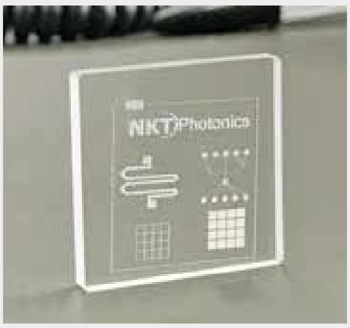
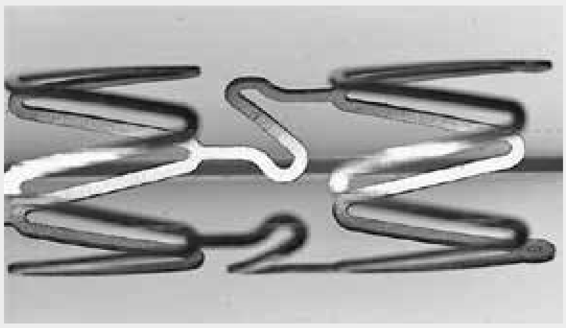
www.nktphotonics.com

Black marking of multi-use stainless steel tools



Glass marked and engraved by laser for lab on chip devices



Nitinol stent with no thermal effects (courtesy of JEM lasers)

CASE STUDIES

LASER CUTTING COMPANY GROWS WITH BYSTRONIC

After completing his apprenticeship and gaining further qualifications, Iain Summerfield found himself at a sheet metal subcontractor in 2001 sweeping the floor and loading material onto four Bystronic CO_2 flat-bed laser cutting machines. Seven years later he joined forces with co-director Paul King to set up their own company, Laser 24, to provide similar subcontract services. In 2015, one of their CO_2 machines was exchanged for Laser 24's first fibre laser cutting machine, a Bystronic 3 kW ByStar Fiber 3015. The effectiveness of fibre laser cutting was immediately apparent and the wider range of materials that could be processed resulted in new work being won.

Fibre technology had matured by then into one that was supplanting CO_2 in almost all application areas. By mid-2018, the subcontractor had attached a 10 kW ByStar Fiber to the ByTrans Extended, which was joined by a second identical production cell six months later. Laser 24 is the only company in the south of England to operate a pair of such powerful sheet metal cutting centres.

A further advantage of having a 10 kW fibre laser source is that there is sufficient power to effectively use air rather than oxygen as the assist gas for certain jobs. It results in an edge quality indistinguishable from oxygen use when cutting material up to 1.5 mm thick and is still acceptable for thicknesses up to 3 mm. Laser 24 is currently considering air cutting, which avoids the cost of using bottled gas, as an economical alternative to plasma cutting for applications that do not require top quality edge finish. Trials are currently being carried out.

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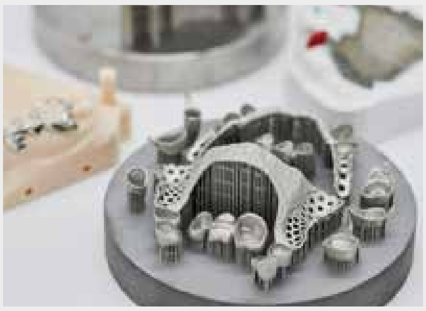
TRUMPF AIDS 3D PRINTING OF DENTURES

Manufacturing dentures using 3D printing makes the process fast, flexible and simple. One company benefiting from this technology is CADSPEED, a CAD digital milling centre based in Hanover. It uses a TRUMPF TruPrint 1000 to manufacture dentures for dentists, orthodontists and dental laboratories throughout Europe and confirms significantly higher productivity, improvement in product quality and far less material wastage as a result of this investment.

Using traditional methods, a dental technician would normally produce one tooth in 20 minutes. However, in the space of just two to three hours, the TRUMPF TruPrint 1000 can manufacture up to 70 teeth per cycle which equates to less than three minutes per tooth.



Another important advantage of 3D printing for CADSPEED is improved quality. It is exceptionally difficult to profile corners and edges using a milling machine – the tooth is simply too small. In addition, the tools cannot reach all areas and sometimes break. Such problems are eliminated with 3D printing.

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LASERDYNE MACHINE INSTALLED AT ENERGY SUPPLIER

The Laserdyne® 795 is equipped with Laser Metal Deposition technology, developed by Prima Additive and customised in cooperation with Enel, the main energy producer and supplier in Italy. Enel's choice of a direct energy deposition machine has been determined by the flexibility of this solution, both in terms of production and repair. This type of application allows the company to reduce warehouse time, reduce downtime of a plant or parts of it, and to save money, allowing repair and reuse of the same component.

This innovative solution, together with the experience in the field of design, simulation and operation, and plants maintenance, will constitute a new and concrete opportunity for Enel Produzione's activity both in Italy and in the rest of the world, as well as for the other Group companies, contributing to excellence in terms of innovation and technology.

The main reasons that led Enel to choose a solution developed by Prima Additive were the size of the work volume, the 7 degrees of freedom that could facilitate the repairability of some items, and the possibility to execute complex shapes (original or re-engineered).

Other important features are the adjustable power of the laser source, the open scan parameters, the customised cad-cam, and the implementation of two separate powder adduction lines which, together with dust engineering aspects, allow a considerable development of the mechanical properties of the parts produced or repaired.

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www.primapower.com

NUCLEAR AMRC WORKS WITH HEAT EXCHANGER SPECIALIST

The Nuclear AMRC worked with heat exchanger specialist Thornhill Group to demonstrate a new welding method for small tube-to-tubesheet assemblies which could halve cycle time. The project called on the Nuclear AMRC's powerful disk laser welding cell, more often used on large components of up to 3 m diameter. Using the laser on tubes measuring just 8 mm diameter presented numerous challenges to the centre's engineers, who successfully demonstrated that large-capacity welding machines can be used for nuclear components of all sizes.

Thornhill Group is the only UK provider of the complete cycle of heat exchanger services encompassing design, engineering, installation, repairs and servicing for clients in power generation, oil & gas, chemical and other demanding industries. One of Thornhill's customers in the nuclear sector was looking to implement a tube-to-tubesheet joint within a restricted space, and asked the company to investigate how this could be designed and manufactured. To complement their own expertise in heat exchanger development and fabrication, the Thornhill team called on the Nuclear AMRC to help determine the feasibility of the customer's design.

The study for Thornhill was one of the first commercial projects for the Nuclear AMRC's disk laser welding cell, which was commissioned in early 2018. The welding head had to be customised for the job, with the large gas nozzle and shield removed in favour of a separate gas shielding nozzle, and laser power was reduced to just 2 kW from its maximum 16 kW. Ensuring a high quality weld meant considering a host of factors, from angle and position of the weld head, to reducing the gas flow to avoid turbulence in the molten metal.

The project proved that a robotic laser welding cell can successfully join small tube-to-tubesheet assemblies, and the customer's design can be manufactured to requirements.

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WRITING THE FUTURE WITH RADAN

A contract to supply metal bread baskets for the Eiffel Tower's restaurant was the catalyst for a laser cutting company to invest in RADAN sheetmetal CAD/CAM software. Vincent Glatre, Site Manager at Métal Industrie, says: "The proprietary software with our laser cutter couldn't solve the complex programming required for these components, and generated more knockouts than parts on the sheet." They urgently looked at several software systems, and the first tests with RADAN's powerful nesting module enabled them to meet the order's deadline.

Glatre says that since then they have strengthened their software step-by-step to make it a productivity tool every bit as valuable as a new machine: "In the early days we used the software that came with our machines, which was fine for simple cutting and common issues, but as we took on increasingly complex work we needed RADAN's automation features that were capable of optimising nesting to save costs on raw material and increasing productivity."

Like many companies, they originally prepared their quotes on internally-developed spreadsheets, but simplified procedures by integrating RADAN's Radquote software, which mastered all their required technologies while also supporting other data necessary for accurate and functional costing, such as analysis and transport.

After investing in a new 170-ton TRUMPF press brake in 2017 they completed their RADAN suite by installing the Radbend module, continuing their strategy of off-line programming, to detect any possible issues before starting to work on the metal.

After looking at several ERP systems, they chose WORKPLAN, which, like RADAN, comes from Hexagon Manufacturing Intelligence's Production Software business. It fully interfaces with RADAN, from quotation through to workshop program management.

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LASERS ENABLE FUNCTIONAL SURFACES FOR INDUSTRY

AN INTERVIEW WITH STEFAN DIMOV

PROFESSOR OF MICRO MANUFACTURING, UNIVERSITY OF BIRMINGHAM

Q. Can you tell us about Birmingham University?

I came to Birmingham University in 2011 after almost 20 years at Cardiff University where I got my DSc degree after my undergraduate and PhD studies at Moscow Technological University.

Birmingham University dates back to 1825 as a school of medicine and surgery and received its charter in 1900. Currently it is the fourth largest UK University. In 2016, 3 of the Nobel Laureates came from our University being recognised for their work in Physics and Chemistry.

Since I arrived, there has been an upsurge in the popularity of mechanical engineering and the number of undergraduates per year has risen from 100 to 240 per year. Birmingham has strong and well cultivated links with local industry tested over the years that create job opportunities for our graduates. Recently we have established a Centre for Custom Medical Devices (CMD) in collaboration with Renishaw to work jointly at all stages of the medical supply chain, from implant simulation and novel designs through to manufacturing prosthetics that overcome healthcare challenges.

Along with Loughborough and Nottingham Universities, Birmingham was one of the founders of the Manufacturing Technology Centre (MTC).

Q. What is the current outlook for universities like Birmingham?

The funding landscape is changing with the advent of the Industrial Strategy Challenge Fund. Currently there are some calls which could attract laser-based application research as part of the Manufacturing Made Smarter programme. It is becoming clear that universities need to position themselves well and work closely with companies to build up capabilities and mutual trust – so that we can work together to develop project ideas that meet the focused needs outlined in the calls.

> *Avoiding the build-up of biofilms and limescale is critical to the long life of any products containing water*

European funding has been very important, especially as part of the "Factories of the Future" programme, and it is not yet clear whether we will have access to the EU programmes and if not, how they will be replaced by other UK or international initiatives.

Q. What are the main areas for laser-based research at Birmingham?

We have a range of R&D programmes in Additive Manufacturing but we are also very active in the area of surface texturing, especially as a tool for functionalising surfaces. In particular, the application of such surface texturing technologies to 3D objects presents a challenge that we are addressing. We are looking to find solutions that can be implemented in multi-axis laser machine tools, rather than lab set-ups that are not repeatable from day to day – having the required accuracy, throughput and reliability for the industrial manufacturing applications. Many of our developments in this field are based on LIPSS (Laser Induced Periodic Surface Structures), especially to create capabilities to produce hydrophobic surfaces which are durable and can resist wear, e.g. to withstand multiple cleaning passes.

Q. Where and when do you expect functional surfaces to make a big impact in manufacturing?

Some of our work is in collaboration with industrial partners in the domestic appliance sector and white goods market in general. Avoiding the build-up of biofilms and limescale is critical to the long life of any products containing water, and manufacturers of high-end products are already using coatings to prolong life of components and systems that are in contact with water and other liquids. If they are prepared to pay for a coating process, then laser treatment can become a viable alternative as long as the economic case for creating such functional surface topographies is made and their lifespan (e.g. number of cleaning cycles) is sufficiently long when compared to the alternatives.

Where parts are made from plastic, the replication of functional topographies can bring the cost down and make it an attractive alternative to coatings. In this way expensive laser treatments can be deployed in mass production without the need to laser process each part – this allows low unit cost and high throughput to be achieved and thus to meet industry demands.

Regarding metals, the replication process could be the answer too but there are many challenges. The most immediate solution is to process metal surfaces with high speed employing nanosecond fibre lasers (to keep the capital cost down). Also, the laser processing can be combined with other surface treatment solutions to achieve the required durability and thus to meet specific industry requirements.

Q. What laser is the next one you will install in your department?

We are currently waiting for the delivery of our new laser micro processing workstation. This integrates a sub-pico near IR laser source with high pulse energy and second-harmonic generation for green processing and also a short green nanosecond laser source (1-4 ns). The workstation will integrate a stack of 3 linear and 2 rotary stages, and 3-D scan head for realising complex multi-axis processing strategies. Also, we are acquiring a CAM system for generating complex beam paths that require the simultaneous use of mechanical and optical axes and thus to structure/texture 3D surfaces.

> *There is a clear need to develop networks and AILU fulfils this role very well*

Q. What benefits has AILU membership given you?

I believe it is very important for academics to be part of a wider community, to meet with their peers and understand how to position their research in the context of constantly changing industrial requirements and also to follow the latest development in industrial photonics. Events like ILAS and AILU thematic workshops are the right places to make this happen. For Early Careers Researchers there is a clear need to develop their networks and AILU fulfils this role very well, too.

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ANNUAL JOB SHOP BUSINESS MEETING 3 OCTOBER 2019, MINI PLANT, OXFORD

The Annual AILU Job Shop Business Meeting has a history of providing the owners of laser subcontract processing businesses with the tools they need to save time and money. The meeting is open to members and non-members and continues a tradition of addressing issues to improve performance in the subcontract market.

Manufacturing with lasers is efficient, flexible and fast – and sharing information with other businesses in the same sector allows the AILU Job Shop Group to assist business owners to improve their performance.

This year's Job Shop Business meeting will be held on 3rd October at the Mini Plant in Oxford. The focus of the day will be on cost saving and “free money” (available initiatives and grants to increase profit) - there are certainly opportunities to take advantage of.

The day will end with an optional tour of Mini's bodyshop and the Heritige Museum in the Visitor Centre.

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NEXT GENERATION TO TAKE THE REINS AT CHARLES DAY STEELS

Left to right - Charlie, Jon and James Day.

Established by Charles Day in 1977 providing a flame cutting service, Charles Day Steels Ltd has since grown into one of the largest and most diverse profile cutting companies in the UK.

Taking over from his father at the age of 29, Jon Day broadened the company’s capabilities through the addition of laser and waterjet profiling, echoing the company’s belief and focus on innovation. This was then furthered with the acquisition of The Laser Cutting Company Ltd in 2012, adding tube laser cutting to the portfolio.

Aiming to build on this proven track record of innovation and customer service, is the next generation. James and Charlie Day (29 and 28 respectively) join the business with ambitious growth plans for the group following successful solo careers in related industries. The brothers will be bringing an energetic approach to drive growth within existing markets whilst broadening the company’s scope into new ones. Charlie will be focusing on business development with James taking the reins on operations. Having grown up with the family business both have always been involved in the industry and will be hitting the ground running.

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SHORT RETIREMENT FOR DAVE LINDSEY

Having retired as MD of Laser Process in 2018, Dave Lindsey - founder member of AILU's Job Shop SIG - is back in business. Dave is now MD of IpCompute UK (trading as IpLaser), has opened a new office in Lichfield and rejoined AILU. IpLaser provides an online quotation system for laser cutting jobs. It is an intuitive estimating tool that has been developed by laser cutting professionals with decades of experience in the industry. It is also fully configurable and capable of including most secondary operations.

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YORKSHIRE LASER UPDATES SOFTWARE

Yorkshire Laser and Fabrication has recently updated its Material Requirement Planning (MRP) system and invested in Siemens latest production scheduling software, investing more than £25,000 to further improve its service to customers.

“Everything we do evolves around our MRP system so moving to the latest version underpins our commitment to advancing the production control process side of the business.” said MD Matt Orford.

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CHAIR'S REPORT

BACK TO BASICS WITH "LASERS FOR MAKERS"

Recently I was called up as a replacement for one of the other Job Shop board members to deliver their presentation at AILU's "Lasers for Makers" event held at Imperial College Hackspace in London. Not knowing what a Hackspace was, and rarely getting the chance to engage in any other activity which doesn't directly involve laser cutting of metal in a Job Shop capacity, I was somewhat apprehensive. However I was pleasantly surprised and indeed inspired enough that I thought it was an experience worth sharing.

A Hackspace is effectively a shared workshop with a wide variety of tools to help those without any facilities create prototypes and working models on a low budget. Some of the machinery Imperial have on offer includes 2 table-top CO_2 lasers, a large CNC wood-routing machine and many 3D printers of varying sizes. Whilst the 3D printers clearly dominate the Hackspace environment due to their flexibility, we were all there to talk about lasers. The benefit of lasers, as we all know, is the variety of materials and speed at which they can be processed, compared to 3D printers.

The Hackspace provides a very creative atmosphere where ideas can be nurtured and developed without the pressures of the real world, like customers to satisfy or deadlines to hit. It was refreshing and indeed inspiring. I even asked if I could use some facilities as my mind started to think of all great things I could make as we don't even have some of the kit they do!

I was surprised at how keen and interested all of the makers were in laser cutting metal. As it is my normal day-to-day activity it's easy to forget that metal cutting lasers are really impressive machines which are all too easily taken for granted. When you don't have access to these machines and when even the subcontract costs are beyond many for prototypes etc., it's very frustrating to be stuck trying to make working parts from just wood or plastics.

The event seemed a great success to me and the most positive thing I took away from it was the number of people whose minds are busily working away on inventing and developing ideas, not just making things to order or deadlines! There are a huge number of like-minded people out there looking to create and make things. They may have no budget and limited experience but I urge you to try and connect with these people, as many of them are next-generation designers, to help them fulfil these ideas in any way you can. I found my afternoon with them very rewarding, and if you get chance, check out your local Hackspace, I'm sure you'll be just as inspired as I was!

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A LIFETIME OF LASERS AND THE EYE: 1965 TO 2019 SO FAR!

JOHN MARSHALL

John Marshall MBE is the first recipient of the AILU Laser Ambassador Award, presented to him at ILAS 2019. The award recognises the pioneering work that he has carried out since the mid-1960s using lasers in eye surgery. He introduced lasers into this field and tackled many ocular diseases including age related, diabetic and inherited retinal disease. Most significantly, over 60 million people have been treated using the corneal laser refractive surgery method he invented and later commercialised via the company Summit Technology.

The 1960s: major laser safety database on retinal damage

In 1965 I had the good fortune to be accepted to pursue a research project leading to a PhD sponsored by the Flying Personnel Research Committee of the Royal Air Force. The project was to determine the potential of lasers to induced damage to the retina which could potentially result in a blinding insult. Remember 1965 was only five years after the first practical demonstration of the laser by Theodore Maiman and for the most part systems were very ineffective and were not thought to be potential weapons by most individuals.

The perception was changed by the Bond film "Goldfinger" and as a result the general public thought that lasers could cut a body in half. My PhD tutor was Kit Pedler who went on to write science fiction and create the cybermen for Doctor Who. Many who knew me in the early days thought that I was working on science fiction too.

My PhD resulted in a database defining retinal damage and relating it to wavelength, pulse duration, spot size and retinal irradiance, and went on to become one of the fundamental databases to be incorporated in the world's codes of practice for laser safety. Being in at the beginning meant that I rapidly got to sit on virtually all of the world's international committees concerned with safety issues of light and lasers, including those of the World Health Organisation, the United Nations and the International Committee of the Red Cross.

Understanding the safety aspects of lasers had a fundamental requirement for understanding mechanisms by which they damaged ocular tissues and this meant that I could utilise different damage mechanisms for their potential in treating different eye diseases.

In the early 1960s, laser-based applications to the eye were a little hit and miss but were perhaps most successful in the early use of pulsed Ruby lasers to treat retinal detachments.

The 1970s: early laser treatments for eye conditions

It was not until 1970 that the Argon laser was first used to treat the eye complications of diabetes and other conditions where blood vessels grew into inappropriate places within the light-sensitive tissue, the retina. Prior to the advent of the Argon laser patients with a problem called diabetic vasculopathy had the option of going home after diagnosis and progressively becoming blind or having part of their brain destroyed, pituitary ablation, which had a 12 - 14% mortality rate. The Argon laser suddenly provided a treatment for this blinding condition and I was happy to become involved in optimising these systems and avoiding sight threatening complications.

While such treatment was very effective in preventing the growth of these new blood vessels it was less successful in clearing fluid from the central part of the retina, the macula. Diabetic macular oedema is still a problem for patients and ophthalmologists and requires further investigation.

In the 1970s lasers also began to be used for treating glaucoma and with the advent of the YAG laser in the treatment of cataracts. The beauty of lasers meant that we could operate on an intact eye and thus avoid any of the problems of infection caused by making incisions. In glaucoma the most common symptom is that the pressure goes up inside the eye. In order to reduce the intraocular pressure (IOP) we could use lasers either to reduce fluid production or increase fluid output. Today the most commonly used procedure is to apply frequency doubled YAG systems to improve fluid output.

There is a misconception concerning the role of lasers in cataract surgery because they were not initially used in the primary surgery, but to treat a complication after surgery. The human lens is contained by a membrane called the capsule and in modern cataract surgery the lens is removed by suction through a hole in the capsule after ultrasonic disruption. The natural lens is then replaced by a plastic intraocular lens (IOL). Unfortunately in many cases the few cells that are left after such surgery begin to proliferate and coat the capsule at the back of the IOL resulting in posterior capsular occlusion, PCO, or a secondary cataract. Nanosecond pulsed YAG lasers are used to make a hole in the PCO thereby instantly restoring the patient's vision.

The 1980s onwards: further development of laser eye surgery

Developments in telecommunications and huge investment in diode lasers in the 1980s resulted in the ability to combine a number of diodes to carry out treatments of the retina and other eye tissues. I was lucky enough to be involved in the development of the first diode system for treating retinal conditions and went on with a colleague, Tony Raven, to see diodes being used for surgery outside the eye. This was the first system for general surgery and was manufactured by a UK company, Diomed, based in Cambridge. Diode-based systems form a major part of the armamentarium of the laser ophthalmologist having almost completely replaced the original gas systems for treating the retina.

Perhaps the best known application of lasers in ophthalmology is what the general public call "laser eye surgery" that is the development of systems to remove the need for individuals to wear spectacles or contact lenses. I became aware of Excimer laser systems because of their use in the print and semiconductor industries. I was amazed that a system such as the Argon fluoride Excimer laser with a photon energy of 6.3 electron volts could be used to progressively ablate materials in submicron increments (see Figure 1). I thought that if this resolution could be obtained in biological tissues then it may well be a way to change the curvature of the eye in such a fashion that it would correct problems of short and long sight.

Short and long sight result from two errors in the development of the human eye. They result from either an anomalous curvature of the major refractive component of the eye, the cornea, or from a significant increase or decrease in the

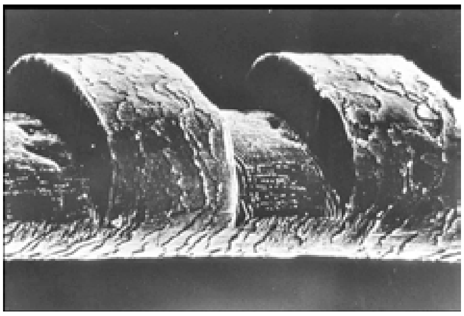

Figure 1: a single human hair with grooves cut into it with the Excimer laser.

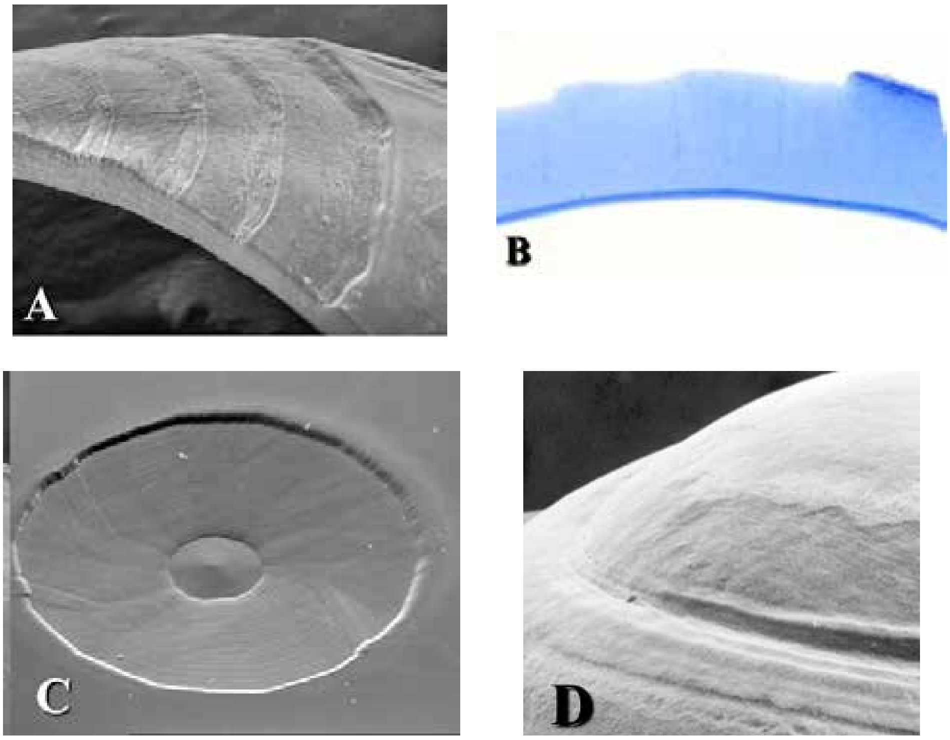

Figure 2: (A) earliest attempts to flatten the cornea looking like a Greek amphitheatre, (B) section through this, (C) later attempts with a computerised system showing a smooth curve cut into the surface (D) a curve steepening the centre using a template. A, B and C correct shortsightedness, D corrects long sightedness.

axial length of the eye when compared with the norm. The cornea has a rapidly replacing surface about five cells thick that sits over the main body of the system, which is composed of collagen fibres in a matrix. The question was, if we removed the five layers of cells and changed the curvature of the underlying surface of collagen, then when the cells grew back after eight hours or so, would they maintain the induced change? This form of the surgery was known as PRK.

Early experiments proved that by manipulating the pulse energy, the main fibrous component of the cornea could be ablated by about 0.2 µm per pulse. Together with Tony Raven we produced grandfather patents for refractive surgery. We achieved changes in curvature by differential ablation of the collagen by passing the primary beam, which was some millimetres in size, through a progressively opening or closing aperture. This arrangement cut something like a Greek amphitheatre onto the collagen tissue (Figure 2A and B) but with stepping motors and computer control the size of the steps could be reduced so that an approximation to a smooth surface was cut (Figure 2C).

The early experiments concentrated on flattening the curvature and addressing myopia, or short sight. We went on together with another colleague, David Muller, to address the problems of hyperopia, or long sight. In order to steepen the curvature of the cornea we manufactured lenses to act as a template and mounted these on a quartz substrate. As the laser fired it progressively ablated the template but left an image of the template cut into the underlying cornea (Figure 2D). The success of these early experiments resulted in the foundation of the first company to successfully achieve FDA approval for refractive surgery for myopia, Summit Technology.

It took approximately 10 years from the initial concept and proof of principle experiments to gaining FDA approval. Now more than 60 million individuals worldwide have undergone some form of Excimer laser refractive surgery. Today most refractive surgery lasers use small spots and high scanning rates controlled by increasingly sophisticated computer algorithms. They are capable of correcting almost the entire range of refractive errors including long and short sight and astigmatism.

The surgical technique now includes a process whereby the top of the cornea including the five layer of cells is lifted after a laser-based incision, rather like lifting the top of an egg, the correction is then undertaken and the flap put back. This is termed LASIK and is perhaps the most popular form of the surgery. The advent of femto lasers has seen another development whereby a small lenticule is cut beneath the surface of the collagen and removed through a small canal also cut by the laser. This technique is known as SMILE and may have some advantages in terms of preserving the biomechanical integrity of the cornea.

In recent years I have been involved in developing methods for stiffening the cornea to compensate for any potential mechanical changes induced by removing tissue using laser surgery. The stiffening techniques use riboflavin and ultraviolet light to induce cross-linking between bonds present in the corneal tissue and thereby increasing its rigidity.

The present: investigating age-related macular degeneration

Today my major interest is prevention of visual loss resulting from the most common cause of untreatable blindness in the developed world, age-related macular degeneration (AMD). The biggest risk factor for AMD is age and ageing in the outer retina. Being an outgrowth of the brain, the cells of the retina cannot divide and replace themselves but they have to absorb radiation (i.e. light) in order to generate the sensation we know as vision.

The cells that actually absorb and respond to light, the rods and cones, have developed an amazing process whereby the light-sensitive membranes are actively replaced on an almost hourly basis. You can imagine this portion of the cells rather like a packet of biscuits or a photomultiplier. Each cell contains about a thousand biscuits and they are constantly being replaced at one end and “bitten off “ at the other end when they have come to the end of their useful life, about every two weeks.

The cells doing the eating get a little bit clogged by our 30s and certainly our 40s and in turn try to get rid of the clogging material to a membrane that they sit on, called Bruch's membrane. This membrane is located between the blood supply and the light-sensitive cells and governs the metabolic supply to these light-sensitive cells. With increasing age this system begins to become very compromised.

With my colleague Ali Hussain and an Australian company, Ellex, we have developed a nanosecond pulsed laser with a unique beam profile (2RT) whereby within a 400 µm spot on the retina, only some of the cells are brought above the threshold for damage. Those foci of damage result in the release of therapeutic biochemical agents to clean up Bruch’s membrane whilst the surrounding undamaged cells supplied the necessary nutrients to maintain vision during the healing process. The first clinical trial of this device shows that it seems to delay progression from early disease to end-stage complications by at least a factor of four.

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SEE OBSERVATIONS P28

PICOSECOND SCRIBING AND DRILLING OF PHOTOVOLTAIC FILMS

DIRK MÜLLER ET AL.*

Industrial picosecond lasers are well-suited to the scribing, cutting and drilling of thin films. A combination of high average laser power, extremely high repetition rates and 24/7 reliability results in superior quality, improved yield, and lower cost of films made of metals, semiconductor, plastics and dielectrics. In this article we look at some applications examples from photovoltaics – an industry that needs the 24/7 processing and high yield of traditional microelectronics, yet can only sustain one-tenth the cost.

Emerging applications in thin film solar devices

While crystalline silicon devices currently own the largest market share, thin film solar is an important alternative that is steadily growing because it involves lower material costs and offers the promise of deployment on curved and/or flexible surfaces. There are several different types of thin film solar products, with individual manufacturers favouring different semiconductor materials as well as different panel sizes. All thin films currently in production rely on a sequence of scribing steps, called P1, P2 and P3, which are used to pattern the various layers following vapor deposition – see Figure 1 (and all the rigid products are based on glass front panels with a thickness in the 2-3 mm range).

By alternating the use of vapor deposition and scribing, the semiconductor and conductor layers are patterned to create active strips, 5-10 mm x >1000 mm, that are physically in parallel and electrically connected in series. In this way, the overall panel is able to generate hundreds of watts of power.

The first step is to deposit a uniform (a few hundred nm) layer of transparent conductive oxide (TCO) on the glass which will form the frontside electrodes through which sunlight passes to reach the active semiconductor layer. The TCO is then patterned by the P1 series of scribes which must cut through the entire TCO thickness. This is followed by deposition of p- and n-type semiconductor, with a total thickness of 2-3 microns. The P2 scribe then cuts through the semiconductor layer dividing it into active strips. A thin (< 1 micron) layer of metal (aluminum or molybdenum) is then deposited across the entire panel to form the rear electrodes. This is patterned by the P3 scribe which cuts through both the metal and semiconductor layers.

Why picosecond laser processing?

Photovoltaic panel fabrication needs closely-spaced narrow scribes, minimising the area of the panel that is wasted (inactive), as shown in Figure 1. But this also means that the application cannot tolerate peripheral thermal or mechanical damage such as microcracks or debris.

Nanosecond lasers have proved to be a good match for the P1 scribes which remove a few hundred nanometers of TCO. However, the P2 and P3 scribes involve thicker layers (semiconductor or metal) and the challenge is to fully cut through these layers without causing thermal damage to nearby or underlying material. The picosecond laser is a good match for this task because the pulse width is short compared to the thermal diffusion time; minimising thermal damage by cold picosecond ablation eliminates the chance of short circuits. Just as important, commercial mode-locked lasers provide extremely high repetition rates and high average power (up to 100 W). The combination of low pulse energy and high repetition rates also

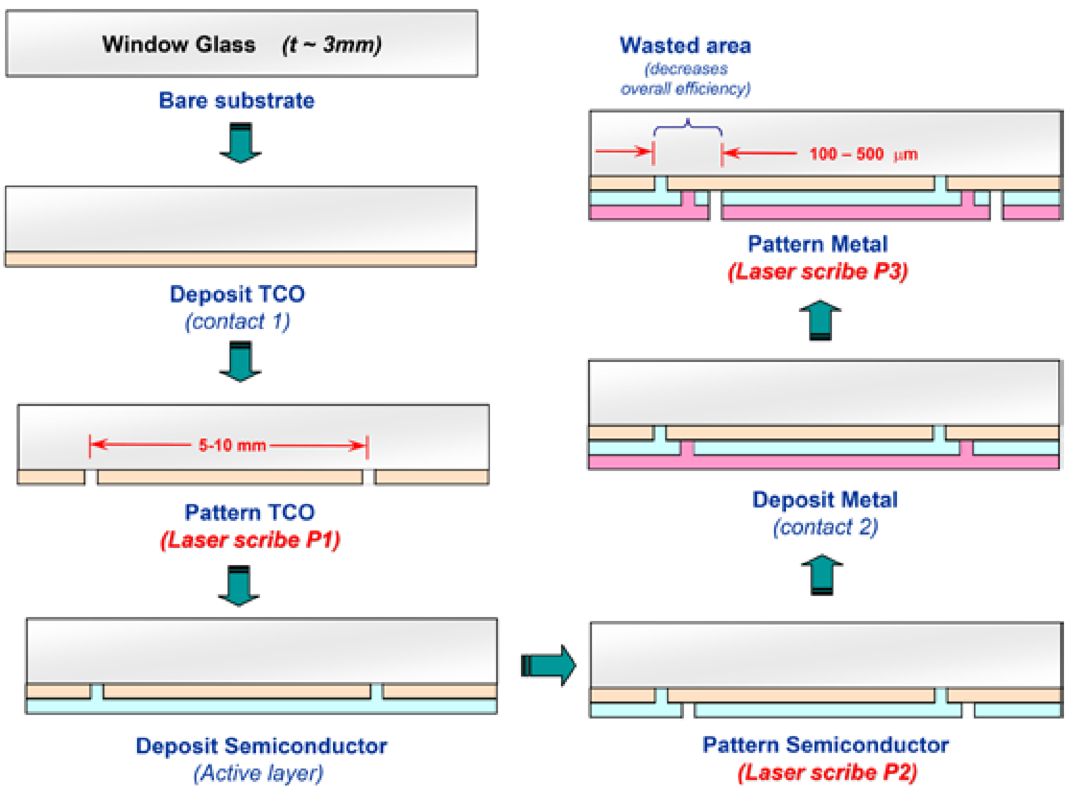

Figure 1: The fabrication of thin film solar panels involves three separate scribing steps which can all be performed by laser.

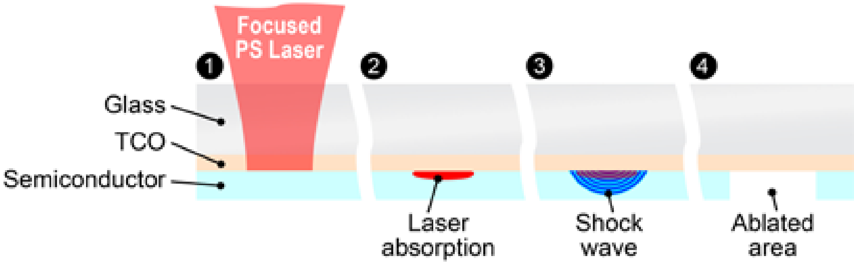

Figure 2: In spallation 1) a laser beam passes through transparent layers, 2) it is focused on the interface with a layer that absorbs the laser wavelength so that rapid heating occurs in a very thin layer, 3) a shock wave expands out, and 4) the target layer is blown off.

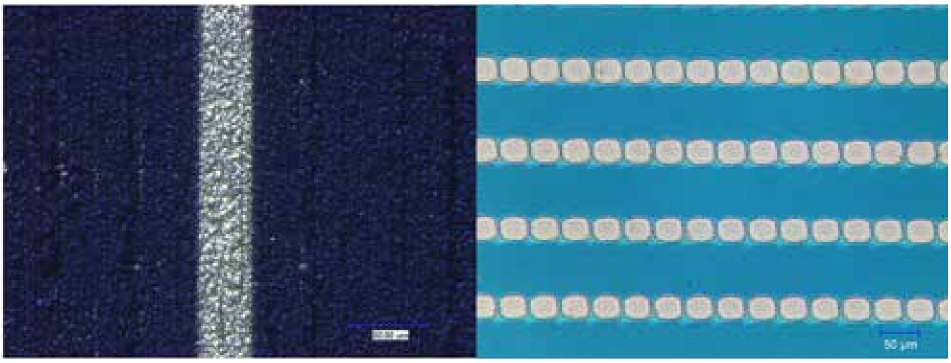

Figure 3: (left) A gaussian profile and overlapping pulses can create a high quality scribe in thin (< 100 nm) SiN on silicon, (right) Single shot ablation of a 70 nm thick SiN layer on silicon using a HYPER RAPID NX IR laser and a top hat beam optic; each dot is approx. 40 x 40 microns and the feedrate is >30 m/s.

delivers high throughput whilst eliminating the chance of functional damage to the panels.

Picosecond lasers are now also available in multiple wavelengths, which allows the use of a highly efficient film patterning technique called spallation for both P2 and P3. In this process, the laser wavelength is chosen so that it passes through the glass and through the TCO but is strongly absorbed at the interface with the semiconductor (for P2) or metal (for P3). This vaporises a few atomic layers of the material removing the overlaying layers completely in a single laser pulse (Figure 2).

Picosecond processing is proven in c-Si solar

Picosecond laser scribing and cutting has previously been used successfully in the production of c-Si solar cells, for example in creation of openings through the SiN passivation layer to allow direct electrical connection to the active semiconductor layer. In some cases, the application needs a long continuous groove. This can be created by using a beam with a gaussian profile and then overlapping the pulses – see Figure 3 (left). However, some SiN on Si scribing applications need to avoid any pulse overlap to completely avoid any damage to the underlying silicon. Figure 3 (right) shows an example of this using a beam with a uniform profile shaped using a top hat optic. The closely spaced square holes in the (<100 nm thickness) SiN shown here confirm that the ps laser also causes no lateral thermal damage to the SiN. In these single pulse applications, the high repetition rate of the ps laser – up to 5 MHz – means that the limiting factor is the scan speed. Galvo scanners can deliver speeds up to 30 m/s, which translates into 1 million holes/s. Faster polygon scanners can increase the speed to several million holes/s.

Cutting glass modules

Packaging of solar devices is also benefiting from picosecond lasers. Specifically, a unique filamentation method for cutting glass called SmartCleave™ enables even strengthened glass to be rapidly cut in a cold process that can create tight curves and holes – see Figure 4 – and that produces excellent edge quality (Ra < 0.5 µm) often with no need for post-processing. In brief, as the picosecond laser beam passes through the glass thickness it automatically oscillates between focused and unfocused, drilling a narrow micro-perforation through the glass. Movement of the glass and/or laser creates a curtain of these filaments which define a smooth fracture, which in some glass types does not even need any kind of shock for separation. Unlike mechanical cutting, the edges are free of microcracks and residual stress, eliminating a common failure mechanism for thin glass panels.

Summary

Like most other electronic-related industries, the photovoltaic market has a growing need for precise micromachining that improves performance, yield and cost. The picosecond laser is proving to be an ideal tool for several tasks in this important industry.

*** Dirk Müller, Hatim Haloui & Joris Van Nunen**

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www.coherent.com

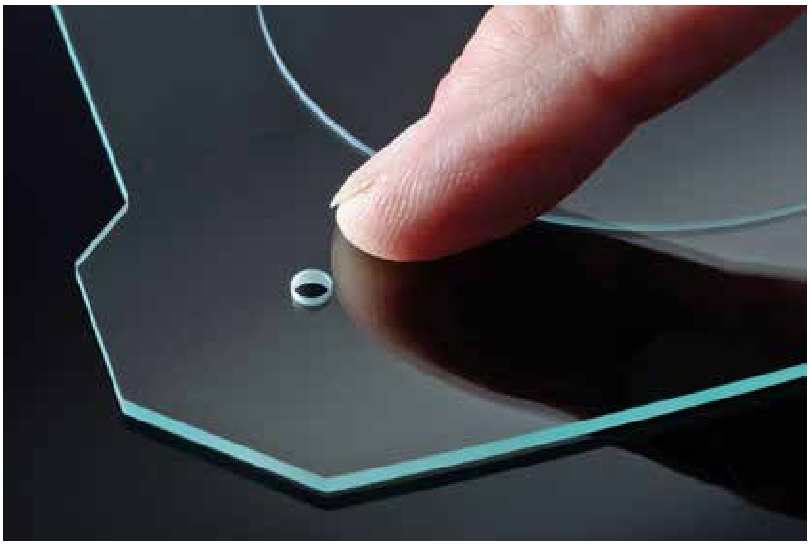

Figure 4: Picosecond lasers enable the SmartCleave™ filamentation process that can cut tight curves in glass, including pass-through holes.

Dirk Müller is Director of Strategic Marketing for micro-electronics. He aligns laser-based solutions to emerging manufacturing needs.

SEE OBSERVATIONS P28

LASER SHOCK PEENING IN THE MEDICAL SECTOR - AN OVERVIEW

XIAOJUN SHEN

Laser Shock Peening (LSP) has been proved to be an innovative surface modification technique since its development in the 1970s. The technique was initially employed to resolve aviation and manufacturing problems for improving fatigue life, anti-corrosion, and wear resistance. Since then it has been used to improve the performance of aerospace components of engines. In recent years, increasing numbers of researchers have tried to find its possible value in the medical sector. This study is focused on recent research regarding the surface modification of medical-grade metals and alloys subjected to LSP.

Residual stress and fatigue

Induction of compressive residual stress is the primary goal of LSP as this has many benefits for improving the functional properties of metallic components. One of these benefits is that it can decrease the risk of metal fracture. The effects of LSP on initiation and propagation of fatigue cracks in aluminium alloy AA2024 with a thickness of 2.0 mm have been investigated [1]. This study observed a significant decrease in the fatigue crack propagation rates due to the compressive residual stress. Additionally, LSP is also used to solve the cracking and fracture problems of nickel-based alloys.

In a previous study, my research colleagues and I reported that the fatigue life of K403 nickel alloy samples subjected to 3 impacts of LSP were improved by 244% [2]. Through analysing the crack fracture morphology, it was found that it took more energy for the fatigue cracks to propagate in the laser shock peened samples than in non-peened samples.

Researchers have started to use LSP to improve the fatigue life of medical implants; initial work has shown that a flat rod of Ti6Al4V (TC4) titanium alloy conventionally used for biomedical implants can be laser peened to induce in-plane compressive residual stress ranging from -300 MPa - 350 MPa [3]. Additionally, an increase in the fatigue load ratio was observed.

In order to investigate the residual stress distribution of TC4 hip replacements, another investigation showed a 3-D hip modelled in Abaqus software to simulate the initiated cracks as the implant failed [4]. By using LSP, a compressive residual stress of 600 MPa was formed in the surface, shown in both simulated models and residual stress experiments. TC4,

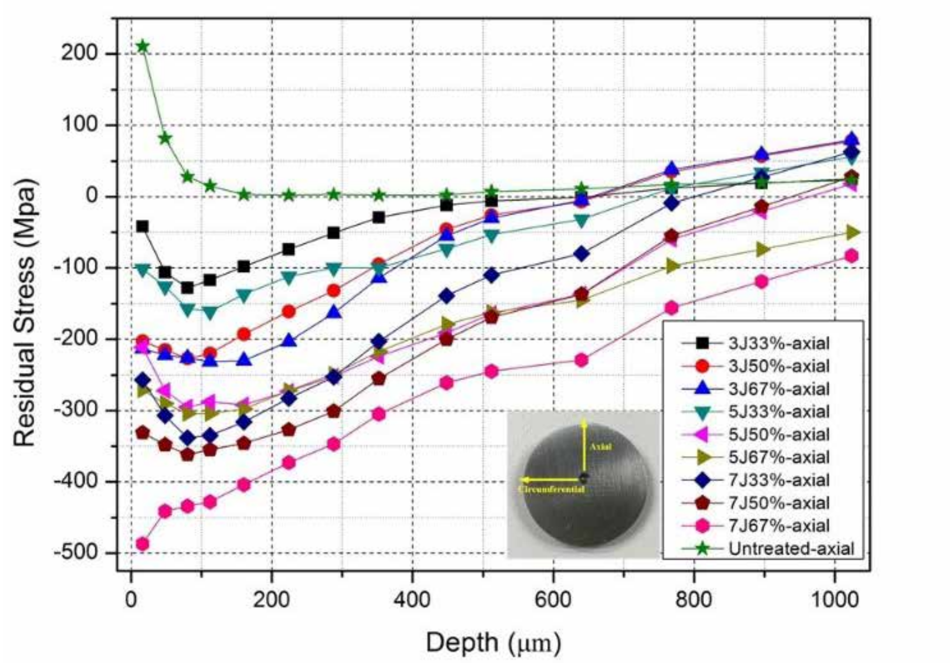

Figure 1: Illustrating the cross-sectional distributions of residual stress of Ti-6Al-7Nb before and after LSP (axial direction) [5].

however, is less ideal for a bio-implant than Ti-Al-67-Nb. This is because vanadium (present in TC4) is toxic when it is released into the body while niobium is non-toxic to the human body. In a previous study by myself and co-workers [5] we utilised Ti-Al-67-Nb for the first time to induce compressive residual stress of -41MPa to -516 MPa by applying laser energy of 3J, 5J and 7J with overlaps of 33%, 50%, 67% respectively. Results illustrated in Figure 1 show that Ti-Al-67-Nb can be laser peened as well as the other titanium alloys previously studied by others.

Corrosion

Corrosion has been a crucial problem with orthopaedic implants since metals were employed as biomaterials. For example, magnesium has excellent biocompatibility and has been widely used for fabrication of medical devices. Additionally, magnesium made implants can greatly reduce stress shielding effects as the density of magnesium and its elastic modulus are very close to human bones (density: 1.74 - 2g/cm^3 vs 1.8 - 2.1g/cm^3; elastic modulus: 42-45 GPa vs 40-57 GPa) compared to other traditional metal materials such as stainless steel and titanium alloys. However, magnesium was found to corrode in physiological and enriched Cl^- ions solutions [6]. What is more, hydrogen gas pockets were generated adjacent to the implants while Mg alloy was corroding. Therefore, the use of magnesium was greatly limited by its poor anti-corrosion capability in its further application in orthopaedic implants.

As a result, much research is being dedicated to improving the anti-corrosive properties of magnesium, with some success. Guo et al. [7], explored the process capability of laser shock peening to control the corrosion of magnesium-calcium implants by tailoring the surface integrity. More specifically, the importance of parameters such as overlap have been shown during the experiments, for example high overlap with lower power density on commercial purity Mg in simulated body solutions (Hank's solution) [8]. The results showed that the corrosion rate of peened samples was at least six times lower than unpeened samples and 66% overlap scans presented the least corrosion. Therefore, the improvement of corrosion resistance by LSP will enable metallic implants to endure longer in the human body, and reduce the risk of failure caused by corrosion.

Wear

Wear resistance is another important mechanical property of medical implants. Wear failure is responsible for 13.6% of all implant failures [9]. As mentioned, titanium alloy is an excellent material for manufacturing medical devices due to its superior biocompatibility and mechanical

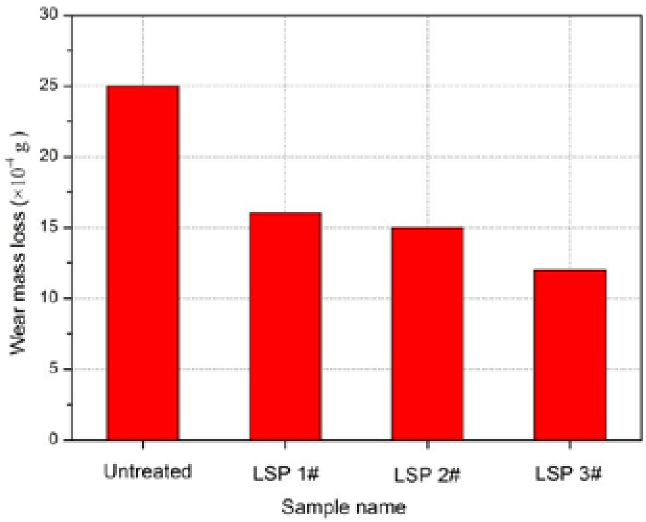

Figure 2: Wear mass loss of Ti-6Al-7Nb alloy [10].

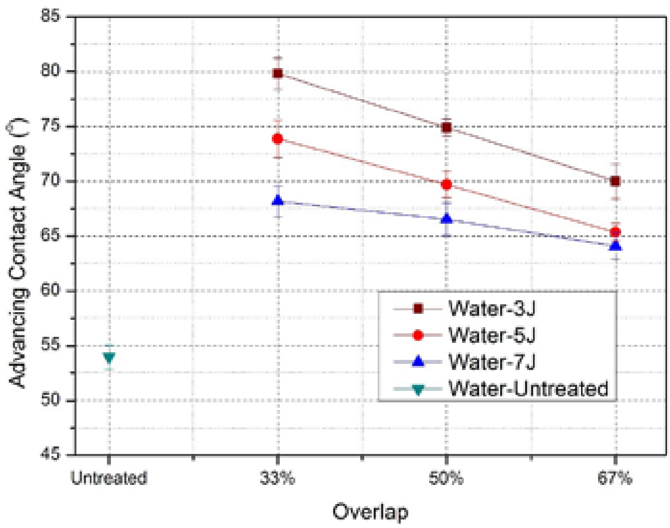

Figure 3: Advancing contact angle on both untreated and laser shock peened specimens for distilled water [5].

properties. However, its wear resistance ability is comparatively low and sliding wear data of titanium subjected to LSP is still scarce. In our previous work, a sliding wear experiment of Ti-6Al-7Nb subjected to LSP was carried out. The wear mass loss comparison of Ti-6Al-7Nb alloy coupons after dry wear experiments are shown in Figure 2. It can be seen that the wear mass loss of impacted coupons after successive laser peening impacts were much lighter than untreated coupons (25*10^{-4}g). This decreased with the increasing impacts. Hence, multiple LSP can effectively improve the sliding wear property of Ti-6Al-7Nb.

Wettability

Wetting characteristics of bio-material surfaces integrated with surface characteristics such as surface energy, macro and nano-topography play an important role in cell/protein adhesion and osseointegration (the connection between living bone and the surface of a load-bearing artificial implant). Wetting determines the biological chain interactions at the implant-tissue interface that include protein absorption to hard and soft tissue interactions, and cell interactions (adhesion, differentiation and migration).

Caralapatti et al. [11] recently investigated the effect of high repetition laser shock peening on wettability of pure Mg. It was found that the surface wettability of peened Mg samples was increased, with the contact angle being increased to 81.3°. Prabhakaran et. al. [12] came to a similar conclusion when they used LSP to peen the surface of austenitic stainless steel which is hydrophilic in nature. The contact angle of unpeened samples was 34.24° and the surface roughness was also increased by LSP. The unpeened austenitic stainless steel is hydrophilic in nature. But, after 1 impact, the contact angle was increased to 95.75°, thereby becoming hydrophilic as a result of laser shock peening.

Our group research is focused on the modification of wetting characteristics using LSP. The effects of laser energy (3J, 5J and 7J) and beam footprint overlap (33%, 50% and 67%) of LSP were explored on Ti-6Al-7Nb alloy, quantified by using the measurement of dynamic contact. The dynamic advancing contact angle of Ti-6Al-7Nb before and after LSP wetted with distilled water is presented in Figure 3. The contact angle of untreated samples with distilled water is 54°. In comparison, all LSP contact angles are higher than the untreated one. The contact angle values rise with the increase of laser energy at the same overlap. Meanwhile, the contact angles decrease with the increase of overlap at the same laser energy level.

Biocompatibility

At present, published literature evaluating cell behavior subject to surfaces treated by LSP is still scarce. A study on vitro cell culture demonstrated that LSP did not compromise the cytotoxicity of AZ321B in vitro [13] and still provided good strength to the part.

Creating Groove architecture on the titanium surfaces using LSP can enhance the osseointegration of an implant with the host tissue [14]. Osteoblast cell adhesion and differentiation on Ti-6Al-4V implants were also improved due to the modified surface morphology by LSP. Like other mesenchymal-derived cells, osteoblasts are one of the most crucial cell types during the recovery stage after the surgical implant procedure. They need anchorages to survive, proliferate, and differentiate, which LSP modified surfaces can provide.

Conclusion

Laser Shock Peening has a great potential to enable biomaterials to improve fatigue, corrosion, wear resistance, and create surface 'anchorages' for cell attachment. This surface modification technique is very useful as it not only induces unique topography but also induces compressive residual stresses that are highly beneficial for the end user.

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SEE OBSERVATIONS P28

LASER PROCESSING AND REMOTE MAINTENANCE IN FUSION DEVICES

KEELAN KEOGH

Over the last 6 years the Remote Applications in Challenging Environments (RACE) department at the UK Atomic Energy Authority (UKAEA) has been investigating the use of laser processing in remote handling maintenance operations. Over the past 20 years RACE has gained a large amount of experience in over 30,000 hours of remote handling operations by maintaining the JET (Joint European Torus) fusion device based at Culham, Oxfordshire. The key areas of remote maintenance inside a fusion device include handling components, bolting operations, mechanical cutting techniques, and TIG welding activities. However, these techniques are slow, and the reactors of the future require short maintenance durations to maximise power output. Laser processing has the potential to provide significant gains in processing speed, to cut down the maintenance time and increase the operation availability of the reactor.

Remote maintenance challenges

Remote maintenance of a fusion reactor is a major challenge. Inside, the environment must be kept ultraclean as contaminants affect the operation of the reactor. The reactor also becomes highly radioactive for a relatively short period after operations which prevents human access, requiring full remote maintenance of the machine and connected equipment. This has many similarities with designing for space robotic applications.

RACE has been facing these challenges on JET and has also been investigating solutions for the next large-scale fusion machines that are under development: ITER and DEMO. ITER is currently being built in the south of France and will be the world's biggest fusion reactor. This international project is supported by members from all over the world representing 80% of the world's population. ITER will create stable fusion plasma and prove the output power of such a device can be more than the input by a factor of 10. After ITER, a demonstration powerplant connected to the grid is planned, called DEMO.

Remote maintenance of fusion power plant has the additional challenge of minimising maintenance durations to get the reactor operational again. The remote maintenance system must be highly efficient and reliable to ensure the reactor can begin power generation again. It is proposed that DEMO will have a 6-month maintenance cycle every 5-10 years

Figure 1: Concept Section of DEMO reactor with vertical port showing service pipes and armour extraction.

[1] depending on its operational use. This maintenance intervention is required because interactions of the plasma on the interior of the reactor cause damage to the front armour, which must be removed and replaced (Figure 1). To remove these sections of the reactor, hundreds of coolant pipes connected to these components will need to be disconnected and removed from the access ports. Due to the number of pipes for each reactor component, there will be significant space constraints in the access ports. To solve this, the current maintenance strategy focuses on in-bore operations for DEMO.

Advantages of laser processing

Traditional remote maintenance activities used on JET and planned for ITER have used mechanical cutting and TIG welding techniques to replace pipe segments and components in vessel. In future power plant reactors these activities are key to the maintenance of the reactor.

As a key activity, the overall duration of these operations has a critical effect to the cost of electricity. Investigation of the current techniques of dry mechanical cutting and multi-pass TIG welding showed estimated durations of 30 minutes to cut through one pipe and eight minutes to weld them back together. There are close to 1000 pipes that must be replaced.

The physical act of cutting and welding of the pipe network equates to approximately 20% of the overall 6-month maintenance window of the reactor. Using laser processing systems, the cutting and welding process time is reduced to approximately 0.8%. In a future fusion reactor, like DEMO, this would be a significant cost benefit to the operation of the plant and the down time. But the challenge to achieve this time advantage is the deployment and operation of laser processing heads in a fully remote system.

University trials

Due to the exotic nature of many nuclear steels proposed for DEMO, an initial piece of collaborative work was carried out with Cranfield University, to investigate the weldability of the pipe material known as Eurofer-97, a ferritic

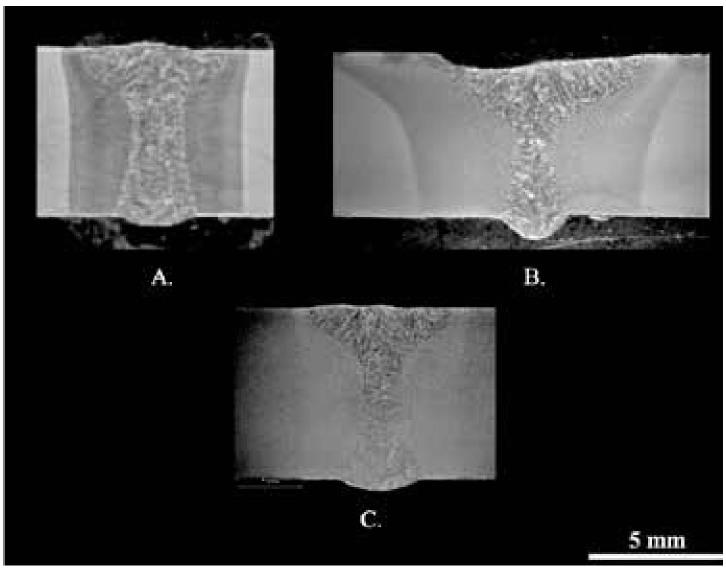

Figure 2: Cross-section micrographs of the laser weld samples: (A.) P91 Keyhole, (B.) P91 Hybrid and (C.) Eurofer97 Keyhole.

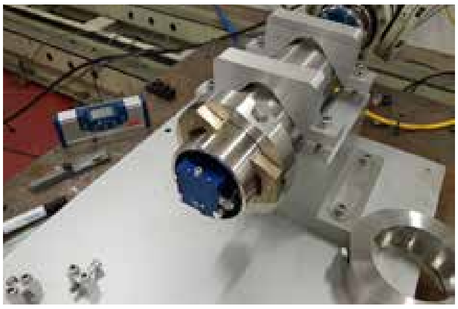

Figure 3: Bespoke Optics testing at TWI

Figure 4: Cutting tool

martensitic steel with low neutron activation properties. Plate samples of P91 and 316L, 10 mm thick, were used as a substitute material for the more exotic Eurofer.

These were welded at Cranfield University to optimise the process parameters and the achievable weld quality [2]. Once the parameters were optimised on the substitute material, tests were carried out on a 5 mm-thick available sample of Eurofer. These trials demonstrated the feasibility of laser processing for this application (see Figure 2), but available tooling heads were not suitable for deployment in the small bore pipes. To cut and weld pipe diameters as small as 90 mm with 5 mm wall thickness a bespoke experimental solution was required for remote deployment.

Remote maintenance tool solution

A core team of mechanical engineers at RACE (Keelan Keogh, Simon Kirk and Tristan Tremethick) developed prototype remote tools. The team investigated various concept designs using laser processing parameters identified with earlier tests carried out at Cranfield University with the aim to cut and weld a 5 mm thick walled steel pipe with 90 mm internal diameter.

The design was developed by RACE, working alongside colleagues at TWI and IPG. Tests were carried out at TWI's facility in Cambridge (Figure 3). These tests proved the heat management and optical set up of the tool could withstand the duration of the process.

With the data from the trials at Cranfield and optics tests carried out at TWI, the full tool, including the housing for the laser, has been designed and tested on DEMO-relevant materials. The tool is designed to be deployed through a 12 m long 90 mm pipe. When it reaches the connection point it will use laser processing to connect or disconnect the pipes from the inner wall of the reactor. These tools have been prototyped (Figure 4) and tested at TWI.

The cutting process has proven highly successful, with minimal debris released in the area and clean separation of the pipes. In other scenarios the cut surface would be described as poor because parameters have been selected that leave much of the molten metal stuck to the pipe. However in this process, minimising released debris is of high concern to ensure cleanliness is kept inside the reactor. The quality of the cut can be seen in Figure 5.

Achieving a welding process to nuclear standards has proven more challenging. The tool has successfully welded pipes with a good weld form but has not made a fully compliant weld to date.

Using such a tool on a DEMO reactor in the future would be advantageous. Primarily, a tool of this sort will be required for reactor maintenance tasks such as the cutting of pipes to remove neutron-damaged parts, as well as their subsequent replacement and welding of the new components. Both laser cutting and welding heads were designed to be small enough to fit inside the reactor's pipes. The design also offers potential applications beyond fusion. This includes maintenance work in a range of challenging environments such as the oil and gas industry.

This work (funded by EUROfusion) has already received international recognition with Simon Kirk's design of laser optics awarded second place at the 2018 European Prize for Innovation in Fusion Research.

This technology has huge advantages to the maintenance strategy and duration of DEMO, helping to provide a viable power plant solution. We have made great progress with these initial trials, and plan to develop this technology with further trials and the DEMO design develops.

Conclusion

In summary RACE has shown the feasibility of cutting and welding the hundreds of pipes that will be inside future fusion powerplants. With laser processing, remote tools will be able to operate within the proposed 6-month maintenance window. The process is feasible but not yet reliable and will require future development to improve reliability and consistency of the welding process, reducing the risk to the maintenance operations, culminating in the proven high quality highly repeatable process required for DEMO operation. The cutting process is demonstrably a more successful process than welding. Laser processing has significant advantages over traditional techniques and their use would dramatically reduce the overall process window. The next challenge is to reduce the logistics and deployment time using advanced robotic solutions to further reduce the overall duration of the maintenance. These developments for fusion technology also have high potential for other applications where high-speed remote cutting welding is needed.

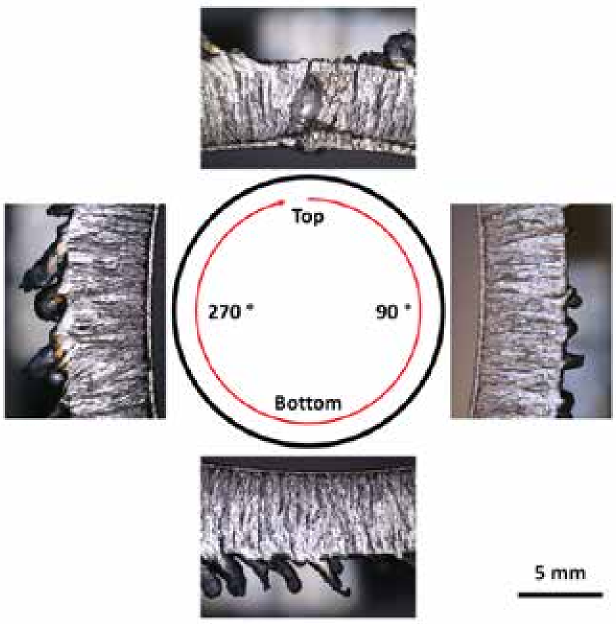

Figure 5: Cut edge of pipe after processing

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Acknowledgements

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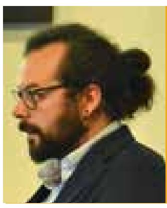

Keelan Keogh is a Mechanical Engineer at UKAEA, researching advanced techniques for cutting, welding and remote handling in experimental reactors.

SEE OBSERVATIONS P28

DISMANTLING NUCLEAR POWER PLANTS USING LASER TECHNOLOGY

OLIVER MEIER

Dismantling nuclear power plants is a huge challenge. The overall aim is to reduce the amount of nuclear waste to a minimum. Hazardous manual work also needs to be minimised. The use of laser technology enables the nuclear industry to get closer to both those goals. Radioactive contamination is mainly found on the surface of components and so it needs to be removed and stored. The rest of the part can be recycled or scrapped in the conventional way, after proving a residual contamination below the required limits.

Conventional decontamination methods

Conventional methods used for decontamination of nuclear components are mechanical processes (e.g. grinding or sand blasting), chemical- or electro-chemical processes. These methods create a number of additional challenges, such as secondary waste (chemicals, abrasives), and contamination transfer. Moreover, some of these methods are relatively slow and costly. Some processes are limited with regards to geometrical accessibility, especially when inner surfaces of tubes and vessels need to be treated.

There is a demand for alternative processing methods which do not create secondary waste, avoid contamination transfer and allow a high degree of automation because of the large surfaces to be treated. These methods should be universal and cost-effective.

Can lasers provide a solution?

The proposed decontamination and dismantling solution is laser ablation, based on pulsed laser radiation with a high pulse peak power and a pulse repetition frequency in the range of 10-100 kHz. When focused on the material, a thin layer will immediately evaporate by means of the high energy pulses and thus ablate a spot of some tenths of a millimetre in diameter and some microns in depth. With fast movement of the beam in one direction and a slow movement of this line in the perpendicular direction, a homogeneous area will be ablated. Feed rate of movement and pulse repetition rate are selected so that the pulses overlap.

Using an average power level in the kW range, the laser ablation process is fast (typically 1-4 m^2/h) flexible in terms of programmable patterns, part geometries and different metal alloys, and contact-free. Moreover, by using a suitable optics design, a reasonable position tolerance of the focal plane of approximately ±2 mm can be achieved. Due to the fact that most metal surfaces contain oxide layers and these oxides are usually darker than the base material, selective absorption occurs. The contaminated oxide layer allows a higher absorption of the laser radiation compared to the base material, so the ablation process is more or less self-regulating and ablation of the base material is slowed down.

Typical ablation depth is 5 µm, so the volume of ablated material is very low compared to the volume of bulk material. Therefore, a relatively low air flow rate is sufficient for a safe emission of particles. These particles are collected in filters, and disposed of in accordance with regulations.

The following workflow is planned:

1. Rough cleaning of contaminated components.
2. Disassembly of the components into segments of approximately 1,500 mm x 1,500 mm.
3. Automatic decontamination by laser ablation.
4. Scrappage of contamination-free components.
5. Disposal of contaminated filter elements.

Demonstrating the method

Preliminary investigations for laser ablation of oxide layers on stainless steel sheets were carried out. The surfaces of rolled sheets were machined. This differs from the surface topography of the inside of the reactor pressure vessel, but the machining of strongly curved surfaces demonstrates that the laser beam removal method has a good focus position tolerance, which allows processing of uneven surfaces. At the same time, parameter sets for laser ablation for decontamination were developed. All previous investigations were carried out on contamination-free components, which meant that decontamination by laser ablation still needed to be explored.

A demonstration at EON power plant in Wuergassen, Germany, was carried in 2008. For ablation tests, a 500 W nanosecond pulse laser and a fibre-coupled scanner optics were used. Since the investigations were carried out in a controlled area, the following components of the system technology had to be protected against contamination:

- Laser processing head including laser light cable.
- Test rig.
- Manually operated part of the laser including the supply cable.

The laser was outside the controlled area and the beam was guided by means of fibre optic cable, which has been passed through a core hole in the control zone. The length of the fibre optic cable was limited to 10 m. The extraction of the aerosols was carried out by a mobile filter unit, which was fixed directly above the laser

Figure 1: Controlled experimental area.

Figure 2: Cleaned area after a single laser ablation.

head. The existing cabin extraction was disabled during the experiment. As a result, reliable values for type and quantity of emissions could be determined in a spatially resolved manner (Figure 1).

The client provided surface-contaminated sample parts. Handling of the contaminated components was carried out in cooperation with radiation protection experts. To set up the removal process, preliminary tests were carried out on contamination-free components. Figure 2 shows an example of the processing result after a single laser ablation of the near-surface oxide layer of an aluminum profile. The robustness of the process can be clearly seen by the homogeneous removal result over the entire surface, which includes the steep component areas as well as the corners of the ribs.

The components were machined by alternately ablating a square field (about 60 mm x 60 mm) and placing the component on a test fixture (Figure 3). Contamination removal results were evaluated by means of wipe tests and measurement of the radiation dose rate.

The results showed good decontamination success (about 2/3) after a single surface treatment. The remaining residual contamination was due to component handling, which resulted in a return contamination through the support surface as well as ablation condensate. This can be remedied by improved component handling (e.g. conveyor belt or fixed restraint) as well as an optimised air duct to extract emissions. However, residual contamination remaining in the near-surface region cannot be excluded, so that repeated processing of the same surface field may be necessary. It is expected that the residual contamination can be almost completely eliminated in the case of multiple removal of deeper layers.

The processing time per field (60 x 60 mm) was approximately 6 seconds, which corresponds to a surface removal rate of approximately 2 m^2/h. Due to the required component handling between the processing steps, an area coverage of 1 m^2/h is expected for future applications.

Future case studies

Recently, LASER on demand was asked by different end-users for in-tube decontamination, particularly for evaporator tubes. Approximately 300 km of straight tubes from 30 evaporators with a total weight of 162 tons require treatment. Currently, this is carried out by chemical decontamination and subsequent melting down (if required level of remaining contamination is reached) or complete disposal.

Tubes will be cut into pieces of 1m length followed by automatic laser processing. The tubes may be cut into half shells and flattened if necessary. Then, the laser ablation process is used followed by an automatic measurement of remaining contamination. This allows an automatic re-work if necessary (Figure 4).

Figure 3: Component machining.

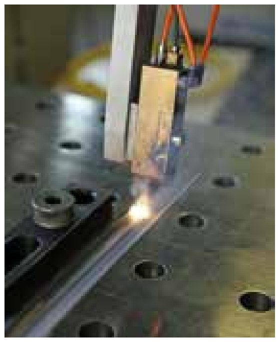

Figure 4: Laser processing head.

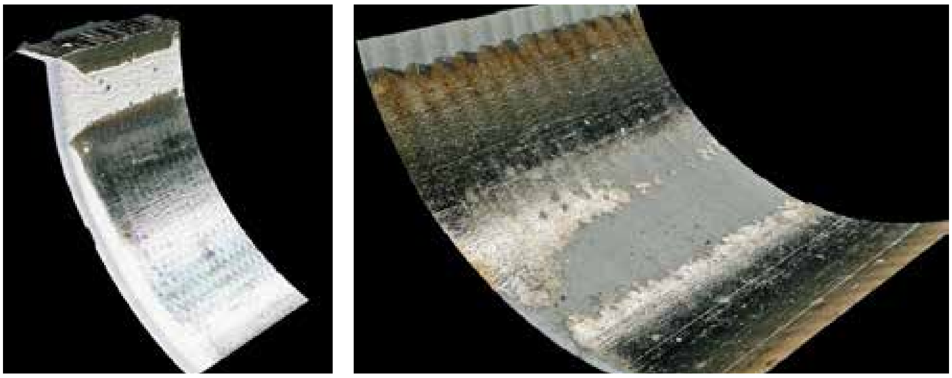

Figure 5: Incomplete laser ablation due to curvature of tube surfaces.

Figure 6: Improved laser ablation after flattening tube half-shells.

Depending on the tube inner diameter, the process robustness at curved surfaces is limited, which may lead to an insufficient ablation (Figure 5). This can be avoided by flattening the tube half shells before the laser ablation process (Figure 6).

Conclusion

Laser-based decommissioning techlologies show great potential. The amount of material to be processed requires fully automatic solutions. The resulting high economic benefit is based on the drastically reduced amount of contaminated waste. The volume reduction rate of the laser based process is better than 1:100, or 10 kg of waste per 1 ton of material. Depending on the surface conditions, ablation rates between 1 and 4.5 m^2/h can be realised.

In future, a direct in-tube ablation process will be tested to overcome known limits and avoid the necessity of cutting half-shells, which will save time and money. That solution will be integrated into a fully automatic system. The first prototype is planned to be set up and tested under real-life conditions by the end of 2019.

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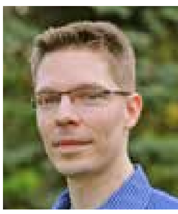

Oliver Meier is owner and managing director of LASER on demand GmbH, a German SME for laser processing technology and mobile laser use.

SEE OBSERVATIONS P29

THE RISE AND RISE OF THE FIBRE LASER

JOHN POWELL

John Powell is the latest recipient of the AILU Award, presented to him at ILAS 2019. The award recognises an individual who has made an outstanding lifetime contribution to the industrial use of lasers in the UK. John "wrote the book" on laser cutting and has run one of the earliest commercial laser job shops successfully putting into practice his knowledge, having studied at Liverpool University under Bill Steen. John also was an instrumental founder member of AILU and had the vision for pulling together the UK job shop community.

Way back in the mists of time the laser cutting market was completely dominated by the carbon dioxide (CO_2) laser. These had progressed from laboratory toys to industrial machines in the 1970s and 80s, and by the 1990s they were multi-kilowatt plug-and-play devices with a high level of reliability. By the turn of the millennium the laser cutting industry was generally considered to be mature and growing steadily. No-one was expecting any major steps forward in the technology by that point.

So, in about 2006 I was not alone in being highly sceptical of the claims salesmen were starting to make about a revolutionary new laser cutting technology – the fibre laser.

Early results from these new lasers were interesting but patchy – they were probably going to overtake CO_2 lasers for cutting thin section (3mm and below) steel because they cut faster, but in thicknesses above about 5mm the surface quality was well below what we'd come to expect from the CO_2 machines.

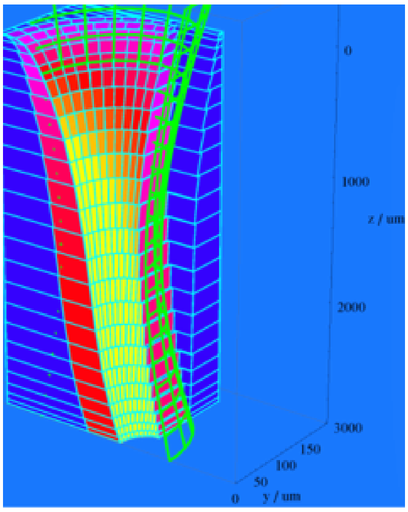

Figure 1: CO_2 laser light creates a smooth cutting front which automatically produces a high quality cut edge [1].

Experts like Dirk Petring [1] got to work on why the cut quality on thicker sections was inferior and soon found the answer; in the case of CO_2 lasers the cut front was smooth and so the liquid metal flowed downwards in a very orderly way (see Figure 1) – leaving only minor ripple patterns on the cut edge.

In the case of fibre lasers the different wavelength of the light meant that the laser beam bounced around a lot more inside the cutting zone (see Figure 2), creating hot-spots and little bumps on the surface of the melt as it flowed down the cut front. These hotspots and bumps resulted in a much more turbulent, fluctuating melt flow which left behind a rougher cut edge (see Figure 3) – which got progressively rougher at thicker sections.

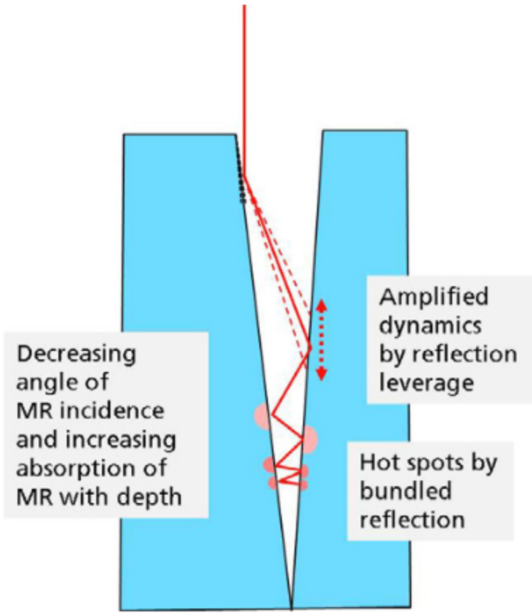

Figure 2: The 1 micron wavelength light from a fibre (or disk) laser bounces around inside the cut zone creating hotspots and bumps on the cutting front [1].

Once the problem had been identified, the applications team at IPG (who developed the fibre laser) got to work to come up with answers. They and similar teams at firms such as Bystronic, Salvagnini, Mazak, Mitsubishi, Kimla and Cincinnati, who use IPG lasers in their cutting machines, and TRUMPF (who had developed the disk laser which, from the point of view of cutting is very similar to the fibre laser) created technological answers which resulted in cutting qualities which were comparable to (or even better than) CO_2 quality cuts – as you can see in Figure 4.

With cutting quality under control, fibre lasers were now on a roll. This is demonstrated by comments made by Dave Larcombe (then MD of Bystronic UK) in the April 2017 edition of Machinery World. In this article Dave stated that for the last year and a half Bystronic had not sold any CO_2 lasers, but sales of fibre lasers were doing very well.

My own experience confirms this – the last two lasers my company bought were fibres – and the next one will probably be another fibre. The trend towards fibre lasers is also clear from the literature on the subject. In 2008 I wrote the LIA Guide to Laser Cutting [2] which included only a tiny section on fibre lasers. The most recent version of this book (The LIA Guide to High Power Laser Cutting, 2017) [3], devotes about half of the book to fibre lasers. Table 1, taken from the guide, shows the increased speeds at thin section which a fibre laser can achieve when cutting stainless steel (these results are not for a particular model of laser – just generic 5kW machines).

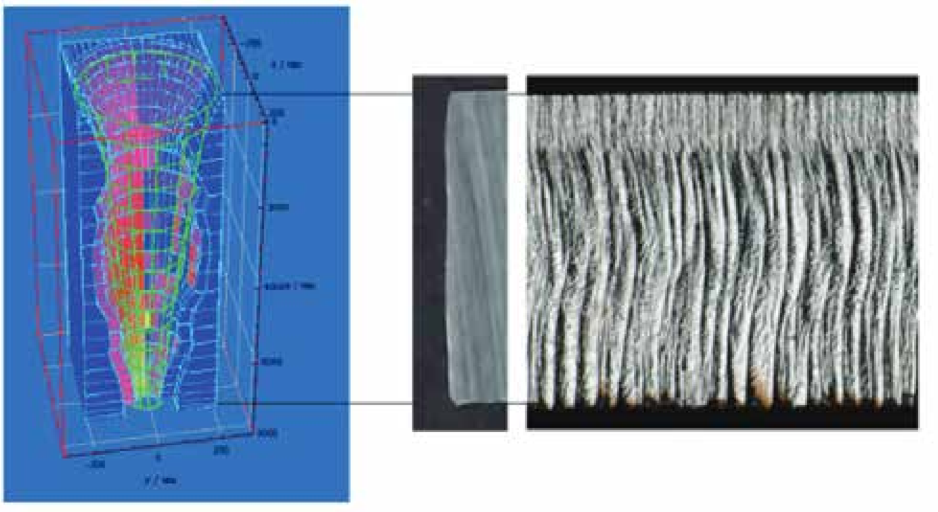

Figure 3: The hotspots and bumps on the fibre laser cutting front produced a rougher cut edge until R&D teams at a number of firms and institutions developed techniques to tackle the problem [1].

Figure 4: High quality cut edges are now possible in thicker section metals (Photo courtesy of IPG)

Thickness (mm)	Cutting speed – CO_2 laser (m/min)	Cutting speed – fibre laser (m/min)
1.0	20.0	48.0
2.0	12.0	24.0
3.0	5.0	11.0
4.0	4.0	6.5
5.0	3.0	5.0
6.0	2.4	3.7
8.0	1.6	2.0
10.0	1.2	1.0
12.0	0.9	0.75
15.0	0.6	0.45
20.0	0.4	0.22

Table 1: Stainless steels - 5 kW laser cutting machines (nitrogen assist gas) [3]

As most laser cut stainless steel is below 6 mm thick it is easy to see that the speed advantages of the fibre laser are commercially important. Similar (or better) improvements in productivity are also possible with non-ferrous metals and carbon steels. The only place where the fibre laser falls down is in the cutting or engraving of plastics and wood-based materials – because the 1 micron wavelength light passes straight through these materials.

In addition to increases in productivity, the fibre laser has other advantages over CO_2 laser technology including;

- Reduced energy consumption – because fibre lasers are more electrically efficient than CO_2 machines.
- Reduced start-up time.
- Reduced physical footprint – because the lasers are smaller (although the cutting tables will, of course, be the same size).
- Reduced maintenance downtime – largely because fibre lasers don't have moving parts such as vacuum pumps and blowers which are incorporated into CO_2 machines.

In the early days there were problems with the cost of parts which broke down on fibre lasers – including the fibre connectors and the modules of diodes which power the machines, but these have largely been dealt with as a result of improved reliability and increases in warranty periods.

Given all these advantages it's not surprising that fibre lasers are ruling the roost. It seems that, in the UK at least, the future of the CO_2 laser will be confined to the niche market of cutting or engraving plastics and wood based products.

Reference

[1] Dirk Petring, Thomas Molitor, Frank Schneider, Norbert Wolf. Diagnostics, modeling and simulation: Three keys towards mastering the cutting process with fiber, disk and diode lasers. Physics Procedia 39 (2012) 186 – 196

[2] LIA Guide to Laser Cutting, 2nd Edition (2008), John Powell. ISBN 9780912035161.

[3] LIA Guide to High Power Laser Cutting (2017), John Powell, Dirk Petring, Jetro Pocorni, Alexander Kaplan. ISBN 9781940168111.

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John Powell is technical director of Laser Expertise Ltd which he co-founded in 1984. He is the author of three books on laser cutting.

SEE OBSERVATIONS P29

A LIFETIME OF LASERS AND THE EYE: 1965 TO 2019 SO FAR!

JOHN MARSHALL

This brief review of the use of lasers in ophthalmic procedures by John Marshall is comprehensive in its scope. This is not surprising since John has been involved in many of the developments over the past 50 years from the use of lasers to treat eye-related diseases caused by diabetes, glaucoma and cataract surgery complications leading to posterior capsular occlusion. However, John is perhaps best known for developing the technique of using short wavelength pulsed excimer lasers to shape the cornea to correct vision defects such as astigmatism, short and long sightedness.

I was fortunate to have first met John in the early 1980s when he came to use our excimer lasers for his early animal cornea trials. As he mentions, 60 million people worldwide have now undergone various types of excimer laser refractive surgery - myself included more than 30 years ago! His current work on developing a laser treatment for age-related macular degeneration demonstrates John's ability to continue to innovate in the latter stages of his career. If successful, this technique could alleviate the blindness caused to millions of people in later life.

John is somewhat unusual in the sense that he manages to combine the varied roles of academic researcher, clinician and entrepreneur able to successfully commercialise potential developments of his research. Familiar with the physics and engineering of lasers, systems and their industrial applications, he has always been well placed to judge their potential uses in ophthalmology and other wider surgical applications.

During his distinguished career John has received many awards and accolades for his work too numerous to mention here. That said, he is now the worthy recipient of another one – the inaugural 2019 AILU 'Laser Ambassador Award' dedicated to 'those individuals who work to introduce laser technology to people outside the laser community'.

Malcolm Gower, Imperial College London

LASER SHOCK PEENING IN THE MEDICAL SECTOR - AN OVERVIEW

XIAOJUN SHEN

With continuously improving living standards, the demand for biomaterials for orthopaedic implant applications has increased dramatically over the past several decades. The orthopaedic titanium alloy (Ti-6Al-7Nb) investigated in Xiaojun's study is widely used for clinical applications. However, there are still some emerging problems, i.e. stress shielding, fatigue and degradation, which seriously impedes its biomedical applications. Laser surface treatment techniques, like laser shock peening and laser surface texturing could provide a good solution to these problems.

Xiaojun used laser shock peening to process titanium alloy and investigate its mechanical, wettability and biocompatibility behaviour before and after laser shock peening. The results showed that laser shock peening can significantly improve the mechanical properties of the titanium and enhance its biocompatibility. This article develops a set of optimum LSP processing parameters for the treatment of Ti-6Al-7Nb to achieve suitable surface properties. The work here is of great significance to promote the application of Ti-6Al-7Nb titanium alloy as biomedical materials. Excellent work!

Yang Jiao, Cardiff University

The article presents an overview of laser shock peening (LSP) research in the biomedical space referencing both the author's research as well as other similar research. LSP has been around for many years and is now a well-established process for inducing compressive residual stresses into a part to improve its performance. Xiaojun gives a brief summary of the history of LSP which had its roots in the aerospace industry but is now being explored for other applications including medical. He references cases of LSP to improve the fatigue life of medical implants with initial work showing that a flat rod of Ti6Al4V alloy conventionally used for biomedical implants can be laser peened to induce in-plane compressive residual stress ranging from -300 MPa - 350 MPa. An increase in the fatigue load ratio was also observed.

In another study investigating the residual stress distribution of Ti64 hip implants it was shown that by using LSP, a compressive residual stress of 600 MPa was formed in the surface, shown in both simulated models and residual stress experiments. The author's work focuses on another titanium alloy, TiAl67Nb because of its better biocompatibility that Ti64. Results presented in the article show that TiAl67Nb can be laser peened. The article goes on to include research on magnesium alloys and their corrosion resistance which was improved under LSP. Similarly, the wear resistance of TiAl67Nb was also shown by the authors to be significantly improved under LSP.

Overall, an informative article on the application of LSP to medical implants. Perhaps some information on the actual process would have been useful and information on the experimental details would have helped some readers better appreciate the technology as it is relatively complex to use.

Milan Brandt, RMIT University, Australia

LASER PROCESSING AND REMOTE MAINTENANCE IN FUSION DEVICES

KEELAN KEOGH

The article highlights very well the versatility and flexibility of laser technology. Good focusability of lasers and fibre delivery optics enabled the required level of miniaturisation of the processing tools, which was the main enabler in this application.

Well done to all the RACE team for demonstrating the feasibility of in-bore laser cutting and welding in such small pipe diameters. The first major achievement has been made, further steps will require significant work on process automation and autonomy including development of robust process monitoring, control and metrology.

To fully benefit from high productivity of laser processing the process will have to be implemented with a high level of automation, including pipe handling and tool positioning, hopefully the fusion nuclear industry is ready for this.

We should also remember the requirements of the material in terms of acceptable thermal cycle range to achieve suitable mechanical properties, which will limit the operating window. But the work shows a very positive message from the conservative nuclear industry.

Wojciech Suder, Cranfield University

PICOSECOND SCRIBING AND DRILLING OF PHOTOVOLTAIC FILMS

DIRK MÜLLER ET AL.*

Laser processing of thin film PV devices using ultrafast lasers has been around for a few years and this article neatly summarises the pertinent aspects of the techniques. For laser engineers the actual details of the processes (such as typical laser wavelengths, fluence and conditions) are of as much interest as the concepts themselves so in this regard it would have been very useful to have some detailed quantitative information on the processing of the different PV layers.

The article also mentions some other areas of major interest currently - beam shaping, ultra-high speed scanning methods and 'crack-free' glass cutting - and this highlights how it is the careful amalgamation of various techniques which is critical in exploiting the full benefits of the latest range of industrial lasers.

Nadeem Rizvi, Laser Micromachining Ltd

DISMANTLING NUCLEAR POWER PLANTS USING LASER TECHNOLOGY

OLIVER MEIER

Oliver's article clearly highlights the significant benefits that laser processing brings to sensitive decontamination applications, such as those required by the nuclear sector.

The ability to remove surface contamination from components without the physical contact and subsequent drawbacks of conventional methods such as brushing, scraping, polishing, shot blasting or indeed through the use of chemical substances, offers a distinct advantage, especially in a sector that is already so highly monitored and regulated.

Just as the laser has become a valued production tool in many other industries, the ability to use this technology either as a hand held system, or integrated to a highly flexible robot system, will offer the broadest range of solutions for the different types of componentry which will require cleaning during decommissioning. Oliver's explanation of the technology in this exemplary article reinforces the case for a greater uptake of laser processing.

Andy Toms, TLM Laser

Fibre-delivered laser beam technology has advanced tremendously over the past decade, with numerous suppliers now capable of providing robust, industry-proven laser sources. The application of this technology to dismantle nuclear power plants has the potential to allow cutting and decontamination processes to be performed remotely, critically removing or reducing the risk to humans. The technology also enables cutting and decontamination to be performed faster than incumbent techniques, and, with the correct manipulation, allows selective processing to minimise waste volume.

Because of this, laser cutting is now progressively being adopted by the industry to dismantle complex metallic components, and supporting the 'safer, cheaper, faster' mantra of the UK nuclear industry.

This article clearly highlights the potential benefits in using fibre delivered lasers for nuclear decontamination applications. Particularly, if the fully integrated laser system is also mobile, the flexibility of the technology for both in-situ and ex-situ operations can also be realised.

Ali Khan – TWI Ltd

THE RISE AND RISE OF THE FIBRE LASER

JOHN POWELL

I remember John's scepticism in the early days, but everything he says here is true. The fibre laser has radically changed the landscape as far as the laser cutting industry is concerned. Because the laser itself is available as a 'bolt on' more and more manufacturers are springing up, particularly from Eastern Europe and China with machines considerably cheaper than the traditional suppliers. In my new role, since I left the job shop business, I am amazed everyday by the sheer numbers of machines out there.

Dave Lindsey, ipCompute UK

As I read this article looking back at the demise of CO_2 and the rise of fibre, I can't help but wonder what will be coming next in the world of lasers. Table 1 shows us clearly that CO_2 is still faster for cutting in some cases, but I think back to my experience at EuroBLECH 2018, with manufacturers of fibre cutting machines proudly displaying samples of cuts up to 60 mm thickness. Of course, the cut quality was terrible, but with further advancements in 1 micron technology, beam shaping technology and zoom optics becoming more common, this can only improve, to the point where fibre is competing with traditional plasma and flame technologies at these thicknesses. It will be exciting to see what developments come next.

Nathaniel Marsh, Laser Trader

PRODUCT NEWS

SYSTEMS & SOURCES

BYSTRONIC'S NEW FIBRE LASER CUTTERS

12 kW flatbed cutting machine

Bystronic has introduced a new version of its ByStar Fiber flatbed laser cutting machine with a 12 kW source for faster, more efficient production of components. The previous maximum laser power was 10 kW, compared with which the latest model is on average 20% more productive when cutting with nitrogen as the assist gas.

The fibre laser cutting centre has a new BeamShaper function and a newly designed cutting head that ensures consistent quality of cut when processing material thicknesses from 3 mm up to a maximum of 30 mm. The results are reduced cost per cut, shorter delivery times, reliable operation across a broad spectrum of applications and low maintenance costs.

New entry-level fibre cutter

A new flatbed laser cutting machine has been introduced by Bystronic, aimed at sheet metal processing companies wishing to exploit the high productivity of fibre technology and its broad range of applications. The competitively priced BySmart Fiber can be supplied with a laser source of 2, 3, 4, or 6 kW and optional automated material handling solutions to allow the full potential of the machine to be utilised.

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COHERENT'S NEW LASER AIDS MICROMACHINING

The Coherent HyperRapid NXT is a high-power picosecond laser that employs advanced pulsing technology to enable micromachining with precision and a minimal heat affected zone (HAZ). Specifically, HyperRapid NXT implements Coherent's PulseEQ technology, which delivers strings of synchronous, invariant pulses on demand from an external trigger signal. This jitter-free, precision triggering and advanced energy control enables system builders to benefit from the high-speed synchronization capabilities now available from state-of-the-art scanners and stages.

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SOFT SIGNAGE CUTTING FROM CREST MACHINERY

Crest Machinery now supplies the new Aristo cutting device, the LCDone, for large format soft signage. A combination of laser and motorised rotating or tangential drag knife cutting can be carried out in one set-up. The Large Format Cutter series provides up to 5x7 m working area.

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ANCILLARIES

II-VI SHOWCASES NEW PRODUCTS

High power collimated laser bars and collimated semi-framed stacks

II-VI Inc. has introduced high power laser bars and semi-framed stacks mounted with micro-optic collimator lenses, offering customers very cost-effective modular assemblies that have high performance and reliability and can be easily integrated into direct diode lasers and diode-pumped solid state (DPSS) lasers.

Laser cutting head with zoom optics for ring-shaped laser beams

The rapidly growing adoption of ring-shaped laser beams for applications such as cutting thick mild steel is driving the demand for versatile laser cutting heads with matched optics. II-VI's new BIMO-FSC-L laser cutting heads, with their wide magnification range of 1.3 to 3.6 and large numerical aperture of 0.18, deliver the complete solution.

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PRODUCT NEWS FROM SCANLAB

Scanlab focuses on demanding applications

The new excelliSCAN 20 scan system targets exceptionally demanding applications such as micromachining and additive manufacturing (3D printing).

The excelliSCAN family's existing features – such as smart servo control technology, a universal tuning and optimised cooling – will be supplemented via the new scanner with its larger 20 mm aperture.

Scan solutions for green lasers

SCANLAB is extending its precSYS product line with a subsystem optimised for 515 nm green lasers. This leads to a much smaller spot size and enhanced lateral precision in processing challenging materials. At the same beam aperture angle, a larger aspect ratio is achievable.

Five-axis precSYS subsystems enable industrial ultra-short-pulse laser micromachining of flexible, definable geometries with high aspect ratios. The availability of a subsystem optimised for 515 nm lasers is particularly attractive in the electronics industry.

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NEW LASER TOOLS FROM JENOPTIK

New vision-enhanced laser system

Jenoptik is introducing an optical system for integration into laser production systems for micromaterials processing. This compact plug-and-play system is easy to integrate and caters for various process-related requirements in laser production.

The system comprises a 2D galvo scanner, F-theta lens, and a camera with integrated image processing and intelligent software. System integrators benefit from shorter development times and a smart software solution, which enables users to get up and running quickly.

New F-theta lens for materials processing

Jenoptik has added a new UV lens to its JENar™ F-theta range for laser material processing: the new fused silica F-theta lens for 355 nm applications, with a focal length of 56 mm and a scan field of 22 mm. Depending on the application, the optics allow very small spot diameters up to 4.5 microns. The lens is specifically designed for use in micro material processing and for ultra-short pulse applications.

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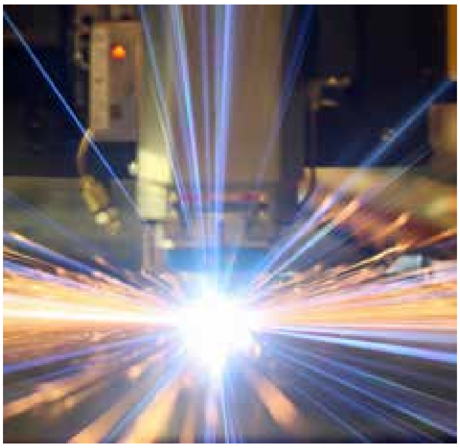
www.jenoptik.com

GAS SUPPLY OPTIONS FROM AIR PRODUCTS



If consumers are using more than 10 cylinders of gas per month then microbulk storage may be a viable option. The storage capacity of Air Products' smallest CryoEase® system is 180 litres which is suitable for sites using around 12 cylinders per month. A key advantage of the CryoEase® service is the high-pressure refill capability - there is no need to vent down your tank pressure and lose valuable gas and production time during the refill process, thus eliminating business interruption.

Contact: Richard Wiktorowicz
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TRUMPF'S OFFLINE WELDING PROGRAMS

The new TruTops Weld programming software allows users to create welding programs offline on a computer while the laser welding cell is producing parts. They then transfer the program to the machine where the TeachLine sensor system automatically adjusts it to match the actual position of the part. This minimises the need for teach-in processes.

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LASER APPLICATIONS IN THE NUCLEAR INDUSTRY
6 JUNE 2019 - WORKINGTON, CUMBRIA

Speakers (L-R): Back row - Andy Gale (Cumbria Uni), Mihail Petkovski (Uni Sheffield), non-speakers. Front row - Lin Li (Uni Manchester), Ali Khan (TWI), , Chris Hope (Sellafield), Keith Lorenz (MTC), Tony Jones (Cyan Tec), David Lawton (Lasermet), Oliver Meier (LASER on demand, Germany), Bjöern Kraemer (PRIMES), Keelan Keogh (UKAEA), Jon Blackburn (TWI).

With the sponsorship of the University of Cumbria and following a successful IMechE event attended by Lin Li, AILU decided to hold an industry specific event for the Nuclear Industry on 6 June. This event was held at ENERGUS, a dedicated conference and training centre in the Lake District.

The workshop attracted over 60 participants, at least half of whom were from within the nuclear industry supply chain - from as far afield as Dounreay in the Highlands, to France and Germany. Participants heard about laser applications in decommissioning and reactor construction. Case studies of successful laser use to tackle problems such as contamination were also presented, as well as safety issues and a view of laser potential from the Sellafield perspective.

Stephen Mullen, Senior Lecturer in Engineering at the University of Cumbria facilitated the event and explained why it was important to bring experts to Cumbria. He said: “These types of events normally happen in the south of the country making it difficult for Cumbrian engineers to attend." Stephen was particularly gratified to see experts with 25-35 years' experience, still come away having learned something new. He continued: “Seeing what was set out as a local event rapidly expand into an international one with people from the continent making their way to West Cumbria to participate, was surprising but proves that professionals will travel for quality training.”

At the end of the event, a demonstration of the Nuclear Virtual Reality Suite was given to around 15 delegates. This was very impressive and they were even able to accept an e-mailed file of an IPG processing head and show how that could be “walked around” in 3D.

Dave MacLellan
dave@ailu.org.uk

LASER WORLD OF PHOTONICS, MUNICH
24-27 JUNE 2019

This year the Laser World of Photonics (AKA Munich Laser Show) was a great opportunity (as ever) to network with over 40 AILU member organisations and take the pulse of the industry. My own assessment was that the show was a little quieter than 2017 and that the mood was a little less optimistic, with a few people observing concerns about uncertainty over trading conditions and market size adjustment in China. Here are a few snapshots of AILU members to give a flavour of the week.

LBP-ULO Optics

II-VI Highyag

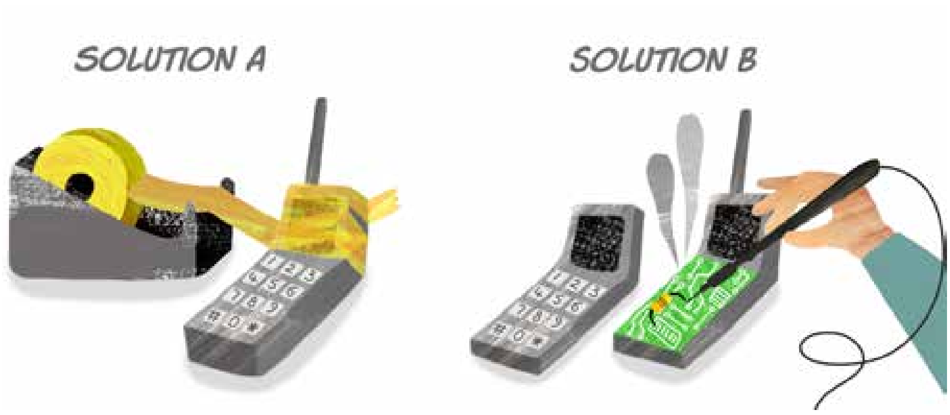
IPG Photonics

TRUMPF

Coherent

PowerPhotonic

ANNOYING TOYS...



@ellenroseillustration

On my first business trip to USA, I arrived on the Saturday and had the option of spending the Sunday touring the shopping malls or visiting the Ford museum in Detroit – I think I picked the wrong one as I ended up looking at a lot of junk and buying not very much.

One thing I did buy was a toy for my son who at the time was about 2 years old. At the time, the mobile phone was still a fairly new and amazing thing and most of them looked like the original Motorola brick phone (think Gordon Gekko in the movie Wall Street, 1987). In this toy shop, there were toy phones modelled on this mobile beast (but obviously smaller and lighter) which had buttons that made a different tone and when you pressed the green button it sounded like it was dialling.

Picking up the toy in the noisy shop, I thought that it would be a bit of fun and since the background noise was quite loud, I didn't have a sense of how annoying it might be when I got it home. In the same shop was my boss who had a son the same age – when I showed the toy to him, he thought it was a great idea to get the same thing for his son – job done!

A few days after coming home, my son was thrilled with his new loud noisy phone, however the novelty was fast wearing off for my wife and me. I looked at it closely and found that it split in half to allow you to replace the battery, and the half that had a speaker had an array of holes to let the sound of the annoying phone out. Aha, I thought, a little sliver of Sellotape (sorry, sticky-backed plastic, other brands are available) on the inside of the phone casing would cover up the holes and attenuate the sound a little bit.

In 5 minutes I had the phone taped up and back together and pressing the buttons found the noise to be much less annoying.

Some time later, I was chatting with my boss and asked him about the toy phone. I rather proudly told him that I had found a solution and applied some tape to make it a little quieter. My boss was an electronic engineer (like me, but more hands on) and had solved the same problem in a different way. He thought that if he unsoldered the wire to the battery terminal and inserted a small resistor, he would reduce the current and therefore the volume of the toy. He experimented with a handful of resistors to get the right sound level and then soldered one in and re-assembled the toy phone. He pointed out that his solution was more elegant because in reducing the volume he was also extending the battery life so it was a win-win.

Months or perhaps a year later, the toy phone in our house was silent as the battery had died. This was great because our son had lost interest and if anyone picked up the phone it was blissfully silent. Talking to my boss it seems his toy phone kept annoying them for an extra year before the battery ran out!

The moral of the tale is there may be several solutions to the same problem. Some will be quick and cheap, others will take more time and are inherently more innovative or elegant. Don't get hung up on whether the solution you chose was the best one, as history may prove otherwise…

Dave MacLellan
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AILU WORKSHOP

Presentations, Exhibition, Networking

ADVANCED LASER FABRICATION IN THE TRANSPORTATION SECTOR

19 SEPTEMBER 2019

IN ASSOCIATION WITH THE NORTHERN IRELAND TECHNOLOGY CENTRE, QUEEN'S UNIVERSITY BELFAST

Northern Ireland Technology Centre Insight Applied

QUEEN'S UNIVERSITY BELFAST

PRESENTERS INCLUDE

Mark Thompson, IPG Photonics (Chair)
Colm Higgins, NITC, Queens University Belfast
Jan Pitzer, Cloos, Germany
Wojciech Suder, Cranfield University UK
TWI, Cambridge UK

Laser machinery & Robotic manufacturers

VENUE

Northern Ireland Technology Centre
Queen's University Belfast
Cloreen Park
Malone Road
Belfast
BT9 5HN

Targeting the off-highway, rail and shipbuilding industries – as well as those organisations making trucks and trailers for transporting goods or material - this workshop is for design and manufacturing engineers and managers in manufacturing organisations in Northern Ireland, as well as suppliers of laser cutting & welding services. Special rates are available for SMEs in the region who are involved in manufacturing and could implement laser manufacturing in their production.

www.ailu.org.uk/events

DATE	EVENT	LOCATION
19 September 2019	**Advanced Laser Fabrication in the Transportation Sector**	**Northern Ireland Technology Centre, Belfast**
3 October 2019	**Annual Job Shop Business Meeting**	**Mini Plant, Oxford**
7-10 October 2019	ICALEO 2019	Orlando, Florida
9-10 October 2019	Photonex EUROPE 2019	Ricoh Arena, Coventry
30-31 October 2019	**Advanced Engineering featuring AILU's Laser Manufacturing Hub**	**NEC, Birmingham**
20-24 April 2020	**MACH 2020 featuring AILU's Lasers for Manufacturing Zone**	**NEC, Birmingham**

20-21 May 2020

SPECIAL EVENT

ILAS 2020 & AILU's 25th Anniversary

Daventry Court Hotel, Northamptonshire

ILAS 2020

7th Industrial Laser Applications Symposium

1995 - 2020