

THE LASER USER

ISSUE 97
SUMMER 2020

AILU

IN THIS ISSUE:

3D Printing Hybrid Materials

Titanium Laser Shock Peening

Laser Welding Aluminium

Photonics in e-Mobility

USP Multibeam Processing

Femto Beam Management

AILU
25
1995 - 2020

**INNOVATIVE SOURCES &
BEAM DELIVERIES:
ENHANCING THROUGHPUT,
TACKLING CLIMATE CHANGE**

THE LASER USER

Editor: Dave MacLellan
Sub-Editor: Catherine Rose

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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 MEMBER

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Cover image: TWI's EHLA (Extreme High-speed Laser Application) depositing In625 on a 316L shaft at 65 m/min. Technical benefits include: high coating coverage, metallurgical bond with low dilution and high density.

Courtesy of TWI.

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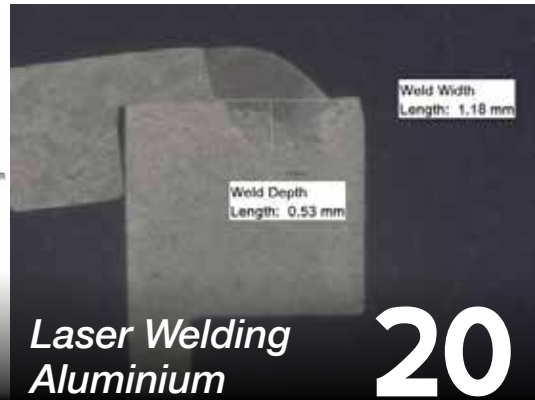
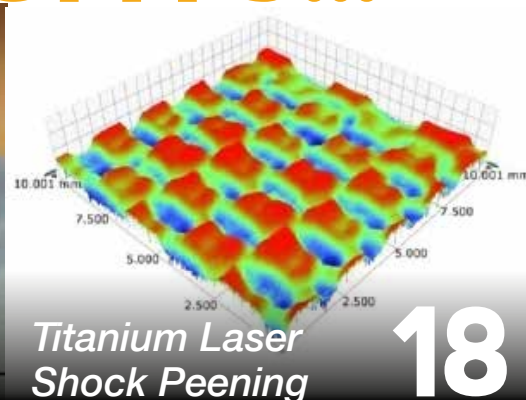
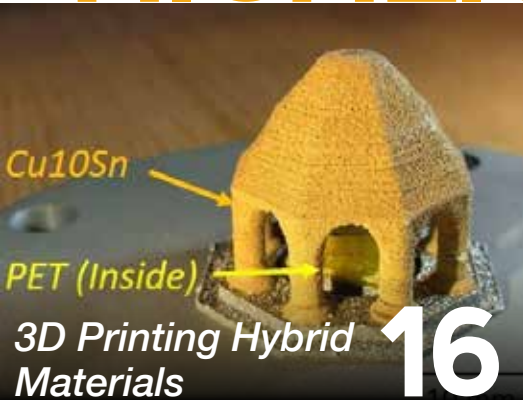
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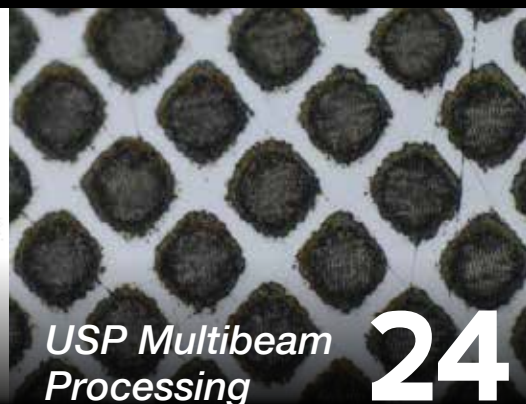
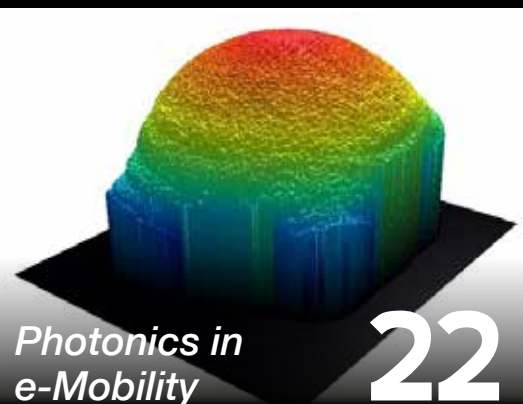
HIGHLIGHTS...



3D Printing Hybrid Materials **16**

Titanium Laser Shock Peening **18**

Laser Welding Aluminium **20**



Photonics in e-Mobility **22**

USP Multibeam Processing **24**

Femto Beam Management **26**

ASSOCIATION NEWS

First Word	4
President's Message	4
Ric's Ramblings	4
Obituary: Bill Shiner	5

BUSINESS NEWS

Business	6
Case Studies	8

EVENT REVIEW

	9
--	---

SHORT FEATURES

Laser marking of shaped surfaces	10
A case study in moving from YAG to fibre lasers	33

EARLY CAREER RESEARCHERS

	11
--	----

EDITORIAL

Interview: Matt Yeates, SteelScout	12
Job Shop Corner	14
Chair's Message	15
A Funny Thing...	34

PRODUCT NEWS

Systems & Sources	30
Ancillaries	31

EVENTS	35, 36
---------------	---------------

MAIN FEATURES

3D printing of hybrid metal/polymer objects	16
Yuan-Hui Chueh & Lin Li	16
Topography & morphology of laser shock peening on Ti-6Al-7Nb	
Xiaojun Shen & Pratik Shukla	18
Laser welding aluminium with an oscillating head	
Alexandre Prevost	20
The full potential of photonics in e-mobility: an overview	
Markus Kogel-Hollacher	22
Multi-beam processing with high intensity ultrashort pulses	
Danijela Rostohar	24
Advanced beam management with high power fs lasers	
Jose Ramos-de-Campos et al.	26
Observations	28

CONTENT BY SUBJECT

Business	
Members' News	6, 7
Laser Marking Shaped Surfaces	
Short Feature	10
Moving from YAG to fibre lasers	
Short Feature	32
AILU Interview	12
Product News	30-32
Job Shop	
News	14
Chair's Report	15
3D printing of hybrid materials	
Main Feature	16
Laser shock peening Ti	
Main Feature	18
Laser welding aluminium	
Main Feature	20
Photonics in e-mobility	
Main Feature	22
USP multibeam processing	
Main Feature	24
Femto beam management	
Main Feature	26
Events Diary	36

ASSOCIATION NEWS

FIRST WORD

By the time you read this, we will have delivered our first online webinar workshop – thank you to all who took part. One of the things about the “new normal” is that events have moved online. As lockdown is lifting gradually, and the possibility of physical meetings returns, I believe we will carry on doing online meetings and webinars in the future, in the mix with our physical events and meetings. Consider this: online webinars and Zoom meetings have no travel time or cost, no international borders, and allow easy replay of recordings – what’s not to like?

In a bizarre way, it seems that the lockdown has in many ways improved our communication – the fact that we can’t meet friends, family and colleagues face to face has actually empowered me to reach out to many more than I would have done otherwise.

Look out for our events in October and November as well as the up-coming ILAS 2021 (get the date in your diary now - 24-25 March 2020). I hope to see many of you in person in the near future.

Dave MacLellan
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PRESIDENT'S MESSAGE

Greetings fellow laser users!

I hope you and your families are all keeping safe and well, and are engaged in appropriate social distancing measures to help keep the R number down. That's not a sentence I thought I would have been writing at the beginning of the year. To be totally honest, not being an epidemiologist (note - I'm still surprised these aren't skin specialists), it is not a sentence I would have understood either. Like many readers, I'm much more familiar with beam-matter interactions, Rayleigh lengths, material properties and challenges like thermal lensing. That's not to say these things aren't important in the current situation – we're aware of numerous success stories where the AILU community is supporting the UK and other Governments in addressing the current crisis, through the manufacture of PPE, for example. Our enormous thanks at AILU go out to anyone helping tackle the current situation, whether part of the AILU community or not.

Although it is difficult to look too far into the future at the moment, industrial lasers are well placed to support the economic recovery that the UK and other countries will desperately need. Many of the arising manufacturing challenges around future mobility (e.g. electrification), clean energy (e.g. hydrogen and small modular reactors), and ageing societies (e.g. personalised

health care) can be met through the adoption of industrial laser technology. The 1 Billion Euro Green Deal programme, funded by the European Commission as part of H2020, will add further momentum to activities in these areas. This call is now out, and UK participants are still eligible.

At AILU, work carries on despite the inability for us to currently hold physical events. There is more inside about a recent successful virtual workshop on electrification, run by TWI's Paola de Bono. We'll be looking to use a similar format for future workshops.

Work on the new website continues – with the AILU team expecting this to be online soon. And planning for a physical ILAS 2021 is in full swing, albeit with contingency plans in place for a virtual or hybrid physical-virtual event if needs must. Look out for updates on the ILAS 2021 website (www.ilas2021.co.uk).

Jon Blackburn
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RIC'S RAMBLINGS

I had the pleasure of “attending” the AILU e-mobility webinar on 8th and 9th July. I found the talks really interesting (although perhaps one less on welding tabs on batteries would have made for a slightly better balance of topics). One thing we couldn't do of course was interact personally with delegates – actually look people in the eye and share a joke or anecdote over a coffee – gosh remember those heady days when we could do that? The really big thing I missed of course was the evening curry that I'm sure Dave would have organised between the two sessions. However, despite the limitations of zoom of really building and maintaining strong relationships (and my longing for a lamb madras) – there was still a reasonable amount of interaction and follow up – so congratulations on achieving that.

What a number of the talks brought to mind though was something that has long been a feature of conferences and workshops in our community - the tit for tat “my laser is better than your laser” debates. For as long as I can remember you will have someone stand up and drag a picture of the worst looking laser drilled hole or welded tab out, processed with an “inferior” laser and sit it neatly next to a pristine example of something they have done with their particular laser (probably taking a good two weeks to perfect). This was particularly prevalent as the pulse length of lasers started to

shorten dramatically. All of a sudden nanosecond pulses were just not good enough – look how fantastic my picosecond laser is! Nonsense they say, picoseconds are so last year – check out the quality of my smashing new femtosecond laser! The particular debate this time round was between the good old IR laser and the new “blue” revolution. Of course what we all know is that careful choice of parameters and processing strategy, combined with a good knowledge of the material properties, allows us to make the right choice and achieve the right balance between quality, throughput and cost effectiveness.

We are in fact blessed in our business, with an embarrassing array of laser types, wavelengths and pulse lengths to choose from and we should embrace the diversity – just make sure you make the right choice for the job in hand.

Ric Allott
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OBITUARY

BILL SHINER

21.4.1941 - 7.5.2020



The Association was sad to hear of the passing of Bill Shiner, one of the leading names in the development of laser technology for industrial applications. We were lucky to meet Bill at AILU's 5th Industrial Laser Applications Symposium (ILAS) 2017 where he gave a very well-received plenary presentation. The following testimonials demonstrate the deep respect and affection for Bill which was held by all who knew and worked with him. (The testimonials have been edited here, full versions are available at <https://bit.ly/Obit20202>.)

"Bill Shiner joined IPG in August 2002 as head of Industrial Laser Sales, primarily focused on the US market. At that time IPG's worldwide revenue was only about \$30 million and the company had not established itself in the industrial laser world. This was a difficult time as the company was just starting to emerge from the telecom downturn and transition to industrial applications. Bill was a well-known industry veteran who brought knowledge and problem-solving abilities to customers, helping IPG to grow sales from that small base to well over a billion dollars today. Ultimately, he spent almost 18 years with IPG.

He was a sounding board and a very trusted advisor to me, as well as providing guidance and advice to many other colleagues. A couple of years after joining the company he was promoted to Vice President, Industrial Sales, taking on a more global oversight. In 2006 he was directly involved in IPG's debut as a publicly traded company on the NASDAQ.

Bill had a keen eye for identifying new technologies and trends. It started nearly 50 years ago as a member of the American Optical Research Lab. Many years later, he joined with me and our IPG team to apply the novel fibre laser technology, which then only generated much lower output power, to large scale industrial applications, using his deep knowledge of the laser industry from both technical and commercial perspectives.

Bill was a recognised leader in the laser community and was elected President of the Laser Institute of America. Through his strong and enthusiastic leadership, the LIA organised a number of high-attendance events that advanced laser processing technology. Bill received the LIA's President's Award in 2009 which honors individuals who have made significant contributions to the LIA and enabled the growth and prosperity of the society.

Bill was a person that could listen, understand, and then propose the best solution to meet the customer's needs. His honesty, knowledge and approach to balance the needs of the end user, application and laser manufacturer were special."

Valentin Gapontsev, Founder and CEO, IPG Photonics Corporation

"I first met Bill at a sales conference for Convergent Energy in the mid 90s. Bill was later to become the Chief Operating Officer of the company in 2001/2002.

Professionally his achievements were numerous, innovative and pronounced. If you are flying in an aircraft, shaving, going places in a car, enjoying the benefits of renewable energy or communicating on your mobile phone you will be connected to Bill. The laser technology and approaches used in today's manufacturing process, for some of the most significant and key industries, have some of Bill's genius woven into them in some way or another.

Bill's early beginnings at American Optical moved into co-founding Laser Incorporated and eventually selling that company to Coherent where he excelled as V.P. of Sales and Marketing. He moved on to Convergent Energy and finally, joined IPG Photonics in 2002. Here, Bill was part of, and central to, a revolution in laser technology development. Bill was honoured by the LIA to receive the President's Award from the organisation after serving for over 40 years on its board and being part of its origins as one of its founding members.

In spite of all he achieved in every aspect of his life, his most endearing quality and characteristic was his unassuming humility. His achievements earned the respect of many business leaders who knew him as a person of integrity.

After retiring in 2018 from mainstream activities within IPG, Bill remained close to the helm of leadership as Valentin Gaponstev's Special Projects Consultant. Rest in peace Bill, we will never forget you and the difference you have made in this world."

Stan Wilford, IPG Photonics

"Bill seemed ever-present in the laser industry even when I first met him, soon after joining Lumonics in the late 1980s. His was the name everyone knew. An evening out with Bill after a tough day on an exhibition stand was always something to enjoy. I last met him in the UK a few years ago when he came to visit me on behalf of Professor Gapontsev and IPG. We had been talking about aerospace applications and I explained what we wanted. Bill, as ever, understood it immediately and championed our cause and "things happened".

He was truly one of the laser industry's founding fathers, an influencer, an inventor, a teacher and we have much to thank him for as we go forward in these uncertain times but times which I think he would have attacked with gusto, searching out the next "big thing". Farewell and thank you Bill."

Clive Grafton-Reed, Rolls Royce

"I came to know the mighty duo of Bill Shiner and Valentin Gaponstev in the mid 1990s during the pre-dawn glow of the age of the high-power fibre laser. They were a perfect combination; Valentin, with one of the finest minds in optics and laser technology and Bill, with his legendary understanding of how and where to apply this beautiful light, his tenacity, acute business mind, and supreme salesmanship. By early 2000, the sun was rising for all in the laser industry, and it was largely due to the transformational impact of Bill and Valentin's work.

As a young 'independent' academic working in the field of industrial laser technology, I was asked by the then President of the LIA to present a keynote paper comparing high-power fibre lasers (IPG) and high-power disc lasers (TRUMPF). The competition between these two companies, was (and still is) incredibly strong. I was fearful of misjudging the talk and my normal self-assurance was ebbing away as I prepared my thoughts.

The day arrived, the room was packed, I was nervous as hell. But as I was introduced to the audience, Bill caught my eye and flashed me a smile and a wink. To have the encouragement of one of the titans of the industry, applying his usual kindness and care for others, put me at ease and off I went.

I was incredibly sad to hear of Bill's passing. He was a man of immense character, great intellect, keen insight, boundless curiosity, and above all unfailing kindness. We will miss him."

Bill O'Neill, University of Cambridge

BUSINESS NEWS

SPI LASERS TO REBRAND UNDER TRUMPF BANNER

TRUMPF have announced a close business co-operation between TRUMPF Laser-und Systemtechnik GmbH and SPI Lasers UK Ltd. Both are wholly owned by the TRUMPF Group. TRUMPF Laser-und Systemtechnik will combine the business operations of SPI Lasers UK Ltd. to bring advantages in industrial applications via both disk and fibre technology and enhance customer service offerings. As of the 1st July, SPI Lasers products will begin to be available via the TRUMPF sales channels.



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LUXINAR'S 1ST YEAR ANNIVERSARY



On 25 June 2019, the official Luxinar rebranding campaign was revealed. One year on, Luxinar continues to further strengthen its portfolio of CO₂ lasers, with the recent launch of the SR08s 80W sealed laser source, and to explore new technologies such as femtosecond lasers.

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SCANLAB MARKS ITS 30TH ANNIVERSARY

SCANLAB GmbH is marking its 30th anniversary as an OEM manufacturer of scan systems that guide and position laser beams. With 30 years of photonics market presence, the pioneering company looks back at continuous growth while also being well positioned for the coming years.

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PRIMA ADDITIVE LAUNCHES IN THE UK

Prima Power UK Ltd has recently launched a completely new range of machinery solutions for Additive Manufacturing, produced by Prima Additive - the specialist division of the global Prima Industrie Group.



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MANUFACTURING INDUSTRY OPTIMISM



A new survey from SteelScout has found that more than 60% of professionals in the manufacturing industry expect the sector to recover from COVID-19 and return to business as usual by mid-2021. However, they highlighted issues in the wider supply chain which might impact the recovery, with almost 30% unable to access the materials they need and 36% it is taking longer just to receive a 'winning quote'.

Almost 80 percent of those surveyed reported that they have adopted new working practices to deal with rules and guidelines around lockdown in the UK. The most common change was remote working, which was used by 49 percent of those surveyed.

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LASEA ACQUIRES OPTEC

The LASEA Group, Belgium, announces the purchase of the majority shares of OPTEC, a company that specialises in UV and ultra-short pulse lasers. The new Group offers all subtractive and additive laser solutions for four preferred sectors - Luxury Goods, Medical, Electronics and Academic.

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CYAN TEC BECOMES ABB VALUE PROVIDER



Cyan Tec has recently been credited as an ABB Value Provider. Over the last few years, the company has provided complex, modular and bespoke automation with the integration of many ABB robots. This includes for laser applications such as cutting and welding. Cyan Tec is now part of an group of companies that make up the ABB Value Provider scheme.

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AIR PRODUCTS IS A SAFE CONTRACTOR

The Air Products UKI Engineering team is pleased to confirm that they have received their reaccreditation from SafeContractor. This external review confirms that Air Products delivers high standards in health and safety management for the installation and maintenance of its equipment at customer sites.



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LVD'S VIRTUAL TECHNOLOGY EVENTS

Following the postponement of EuroBLECH 2020, LVD announces plans for a series of Virtual Technology Events and Technology Days to be held from September through November 2020 to launch and showcase new laser cutting, bending and punch press products for the sheet metalworking market.



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VIRTUAL SHOWCASE FOR PHYSIK INSTRUMENTE (PI)



With conferences and industry exhibitions currently on hold, Physik Instrumente (PI) has set up a virtual trade show that will inspire and inform anyone with precision positioning and motion control challenges, wherever they are in the world. Two dynamic, virtual stands – including comprehensive product demos and ACS software walkthroughs are available.

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HEXAGON AT VIRTUAL EXHIBITION

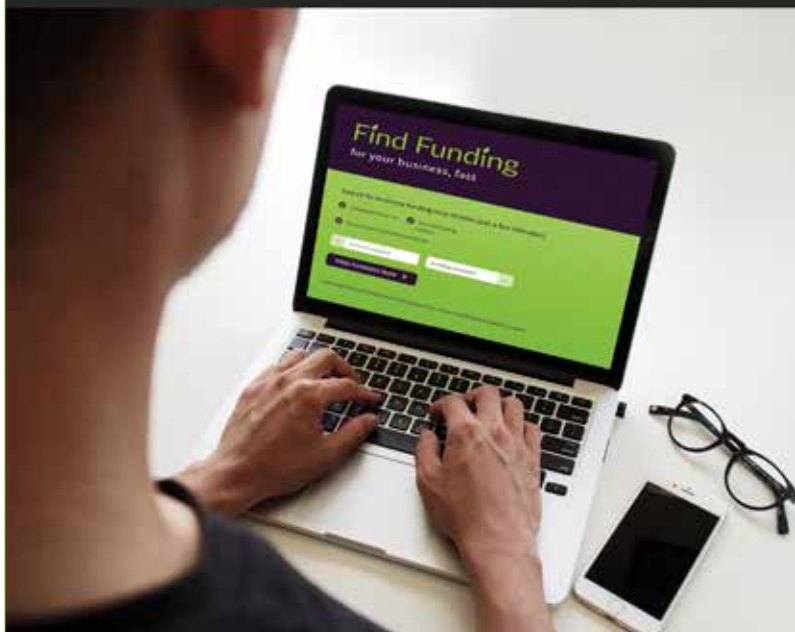
Hexagon's Smart Factory Solutions will be on show at the forthcoming Backing Britain 2020 virtual exhibition. While many trade fairs were postponed because of the Coronavirus pandemic, this project, run by the 'Made in Group,' aims to replicate a traditional trade show entirely online, using technology to enhance and improve the value for exhibitors and visitors. The show, running virtually from 17-28 will consist of around 150 exhibitors, each with their own online stand.



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CASE STUDIES

JOB SHOP USES RADAN FOR COVID-19 BATTLE



Keltech a Waterford sheet metal specialist, used RADAN software to prototype and manufacture emergency medical waste bins for the Irish health service in the fight against COVID-19. And the company has now developed a unique hand sanitisation station capable of dispensing 6,000 shots of gel before needing to refill the unit's four-litre tank.

The initial prototype was built in 7 days, and the first production batch, came off the CNC machines 3 days later. They now manufacture around 500 a week from 2 different material specifications, a stainless steel version, and the most popular a mild steel, powder coated, unit.

Each bin comprises around a dozen individual components, with RADAN creating optimum nests to maximise the yield from each sheet and avoid wastage.

One of their biggest challenges was the opening and closing mechanism for the lid, but RADAN's ability to quickly edit the toolpaths and amend the programs was crucial in speeding up the process. "For instance, where we needed to change the position of holes we could do that quickly and accurately."

Seamus Lawlor, Business Development Manager says "The lid when closed, is perfectly sealed, ensuring the potentially contaminated waste is secure. It's also designed with a silent close feature so as not to disturb patients. The front opening door allows staff to easily change bags...and we use state-of-the-art glossy powder paint which will give a good, easy to clean finish, so we expect the bins to last for between 10 and 15 years.

"This was more of a mission to support the urgent COVID-19 requirements of the HSE rather than looking at the product as a long-term business model, but private companies are now coming to us wanting these bins for places such as nursing homes and other care centres. We're getting interest from the UK, mainland Europe, and the United States."

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TRUMPF - MARKING STAINLESS STEEL MADE EASY

Electrix International, manufacturer and stockist of stainless steel electrical enclosures and cable management systems, is exploiting the many benefits provided by a new TRUMPF TruMark Station 5000 laser-marking system. The new machine has replaced a previous foil sticker to provide a fast, permanent way of marking and identifying products without compromising requirements for hygiene or corrosion resistance.

"Although the foil sticker is difficult to remove, there is a chance it could come off under extreme pressure from a hot jet wash or when subject to a caustic cleaning solution, for example," says Stewart Beer, Manufacturing Manager at Electrix. "This is obviously unlikely for an electrical enclosure, but we were always mindful of this possibility. In addition, to get our products officially certified for safe use within the food industry we approached the NSF [National Sanitation Foundation], who loved the product but indicated that the foil sticker might be an issue."

Since installing the TruMark Station 5000, which is able to accommodate workpieces measuring up to 680 x 500 x 700 mm in size, the company has been busy marking products made from either 316 or 304 grade stainless steel in a range of different finishes, including satin and polished.

At Electrix, the method selected is known as laser annealing, which differs from laser engraving and ablation in that no material is

removed. In laser annealing, marking occurs beneath the material's surface using a precise combination of heat, pulse intensity and speed. When different combinations of these parameters are applied to stainless steel, a variety of tones can be achieved, all of which are permanent. Laser annealing maintains the smooth surface texture of the stainless steel, preventing dirt and grime from collecting in the marks, which is particularly important for Electrix due to the sectors it serves.

"Laser annealing gives us a very clean finish – there is nothing on or under the surface, it just provides a neat black finish that is smooth to the touch," says Mr Beer.



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AMADA'S BEAM CONTROL INCREASES PRODUCTION

AMADA's new VENTIS-3015AJ is the first fibre laser cutting machine to feature the company's Locus Beam Control (LBC) technology, which improves both processing quality and productivity in stainless steel and aluminium.

JC Metalworks Ltd, Loughborough, saw the potential of the LBC technology and installed the first UK VENTIS-3015AJ. Always willing to embrace new technology, Prakash Chavda, Operations Manager commented "Having technology which enables us to process a wider range of materials at a faster rate, without compromising the quality of cut was a huge gain and extremely exciting to us." Mr Chavda continues "As a result of the new machine we have increased our capacity and shortened our lead-times further. By far the biggest gain is the processing of aluminium - the VENTIS has meant that we no longer need to have a secondary process to deburr the material allowing us to process the job much quicker through the

factory. The machine is also fitted with an automation system, something we also enjoy investing in."



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EVENT REVIEW – E-MOBILITY WEBINAR

In July, AILU held its first webinar to replace our planned workshop which was going to be held at TWI near Cambridge. E-mobility is a topic that is very relevant as globally a lot of attention has been focused on the environment and climate change during the world-wide lockdown – a green recovery could give a important boost to the already significant growth in electric powered transportation.

The webinar was held over 2 days, starting on Wednesday afternoon with 2 sessions (sponsored by Air Products and Nuburu) and concluding on Thursday morning with a further 2 sessions (sponsored by Coherent and Precitec).

Paola De Bono from TWI was the Webinar Chair, with TWI also hosting the Zoom Webinar. 60 delegates registered for the event and one of the key advantages was that people could attend from any time zone. Delegates attended from around the world including UK, Ireland, USA, Germany, Israel, Italy and Japan. All delegates received the high-quality session videos and a delegate list after the event.

Speakers covered the welding of cylindrical, pouch and prismatic battery cells as well as the various electric motor welding applications that are being seen, with new power sources (including diode lasers in the blue wavelength from Nuburu and Laserline) as well as the CO₂ applications for trimming non-metals in car manufacture which were



presented by Luxinar. Also shown were solutions for beam shaping using dual core fibres – similar products are available from Coherent and IPG and there was a focus on in-process diagnostics presented by IPG, Precitec and Comau. Vodafone and Ford gave a joint presentation on 5G mobile private networks, AI and how these technologies can be used to implement Industry 4.0. Many of the applications require the welding of reflective materials (aluminium and copper) and welding dissimilar materials – a point covered by SPI Lasers. TWI also discussed the context of non-laser welding solutions for comparison.

Feedback on the webinar was very positive – of those who responded to our survey (27) over 93% said they were likely or very likely to recommend future webinars like this to their network.

Our next webinar will follow a similar format, but on a theme of Micro/Nano applications for laser material processing – see elsewhere in this issue of the magazine for more information.

Dave MacLellan
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TWI INVITED TO NEW ELECTRIC VEHICLE MANUFACTURING PROJECT

TWI has been invited to participate in a new EU project related to the manufacture of electric vehicles. The new H2020 'ALBATROSS' project has been granted funding by the European Commission, with the work being coordinated by aluminium experts Yesilova Holdings of Turkey.

The project is set to investigate improvements to eMobility technology for the European electric and hybrid-electric passenger vehicle market. This includes improving the performance of battery assemblies with regards to matters such as charging time, range, maintenance, and battery module design. There will also be additional environmental benefits through the implementation of fast and cost-effective processes including disassembly, recycling and reuse.

All of these issues are of importance to the future of electrification within the automotive industry and, by extension, could prove influential in the UK's push towards achieving Net Zero.

TWI will provide specialist expertise in laser and friction processes, developing tailored energy distributions to join intermetallic interconnects and battery trays; welding procedure validation through destructive and non-destructive testing; welding tooling design; and joining technology scale-up.

Part of TWI's focus is to promote the manufacturing benefits offered by high-productivity welding for advanced and lightweight battery assemblies.

Should the project agreement be completed, the ALBATROSS Project will build upon existing expertise in electric vehicles and battery assemblies.



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FEATURE

LASER MARKING OF SHAPED SURFACES

The laser marking market is characterised by an increased need to mark or texture non-flat surfaces, such as curved, inclined and stepped surfaces, as well as free-form objects and recessed surfaces. Traditional laser markers and integrated machines are limited to a flat planar field of view that can be adapted for simple inclined planes or cylindrical surfaces by rotating and moving the part during marking. Using conventional techniques, the only way to accommodate more complex shaped surfaces was to resort to the cost and complexity of programmed robotics or complex 5-axis machines.

Beyond the limitations of traditional systems

To overcome these limitations, automated "smart" solutions have been developed, for example, Coherent's SmartMap 3D. This smart system is able to accommodate different placements of the workpiece (Figure 1), without moving the laser or the workpiece, because it takes into account several important parameters, including projection distortion, clipping angle, apex angle, and 3D surface orientation.

Marking shaped surfaces with SmartMap 3D is simpler, faster and more economic because it does not involve moving either the optical system or the part. This is due to the use of a

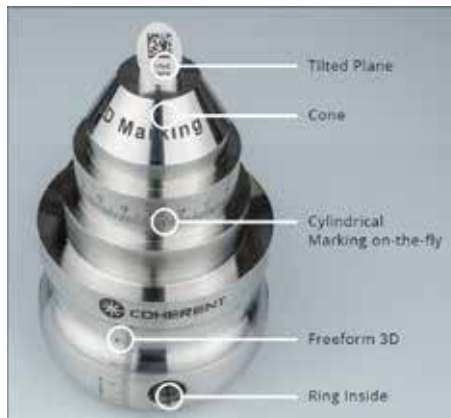


Figure 1. The new "smart" approach enables marking on virtually any shape or surface orientation, even marks inside holes and insets.

fast focus module placed *within* the optics. This allows rapid focal length adjustment.

Since the laser beam emanates from a fixed point during the entire process, the scan system must correct for the geometrical distortions that would otherwise occur during the marking process. This type of distortion correction has been widely employed in the past when working with relatively simple shapes, such as angled flat surfaces and cylinders. But it becomes substantially more difficult for arbitrary, free-form 3D shapes. Upgraded software can eliminate

this challenge by performing these corrections automatically.

Conventional 2D marking is configured so that the laser beam is always aligned close to perpendicular to the surface of the workpiece, i.e. near "normal incidence." However, with 3D marking, the laser can mark at angles that vary significantly from normal incidence. The maximum angle that can be employed is determined by the absorption and reflectivity of the workpiece surface and is called the clipping angle. This can be operator-selected for each job individually to enable the same laser marker or marking machine to mark different materials.

Summary

Laser marking offers unique advantages for creating numbers, symbols, logos, and other graphics on virtually any type of material. Until now, most laser marking has been confined to flat surfaces or simple shapes. This has now completely changed; the advent of a smart 3D marking systems, such as SmartMap 3D, brings pushbutton simplicity and automation, unlocking the full potential of laser marking for industries such as automotive, consumer electronics, appliances, and many others.

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CATCH UP WITH CURRENT ECR RESEARCH

Laser welding for EV battery manufacture

The automotive sector has committed to reducing CO₂ emissions by reducing its dependency on fossil fuel. CO₂ emission regulations have encouraged the sector to increase the manufacture of electric vehicles such as a hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and electric vehicle (EV). Battery system manufacturing holds the future of HEVs, PHEVs and EVs. An automotive battery pack typically consists of a large number of battery cells, sometimes several hundred, even thousands, to meet desired power and capacity needs. Several cells are usually joined together in parallel and/or series to form a module. Electric Vehicle battery manufacturing requires competitive joining technologies to produce joints with low electrical resistance and high strength.

Here at Coventry University, I am working mainly on fibre laser welding of battery tab and busbar materials to produce quality joints for EV battery manufacturing. The project was funded by APC 12 (Innovate UK) and involves Unipart Manufacturing, Williams Advanced Engineering, Hyperbat, Coventry University, HSSMI, TWI, Nodson Dage and Direc-Tec as participating organisations.



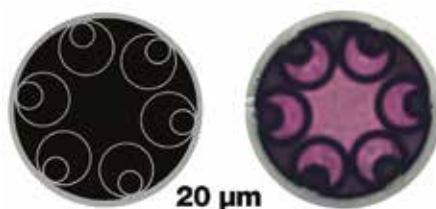
Energy dispersive X-ray analysis showing elements distribution in a fibre laser weld.

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Low loss hollow core fibres

Utilising fibre optics to handle and deliver high laser energy is of great importance for applications such as industrial welding, cutting, and heat treating that demands delivering laser power to remote locations. Replacing the solid glass core of a conventional optical fibre with a vacuum- or gas-filled core of a hollow core fibre (HCF) results in an ultralow nonlinear response, low glass-mode overlap, high damage threshold and faster propagation speeds. This opens the route for these fibres to be the ultimate go-to for laser power delivery applications in the key 1- μ m wavelength region.

Reducing the optical losses, which are currently the main hurdle in these fibres, is crucial. Our research at the Microstructured Optical Fibre Group, University of Southampton, explores a new structure called Nested Antiresonant Nodeless Hollow-Core Fibres (NANF) which in theory offer lower losses than achieved by their counterpart silica fibres. In 2019 we reported a NANF designed for the 1 μ m region with an optical loss approximately a 3 times lower than that of the state-of-the-art at that time. With additional improvements on the structure, this optical attenuation has recently been further reduced by 50%. To the best of our knowledge these are the lowest loss reported in an HCF at these wavelengths. These promising results leave significant margin for improvement and have the potential to revolutionise this area of applications.



SEM cross sections of a Hollow-core Nested Antiresonant Nodeless Fibre.

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WORKING DURING THE COVID-19 PANDEMIC

Here at NKT Photonics UK, we have been operating mostly business as usual but with more of our colleagues working from home. New procedures have been put in place to ensure the safety of our staff who still use the site.

For me, since I work in the Applications Lab on my own, it hasn't been much different from my usual working day! There's always something to do. From routine housekeeping to trying new applications with the laser - it

even gave me the opportunity to do all those tasks that I was saving for a rainy day.

I've checked in to a few online webinars and conferences which I thought was a great way to keep up especially given the number of cancelled events this year. I can't wait to start travelling again and seeing all of my friends and colleagues across the globe!

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TRANSFORMING THE BUSINESS OF BUYING AND SUPPLYING STEEL

AN INTERVIEW WITH MATT YEATES
MANAGING DIRECTOR, STEELSCOUT

Q. Can you tell us a little about your history with SteelScout?

I've been with Tata for around 15 years. Recognising that there were several inefficiencies in the value chain for steel, SteelScout was set up in 2017 using digital commerce principles to improve the value for suppliers and customers alike.

Essentially SteelScout offers a B2B service using B2C sourcing principles that companies

like Amazon have spearheaded. This model is superseding the traditional purchasing methods of sourcing suppliers, sending enquiries to the same ones, comparing, checking and choosing the best of the quotes.

In our first year SteelScout grew 10-fold and in the second year over 5-fold, so that we now have 28 employees supplying

metals from 130 suppliers to over 10,000 registered users. By offering a fast turn around of quotations, typically 20 to 90 minutes, the process of sourcing material using one of our services is straightforward and fast. 95% of the metals currently supplied are steels and the material is around 50/50 flat or long material (sheet, plate, angles, tube, etc.)

Q. How important is the laser cutting sector to your business?

Laser cutting companies are very important to us. Currently they represent around 5% of our turnover. But we see significant potential for growth in this market, and have plans to double the number of customers in this sector in the next year. AILU members will find our services useful in transforming their buying experience, making it easier and quicker, allowing time to focus on higher value adding areas of their operations.

“

AILU members will find our services useful in transforming their buying experience.

”

Q. What metals do you supply and where does your material come from?

In addition to mild steel, alloys and stainless steels we supply aluminium, copper, brass and bronze, though mild steel is by far the largest volume of metal we source. Although we are owned by Tata Steel, very little of our metal comes from Tata mills. The materials we supply can originate from many different UK and international mills, via local & national stockholders. All orders come with online certificates to download so the quality of the material is assured. Keeping track of the documentation is also easy with our online portal.

Q. How has the recent Brexit and COVID-19 crises affected your business?

The main effect of Brexit was uncertainty and the COVID-19 situation has only extended and enhanced the uncertainty in the marketplace. During 2019 the UK Manufacturing PMI (Purchasing Managers Index) fell below 50 and during lockdown it has reached a new low of less than 33. Some stockholders and service centres closed at the start of the lockdown and of course steel production locally and imports were disrupted. Our services found a lot of new users over this period as we provided a rapid single point of visibility for availability from across our supplier network whilst businesses were challenged with unprecedented issues during lockdown. Since June, most of the supply chain is getting back to normal, but demand is subdued.

Q. What is the outlook for SteelScout in the next year?

As our business model is innovative and our services bring value, we are still growing at a strong rate, even in a competitive market, we foresee continued growth for the next years with a tripling of our turnover during the current financial year. We continue to listen to

feedback and improve our online services to enhance the benefits for customers, bringing us repeat business.

Q. Do you have any new initiatives in the pipeline?

We've just been through a process of restructuring our services and launched a new brand and website in June. Essentially, we currently have two components to our business which up until now have been known by the brands SteelScout and MetalHub. These have been rebranded as SteelScout Procure and SteelScout Direct, respectively.

Our Procure service allows customers to use a digital procurement service that takes their needs and scouts the market for the best deal to suit their requirements. They can accept the quote online and be assured that their Personal Account Manager is monitoring the successful delivery to their premises.

Our Direct service allows our customers to do immediate online comparison and ordering, putting control in their hands. A wide range of shapes and dimensions are available in stock and can be ordered 24/7 securely online. As in other markets, online ordering is becoming commonplace, accelerated by the current lockdowns and working-from-home practices which are changing the way people & businesses are buying.

“

Our Direct service allows our customers to do immediate online comparison and ordering.

”

Q. What is the best thing about AILU for you?

As I mentioned the laser cutting job shops are a community that is aware of new technology and much more open to the advantages of digital technology. The events, exhibitions and publications in print and online bring experts and specialists together sharing ideas that can add value to their processes. AILU is a great platform for us to collaborate with as we believe within its members are a group of customers that fit well with our services. The tight community that AILU has built gives us a good overview of the laser users processing metals and enables us to tailor services and test out product concepts with this market sector.

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FIMARK OFFERS SUBCON FUNCTIONAL SURFACES

Charles Dean gives us an insight to new processing opportunities that have opened up with the purchase of a new 5-axis laser.

"December 2019 seems a long time ago now, but it occurred to me at the time that I might have room for GF Machining Solutions' smallest 5 axis laser machine. The L400 was designed so that it could be fitted with either a nanosecond or femtosecond laser, or both, and whilst the femtosecond laser was outside my budget I could upgrade later. I could also have one of the smaller lenses fitted which, giving me a spot size of 30 microns, would allow me to laser features down to the scale known as technical surfaces.

The machine is here now and apart from working on watch components and doing general laser etching and engraving on a micro scale, I am looking forward to seeing what else I can do with it. There seems to be a lot of interest in hydrophobic and hydrophilic surfaces, micro machining and the controlled roughening of surfaces of orthopaedic implants. The latter will improve the knitting of the bone to the implant and the term used is osseointegration. Once you have the CAD model you can roughen repeatably and precisely and vary the texture over the component.

Of course, one of the problems with getting down to the submicron level is measuring what you have done. This is not going to be achieved with a set of Verniers and apparently, for measuring hydrophobic or hydrophilic surfaces, I need something called a goniometer. It turns out that you can buy one that takes a mobile phone, which is controlled with an app and can measure everything automatically. That sounds like just the kit I need."

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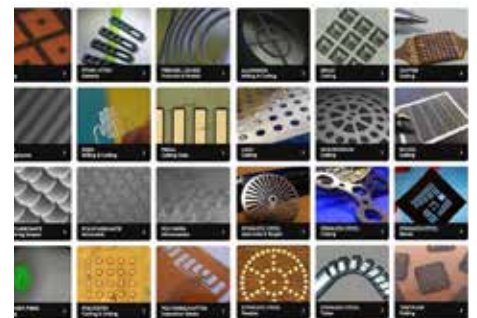
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LASER MICROMACHINING LAUNCHES NEW WEBSITE



Laser Micromachining Ltd has launched a completely new website to highlight its range of precision laser services. The new website includes over 500 examples of the micro-structuring of polymers, metals, ceramics, glasses, semiconductors, thin films and composites.

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CENTRAL PROFILES INVESTS AND EXPANDS

Central Profiles is continuing to invest, with new additional premises and a new automated laser cutter. The company has listened to feedback from their clients and discovered that the need for fast turnaround and diversity in cutting services was a real unique selling proposition.

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CHAIR'S MESSAGE



BACK TO WORK

On an unusually positive note, the general consensus I am hearing from the Laser Job Shop community is that work has picked back up and productivity in many companies has bounced back up to 75% or more. However, the global pandemic rages on - currently there are already over 20 million diagnosed cases worldwide and infection rates are still growing rapidly in certain parts of the world. On that cheery note, here in the UK we are all trying to adjust and get back to some level of normality.

Returning back to the bright side... as work for Laser Job Shops picks back up, the normal daily challenges arise of how to get the work out the door. Whilst this is a familiar, but never simple, challenge for all of us, there is a new slight complication on getting back up to full speed - the governments furlough scheme. I was surprised by how generous and forthcoming the government was with this scheme (not something I say often!). Many companies have made use of it to help them through the last few tough months and it has been a real life-line for many. I have found our employees to have been very understanding as we too have utilised the scheme. However, getting employees back to work after being on the furlough scheme has several challenges.

Firstly, employees are rightly concerned to know that the workplace is Covid secure. An almost impossible task in itself, but of course I'm sure we are all doing our best in that regard.

Secondly, getting employees to work again for only 20% more than they were getting paid for staying at home can be problematic. Whilst we have not had any issues with our employees, this could be really difficult for some. As the scheme becomes less generous over the coming months, this issue will start to press home.

Thirdly, the logistics of returning to work. We have had issues where employees initially find it difficult to return back to work, as they have been on furlough for so long they have got out of their working routine and some have even started to make plans, assuming they would continue to be on furlough. Obviously both parties have the usual employment rights in these cases but be warned, when ending someone's furlough period with little notice, some will be happy, but don't expect everyone to be overjoyed.

The government's new Flexible Furlough scheme is a great way to ease people back into work. Whilst wonderful for employers, there is a risk employees would rather be back fully or off fully. We are hoping to be able to get all employees back to full time sooner rather than later, as I'm sure you all are too.

If you factor in these considerations hopefully your only problems will be how to cope with so much work, well we can all live in hope!

Mark Millar

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3D PRINTING

3D PRINTING OF HYBRID METAL/POLYMER OBJECTS

YUAN-HUI CHUEH & LIN LI

Additive manufacturing (AM) is an emerging technology based on layer-by-layer material addition. The advent of multiple material additive manufacturing (MMAM) takes AM one step further, enabling the printing of multi-material components with tailored properties. Various material combinations can be realised through MMAM, such as metal-metal [1], metal-ceramic [2, 3], and composites [4]. However, the printing of polymer/metal hybrid components through MMAM is scarcely reported [5, 6], and such components mostly fabricated using sequential discrete manufacturing processes, which significantly limits the flexibility of 3D printing. Besides, there is limited research into the characterisation of metal/polymer interfaces such as mechanical properties. This article reports the fabrication of hybrid metal/polymer components through the integration of fused filament fabrication (FFF) and laser-based powder bed fusion (LPBF) developed at The University of Manchester.

Why integrate FFF and LPBF?

The integration of both AM technologies has shown promising possibilities [7]. LPBF, or selective laser melting, has been widely used to produce metallic components. One strength of LPBF is that the galvanometer-manipulated laser beam directly melts the pre-laid metallic powder materials with localised energy delivery, instead of heating components in their entirety. This can protect the printed polymer from thermal pyrolysis during scanning. FFF, sometimes known as fused deposition modelling, is a well-developed and low-cost material extrusion-based AM process for polymer components. The advantages of an FFF process include ease of integration with other AM processes and the capability of delivering fully dense melted thermoplastic polymer directly through a nozzle.

The challenge is to bond metal to the polymer. In our integrated FFF-LPBF system, the laser beam thermally bonds metal and polymer sheets through a mechanical interlocking structure, in a similar way to laser-assisted metal-polymer joining (LAMP) [8]. In a LAMP process, metal and polymer can be bonded together when the laser beam penetrates through the transparent polymer and is absorbed by the surface layer of metal, resulting in the localised heating and melting of polymer layers, which then penetrates into the mechanical interlocking structure through a compressive pressure. Our FFF-LPBF

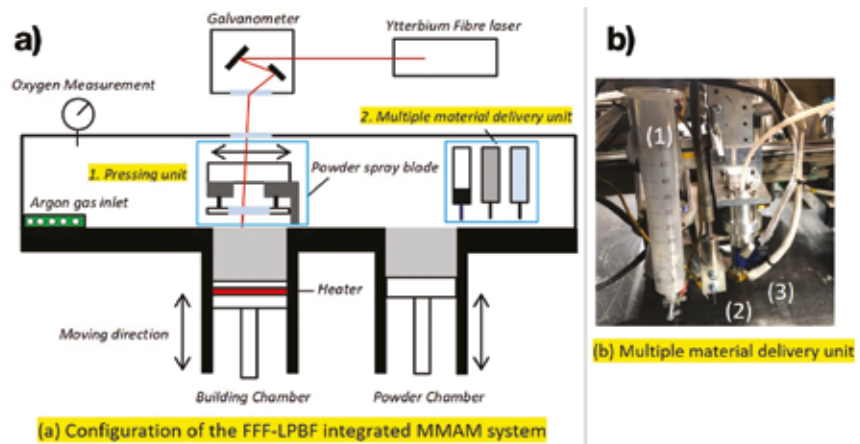


Figure 1: Schematic - FFF-LPBF-integrated MMAM system at The University of Manchester.

system achieves metal/polymer bonding by filling LPBF-fabricated metallic mechanical interlocking structures with FFF-extruded melted polymer and using a laser to improve both polymer penetration and the bonding strength.

Integrated FFF-LPBF additive manufacturing system

Figure 1(a) illustrates the configuration of the FFF-LPBF integrated MMAM system. A 500 W continuous-wave (CW) Ytterbium fibre laser (IPG Photonics Ltd, YLR-500-WC) with a 1070-nm wavelength and a 60 μm beam spot size was equipped with a Nutfield 3XB 3-Axis galvanometer to perform laser scanning. A pre-heating system (up to 300 $^{\circ}\text{C}$) was integrated within the building chamber. The entire system was filled with argon gas to prevent oxidation and installed with an oxygen sensor to ensure low oxygen content during the scanning process.

To enable the printing of multiple material components, a specially designed multiple-material-delivery unit - composed of ultrasonic vibration-assisted powder delivery nozzles (Figure 1(b1)) that can selectively deliver more than one type of metallic

powders, a selective powder removal system (Figure 1(b2)) that can remove powders of a single or multiple layers from selected locations, and a modified commercial type E3D-V6 J-head extrusion nozzle (Figure 1(b3)) that can print polymer components through heating and melting of filaments were integrated with motorised X-Y motion controls inside the system. A pneumatic mechanical pressing unit was used to facilitate metal/polymer joining. The activated air pistons push an N-BK7 (Edmund, UK) glass window (to enable laser scanning at the same time) onto the polymer/metal interface to compress the FFF-extruded melted polymer into the LPBF-fabricated macroscopic mechanical interlocking structures.

The operation procedure of the FFF-LPBF system entailed three steps:

1. A layer of loose metallic powder from the powder chamber was spread onto a substrate and laser-scanned for selective melting. This process was repeated until mechanical interlocking structures were formed. Then, the powder-removal nozzle was activated to remove any residual powder from the structures.

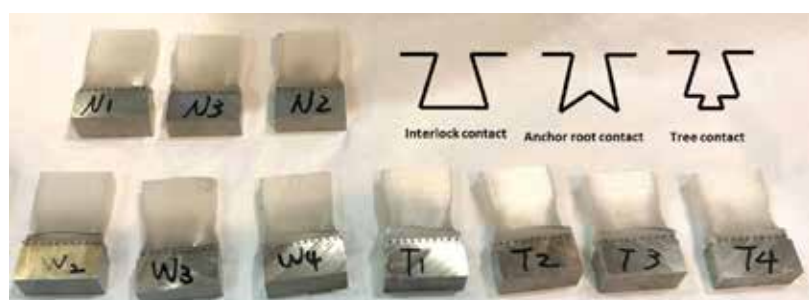


Figure 2: Printed metal/polymer specimens for tensile strength testing.

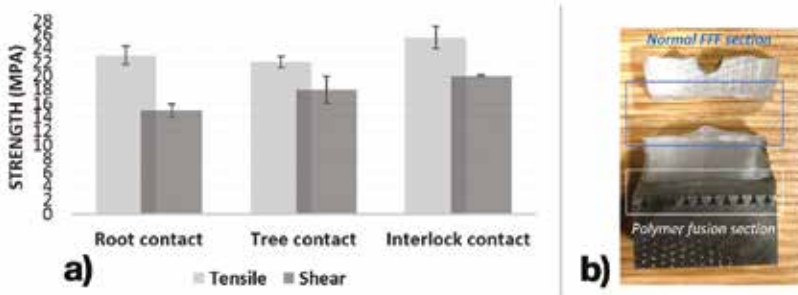


Figure 3: (a) Experimental results of shear and tensile tests and (b) the breakage of the specimens.

- The printed structures were pre-heated to 180 °C, and the FFF-extrusion nozzle was activated to deposit melted polymer into the interlocking structures. After the extrusion process was completed, the pressing unit shifted to the printed structures, applying a compressing force onto the metal/polymer interface. Meanwhile, a defocused laser beam was applied to scan the metal/polymer interface to facilitate the infilling of the melted polymer.
- The extrusion nozzle and the ultrasonic vibration nozzle both deposited additional layers of metal/polymer for the subsequent printing process. The third step was repeated until the entire component was finished.

Polymer/metal joint strength characterisation

To characterise the joining interface of metal/polymer, we designed and printed three different interlocking structures - interlock contacts, anchor root contacts, and tree-shaped contacts (Figure 2) - for tensile and shear strength characterisation.

Figure 3 (a) reveals the average shear and normal tensile strength levels with standard deviations for three different joint specimens. It is clear that normal tensile strengths were higher than shear strengths. Figure 3 (b) further indicates that the metal/polymer interface exhibited a higher joining strength than the FFF-printed polymer part. The

fractured locations of the tensile test specimen were largely in the polymer part. This can be explained by the formation of compressed polymer inside the interlocking structures due to high pre-heating substrate temperatures coupled with a compressive force. By contrast, the FFF-printed polymer part did not have such high density because of a nozzle-filling path limitation (such as gaps between the nozzle paths).

A scanning electron microscope (SEM, Zeiss Sigma VP FEG DEM) was used to examine the cross-section of the printed metal/polymer interface for microscopic defects. Figure 4 illustrates the SEM image with a corresponding energy dispersive X-ray spectroscopy (EDS) elemental map that accentuates the metal/polymer interface. Changing the laser-scanning strategy can also modify the microstructures along the printed metal surface. For example, laser re-melting is typically applied in every layer to reduce porosity and surface roughness during the LPBF process.

In this research, we did not re-melt the mechanical interlocking layers, so as to enhance surface roughness (such as craters and pores) for polymer anchoring. Indeed, a criss-cross section can be identified along with the metal/polymer interface in both SEM and EDS images, suggesting the full penetration of the melted polymer into metal mechanical structures.

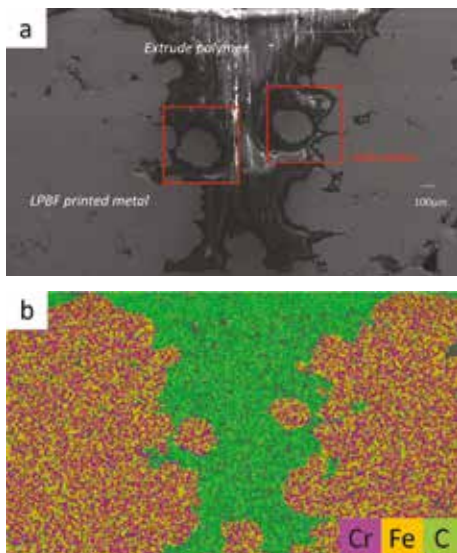


Figure 4: SEM image with an EDS map of the metal/polymer interface.

Potential applications

We printed several 3D multiple-material components to demonstrate the feasibility of our MMAM system. Figure 5 (a) illustrates a pavilion model composed of a 316L stainless steel footstep and eight Cu10Sn columns surrounding a polymer (PET) table inside the pavilion. Figure 5 (b) demonstrates a mobile phone case, whose metallic part (Gold: Cu10Sn, Silver: 316L stainless steel) serves as the main body while polymer parts (PET) acts as an insulator or other electrical components. Figure 5 (c) presents a 3D-printed metal/polymer hip implant with a controllable drug delivery profile. The FFF-printed biodegradable polymer (such as PLA) can be loaded with antibiotics and enclosed within an LPBF printed implant (Gold: Cu10Sn, Silver: 316L stainless steel). This way, when the polymer degrades, the loaded antibiotics can be released through the mesh structure along the surface of the implant.

The detail of this research can be found in [9].

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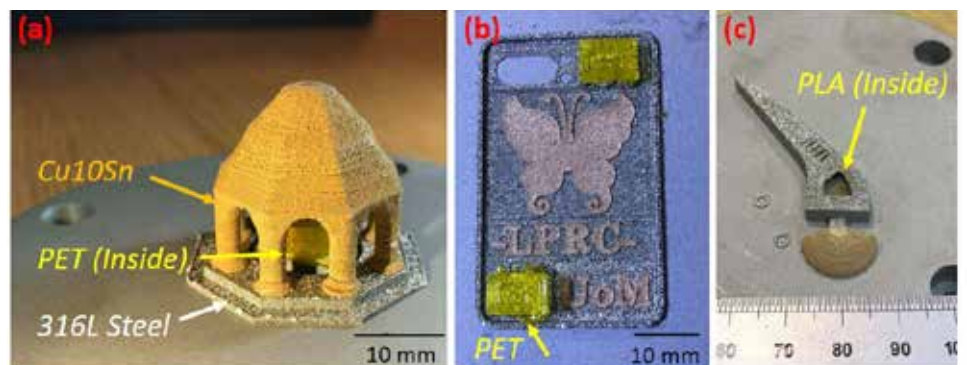


Figure 5: 3D-printed components: (a) pavilion, (b) mobile phone case and (c) hip implant.



Yuan-Hui Chueh is a PhD student in the Laser Processing Research Centre at The University of Manchester, under the supervision of Professor Lin Li.

LASER SHOCK PEENING

TOPOGRAPHY & MORPHOLOGY OF LASER SHOCK PEENING ON Ti-6Al-7Nb

XIAOJUN SHEN & PRATIK SHUKLA

Laser Shock Peening (LSP) can introduce a deep and stable compressive residual stress layer which benefits the mechanical properties. In addition, the component surface topography is also affected. This effect is usually in the form of increased surface roughness of metallic components, which are fairly smooth to begin with [1]. Unlike the surface morphology caused by laser ablation, which removes the material from a solid surface by irradiating with a laser beam [2], a laser shock peened surface finishing is formed by plastic movements activated by plasma shock-waves.

After LSP, surface features such as pits, dimples and pile-up regions are generally observed [3]. This could lead to non-uniformity of micromechanical properties, thereby leading to the failure of materials during service. As such, elastic contact laser shock peening (ECLSP) and laser shock-wave planishing (LSWP) can decrease the surface roughness introduced by LSP [4]. Compared to conventional LSP-treated surfaces, the piled-up region height after ECLSP treatment is much lower than that of the laser shock peened region (0.78 μm vs 1.3 μm). Also, in terms of LSWP, the surface roughness after CNC milling can also be decreased from 3.07 μm to 0.977 μm or 0.577 μm by applying one or two LSWP impacts.

Medical applications

When it comes to medical applications, rough surface finishing contributes to improving the osseointegration of implants. This bonding of implant to bone aids recovery and mechanical stability, the goal being that the bone grows around the implant.

Literature shows that different topography relates to the cell/protein adhesion, proliferation, and differentiation [5, 6]. Normally, the rougher the surface, the higher the osseointegration performance of the implant and so other surface modification methods such as sandblasting, acid-etching, and shot peening are employed to enhance implant bio-compatibility. These techniques introduce surface features such as pits, dimples, and grooves, which are needed for osteoblast cells to settle down on the implant surface and start to survive. Multiple surface modifications with diamond shot peening, acid-etching, and Al_2O_3 blasting can achieve different surface topographies in metals such as titanium alloy, to proliferate bone marrow mesenchymal stem cells (BMSCs) [7]. Apart from

the mechanical and biological applications, the surface topography also has a great influence on wettability which was published in our previous work [8]. Therefore, the characterisations of the surface topography after LSP is critical.

This article mainly focuses on the evaluation of the topography post-laser shock peening an orthopaedic-grade titanium alloy (Ti-6Al-7Nb) at various processing conditions, namely: laser energies of 3 J, 5 J and 7 J, at the overlaps of 33%, 50% and 67%. The broader aim of the research was to induce beneficial compressive residual stresses in the unknown titanium alloy, but also use the surface roughness as a by-product and observe whether beneficial effects in terms of wettability and bio-compatibility can also be achieved with LSP [8]. Atomic force microscopy (AFM) and laser confocal scanning microscopy were used to characterise the surface features of the Ti-6Al-7Nb titanium alloy.

Characterisation of micro feature surface morphology

Prior to characterisation, all laser peening work was undertaken at Coventry University's LSP facilities. In Figure 1, the average surface roughness of the untreated sample is 22.9 nm.

Compared to the untreated surface, the surface roughness has been increased due to LSP (maximum up to 43.4 nm). Amongst the samples subjected to 3 J or fewer than 4 impacts of 5 J, there are no obvious differences between LSP and the untreated surfaces. However, the surface reliefs start to form when the impact increases to 4 at a laser energy of 5 J. This may be due to high plastic movements driven by comparatively high laser energy and impact numbers. As stated elsewhere [9], the surface relief is a typical morphological representation of the free (semi-constrained) plastic flow of metallic surfaces during non-contact plastic deformation, characterising a unique local microscale reverse deformation phenomenon. In 7 J treatment with 1 impact and 7 J at 2 impacts, the number of surface reliefs reached its peak, as well as the surface roughness (42.7 nm and 43.4 nm). What is interesting is that the surface reliefs and surface roughness begin to decrease with the impact increasing to 3 and 4. It is postulated that these surface reliefs can be used as anchorages for the cells adhesion.

3-D topography and surface roughness of Laser Shock Peened Ti-6Al-7Nb alloy

It has been observed [10-12] that LSP can increase the surface roughness with increasing

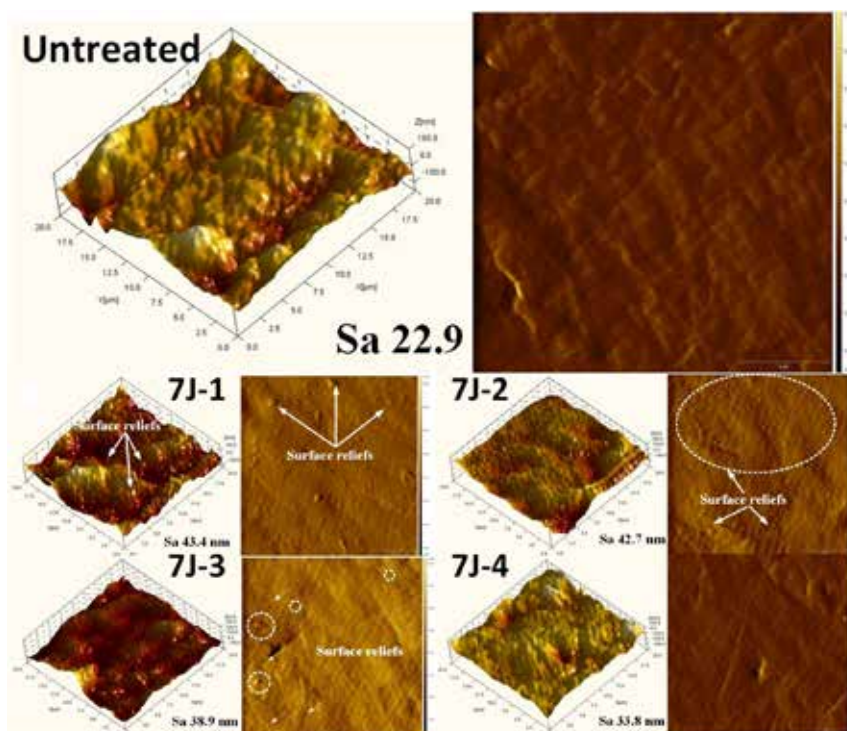


Figure 1: AFM image showing the micro topographies of Ti-6Al-7Nb alloy before and after LSP, where Sa is average surface roughness.

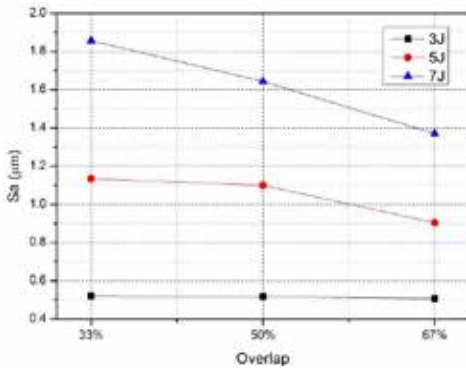


Figure 2: The distribution of average surface roughness (Sa) with % overlap and laser energy (J) [8].

laser energy and multiple impacts. Also, surface topography and surface chemistry determine the wettability of materials. Therefore, studying the effect of LSP on the surface roughness is very pertinent.

The average surface roughness (Sa) along the LSP parameter distribution is shown in Figure 2. The vertical axis shows that increasing laser energy leads to a rise in surface roughness. Also, at a laser energy of 7 J, average surface roughness decreases along the horizontal axis, to 67% overlap, with a reduction of 1.9 µm to 1.4 µm. In the overlap range of 33% to 50%, the reduction of surface roughness was much lower. This is because the power density of 3 J is comparatively lower than that of 5 J and 7 J. Therefore, from the normal direction of the laser process, the depth of the dimples is also more shallow. The depth would somehow affect the wettability of the laser shock peened region determining which wetting regime is more suitable.

Upon changing LSP parameters such as laser energy, overlap, spot size, surface characteristics, grooves and dimples can be acquired. According to the grooves direction, each sample was placed along the longitudinal way (Y-direction). At the same overlap, the surface topographies of 3 J, 5 J, 7 J laser energy are fundamentally the same. Therefore, typical topographies of the samples subject to laser energy of 7 J at 33%, 50% and 67% are presented as shown in Figure 3.

At 33% overlap, due to the 1/3 step movement, comparatively large dimples were formed after LSP, while grooves were not observed. Compared to 33% overlap, a square-grid topography was formed on 50% overlap surfaces, due the 1/2 step movement during the LSP. Additionally, grooves were formed on the surfaces. At an overlap of 67%, due to the larger step movement step (2/3), the width of the groove is much smaller than the those observed at 50% overlap.

The amplitude of the dimples after LSP along the X-and-Y directions are presented in Figure 4. On keeping the overlap consistent, it was observed

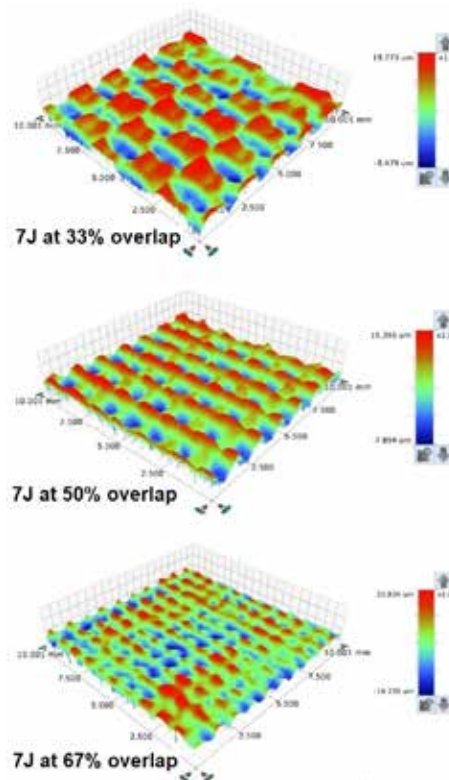


Figure 3: Surface topography of laser shock peened Ti-6Al-7Nb alloy at 7 J, with 33% ,50% & 67% overlap [8].

that the amplitude of laser shock peening-induced dimples was generally proportional to the laser energy in both the X and Y direction (except 67% group in the Y-direction). However, in terms of the relationship between the overlap and the dimple depth, the trend is not clear.

Conclusions

This investigation focused on the effects of LSP on the surface topography of an orthopaedic-grade titanium alloy. The following conclusions can be drawn:

- At the microscopic level, surface reliefs were formed when the laser energy and impact number was enough (starting from 5 J, 4 impacts). These reliefs are considered beneficial to cell adhesion.
- By multiple energy and overlap of LSP, different surface morphologies are formed. The surface roughness rises with the increase of laser energy when the overlap is kept constant. In addition, when applying constant laser energy, the overlapping laser pulses leads to lower surface roughness.

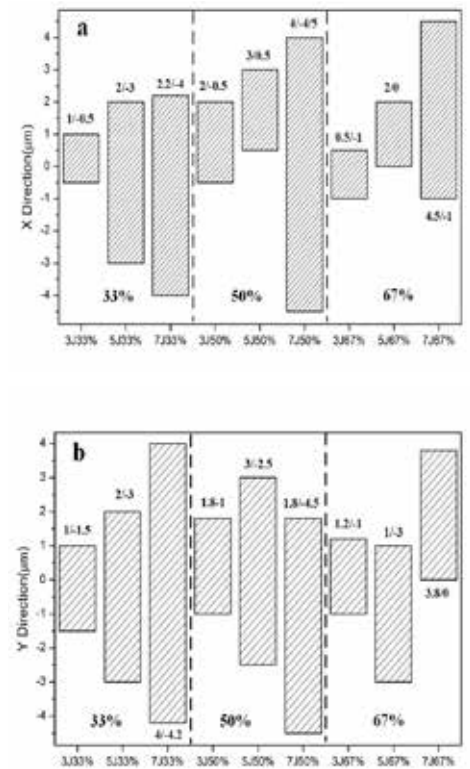


Figure 4: Comparative plot showing the amplitude of LSP-induced dimples at X-direction in (a) and the Y-direction in (b).

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LASER WELDING

LASER WELDING ALUMINIUM WITH AN OSCILLATING HEAD

ALEXANDRE PREVOST

The future looks bright for fibre lasers, and in the next decade many traditional welding techniques will be replaced in favour of fibre lasers. Indeed, diode pumped fibre lasers are cheaper, with lower ongoing cost of maintenance and spare parts, as well as being environmentally friendly. At Pyramid in 2019, a decision was taken to develop a range of laser welders to include a fibre laser with an oscillating head. This article presents an overview of the optimisation of the welding process of aluminium packages in a sensitive industrial application.

What is oscillation welding with a CW fibre laser?

Continuous Wave (CW) lasers can deliver a continuous beam of intense light. For oscillation welding, these are single mode, high brightness lasers which, with the right optics can be focused to around 50 µm diameter spot. This is roughly 10x smaller than an equivalent pulsed Nd: YAG laser 0.5 - 0.6 mm. The high brightness beam has a power density which is high enough to enable keyhole welding. To generate a weld, the beam is oscillated along the weld path by a galvo scan-head (see Figure 1), where the combination of laser power, focal spot size and oscillation parameters control the weld size.

One of the main advantages of this welding method is that the width and depth of the weld are controlled by programmable rather than fixed parameters (e.g. the beam shape), making the system very flexible so that different weld cross-sections can easily be produced with the same workstation.

These characteristics enable a high power density to be reached, which is enough to melt most metals and in some circumstances vaporise them. This enables

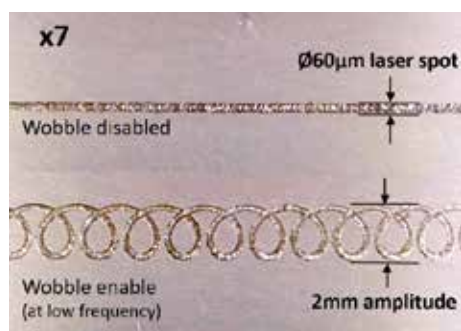


Figure 1: Example of a low power, low frequency and 3 mm amplitude wobble path compared to linear path with a CW fibre laser.

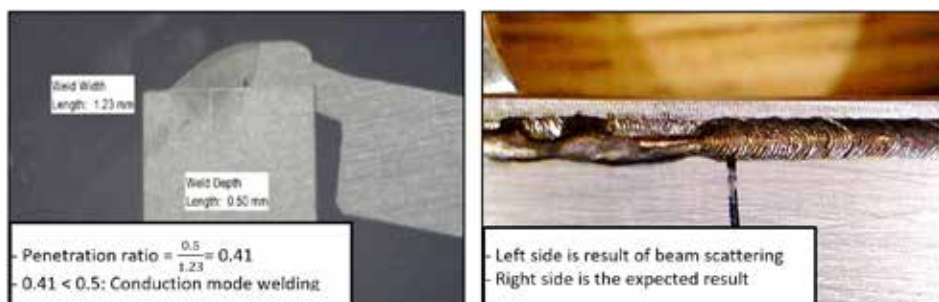


Figure 2: Weld cross section of the package (left). Evidence of discontinuity in the weld (right).

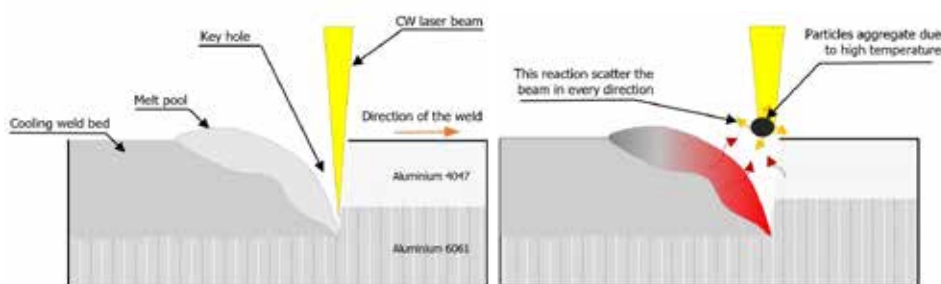


Figure 3: Illustration of keyhole welding (left). Illustration of plasma ball formation (right).

classification of two types of welds - conduction-limited and keyhole welds [1]. Strong interactions exist between the molten pool and the fibre laser beam which can lead to poor welds when left uncontrolled. The issue we encountered originally existed in deep and narrow keyhole welding. However, this effect was also witnessed in shallower welds, in conduction-limited mode (penetration depth/weld width < 0.5) [2].

Plasma-like ball formation and beam scattering

Hot gas formation in keyhole welding appears when metal is vaporised (see Figure 2). Indeed, evaporation pressure in the keyhole causes the plasma to expand above it, aggregating metal vapour and dust. Above the keyhole, the temperature rises because of different effects such as thermal lens focusing or reflection focusing on the molten pool [3]. The temperature enables a "plasma ball" to form, absorbing some of the incoming beams or scattering it in multiple directions (Figure 3).

The laser beam is then defocused leading to a larger focus diameter and a change in the focus position which reduces the power density. Laser radiation is also absorbed in the plasma cloud. The extended plasma cloud causes the penetration depth of the weld to decrease to a

point where the welding process may even be interrupted entirely [4].

Importance of shield gas & extract setup

To prevent the above situation, a setup comprising shielding extraction and shielding gas is required. The type of shield gas is important with neutral and inert gas being preferred as there is less interaction with the molten pool. Varying results were seen during our trials, and eventually one arrangement proved to be repeatedly successful, comprising of a shield gas jet on one side and extractions on the other.

We used nitrogen as the shield gas jet in a controlled atmosphere composed mainly of nitrogen with 5% helium. To demonstrate the effect, two identical packages are shown in Figure 4, welded with the same process parameters where one is welded with extraction and shield gas, the other is welded without. The difference in the plume above the weld is significant, showing how well the shield gas and extraction system control the plasma effects.

Note that in this application the shroud gas and extraction play little importance in protecting the optics. Indeed, the scan lens focal distance is quite large (>250 mm) which is a reasonable way from the work area. It is this distance that assists in preventing spatter and fumes reaching that far.

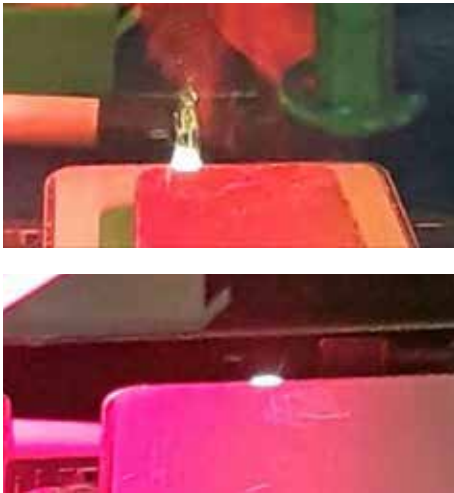


Figure 4: Reduction of the plume by the means of shield gas and extraction system.

Fillet weld – lid positioning

When welding a hermetically sealed lid onto a package body there are three types of weld that could be used. A simple smooth lid that is placed onto the flat top surface of the body would need to be lap welded, whereas a lid which is inserted into a recess in the body could be butt welded. Oscillation welding of butt joints can be achieved with a maximum gap of around 0.1-0.2 mm (reference to SPI Lab Reports). If the lid has an undercut machined around the underside perimeter edge it can fit into the recess with a lip on the top surface, which can be fillet welded - this is the type of weld used in this instance (see Figure 5).

However, with fillet welds, a lid misalignment will cause the weld to have an unequal weld path. The cross-section of welds show two opposite edges of the same package on which the lid has been misaligned. By observing the sections below, we can tell the weld shape is different. One has been welded more on the housing (Figure 5a), the one more on the lid (Figure 5b).

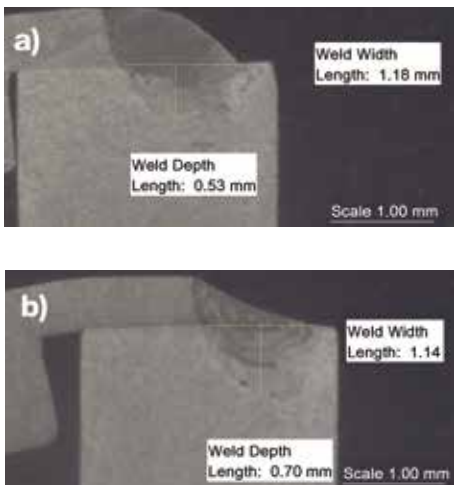


Figure 5: Weld cross section of opposite side of a package with slight lid offset.

CW wobble welding - overview of welding parameters and their effects.							
Based on welding trials at Pyramid on aluminium alloy 4047/6061							
				Scale 1 to 6		1 is low effect 6 is high effect	
ROOTS		EFFECTS					
Source	Parameters	Depth of the weld	Width of the weld	Visual shape of the weld	Process speed	Type of weld (Cond-Lim/Key hole)	Creation of plasma
Laser	Power	6	2	4	1	6	3
	Focus height	3	5	2	1	3	5
	Focus positioning	4	1	2	1	4	5
Scanner	Frequency	1	2	2	3	4	1
	Amplitude	5	6	3	1	5	4
	Wobble shape	1	3	1	1	1	1
	Path positioning	1	2	4	1	1	1
	Spot offset	1	1	4	1	1	1
	Average speed	6	1	1	6	5	4
	Start/End overlap	1	1	3	1	1	1
Shroud gas	% Oxygen	1	1	5	1	2	4
	Extract	1	1	6	1	2	6
Material	Reflectivity	3	2	3	1	3	4

Table 1: Non exhaustive list of weld parameters, their effect on the resulting weld, sorted by intensity of interaction.

However, the cross sections highlight that a small misalignment of the lid has in fact limited impact on the internal structure of the weld, showing a minor impact on the width (1.14 mm/1.18 mm) and a reasonable impact on the depth of the weld (0.70 mm/0.53 mm).

Operating characteristics

This laser technology is highly flexible (see Table 1). Weld depth and width can be controlled independently, making it more forgiving in terms of gap and tolerances for welded devices.

The power, amplitude, frequency and average speed are the main parameters to consider. In some applications heat distortion is critical (i.e. fibre optic telecommunication devices) therefore the aim is to keep heat input as low as possible. Our case study for a fillet weld on aluminium package (grade 4047-lid to 6061-housing) showed optimum results were achieved with the following setup which produced a reliable, hermetically sealed weld with a repeatable penetration depth into the base material.

SPI RedPower 1.5kW laser
 Raylase scanner Head
 Focusing lens = 255 mm
 Collimation lens = 100 mm
 Focal spot size = 51µm

Weld speed = 75 mm.s-1
 Laser power = 600 W
 Amplitude ϕ = 0.8 mm
 Frequency = 400 Hz
 Extract on / shield gas on

Summary

In conclusion, welding aluminium grade 4047 to 6061 in an industrial environment has been a success using a CW laser with oscillating scan head. Further positive tests in the laboratory showed good quality and consistent welds can also be achieved on many different metals using the extended process window offered by this

new technology.

The welding potential of the following metals has been proved either in the laboratory and/or already confirmed in an industrial application:

- Aluminium grade 4047; 6061
- Silicone Aluminium
- Stainless steel grade 304; 316
- Titanium alloy Ti-6Al-4V
- Brass 95/5
- Kovar (nickel-cobalt ferrous alloy)

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E-MOBILITY

THE FULL POTENTIAL OF PHOTONICS IN E-MOBILITY: AN OVERVIEW

MARKUS KOGEL-HOLLACHER

It is becoming increasingly clear that there is more than a gradual transition in the automotive industry, especially when it comes to future propulsion systems. Whether we talk about e-mobility or hydrogen drive, the photonics industry is taking the opportunity to transform manufacturing processes and convincing decision makers of the undoubted advantages of photonic tools, particularly lasers, in the relevant production chains. As most of the applications in e-mobility are new, there is no need to transform an already existing process from the “pre-laser age”. The most profitable manufacturing tools can be used from the outset.

This article reviews some of the applications in battery production from the perspective of a supplier of sensor technology and processing tools. The main focus will be on laser welding where process monitoring and control play an important role.

The current situation

Electromobility is a megatrend which - together with the networking of vehicles, autonomous driving and digitalised production - will significantly change the automobile, its use and its production in the coming years. The electrification of the powertrain in particular is changing the existing value-added and employment structures in the automotive industry, whereby the importance of classic components such as the combustion engine will ultimately decrease, while at the same time the importance of new components of electric mobility will increase.

There are different designs and degrees of electrification - from hybrid to pure battery vehicles - with different electrical outputs, ranges and driving shares. New components significantly change the share of value added in the vehicle. The focus of value creation is shifting further from mechanics to electrics/electronics. The battery is a core element of all electrified vehicles. It stores the energy required for propulsion in the battery cells and delivers them to the electric motors when required. The greatest technical challenge lies in the development of powerful and cost-effective battery systems to realise electrical ranges that can compete with today's conventionally operated vehicles - at similar costs. Currently, compared to petrol or diesel fuel, batteries have a lower energy density. For example, for a range of 100 km, only 6-7 kg of conventional

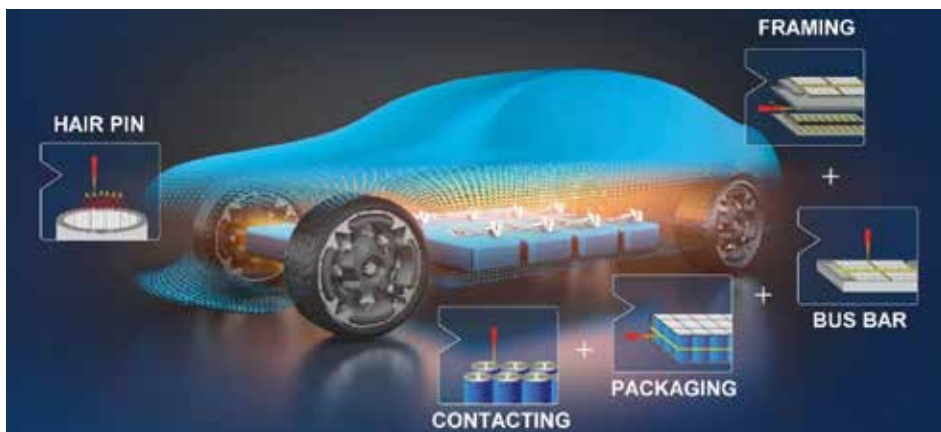


Figure 1: Overview of typical laser welding applications in e-mobility.

fuel (including the storage system) is required in the vehicle. This value increases to over 130 kg with today's battery systems. Consequently, achieving higher energy densities is the focus of R&D on battery systems.

In the short- to medium-term, battery cells with lithium-ion technology (Li-Ion) have the greatest potential. These are currently being used in almost all relevant electrified vehicle concepts. In addition to the cells, the battery system in the vehicle also includes battery management (including monitoring), electronics and sensor technology, components for cooling, safety elements and the battery housing. Between 60-80% of the overall production cost of a finished battery pack can be addressed by laser material processing. Laser applications in this field are available from the photonics community to increase the quality and efficiency of the processes which can reduce the final cost significantly.

Photonics in battery manufacture

Several key steps in battery production involve welding or bonding, which includes processing of internal components, sealing of individual cells

and generation of connections between battery cells to final, customer-specific packs. Welding applications emerging in this context include cylindrical and prismatic cell seam sealing, pouch cell tab welding, battery pack connection and welding of hairpins in electric motors (Figure 1).

The battery systems in particular suffer from challenges which are on one hand the increasing number of product variants, and on the other hand concepts associated with lack of standardisation for process and product design. Again, the extremely high flexibility of the laser as a tool comes into play as manufacturing systems are faced with the challenges of adapting to high volume production, new designs and satisfying quality targets in given production cycles.

However, there is one major disadvantage: damage of the battery due to uncontrolled weld penetration, leading to the risk of piercing of the battery cell, with subsequent leaking of harmful gases and risk of fire. One single defective weld can cause the whole battery pack to malfunction (i.e. voltage drop). The call for automated, reliable process sensor technology is clear.

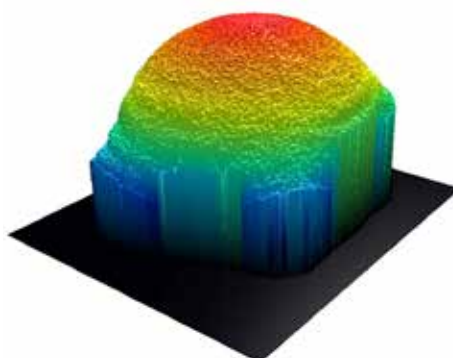


Figure 2: OCT measured topography (left) of a laser welded hairpin (right) for quality inspection.

It is not only high flexibility that is desirable when new technological solutions are designed and tested. When it comes to in-process monitoring of weld quality, along with corrective and/or preventive actions in order to achieve zero scrap, the laser process demonstrates its advantages. Process monitoring sensors have been developed alongside the increasing use of lasers, based on the one creed: 'don't stand in the way'. This means that in particular, devices have to be light, small, easy to integrate and must never slow down cycle times. In this context we talk about monitoring systems based on photo diode technology [2, 3], evaluating quality based on the emissions emerging from the interaction zone. We also talk about the adaptation of Optical Coherence Tomography (OCT) sensor technology [4-8] to the processing tools, being able to perform real measurements in physical units deriving a go/no go message (see Figure 2). Within laser material processing, this sensor technology came into focus about 10 years ago when Precitec was the pioneer and driver for the transfer of OCT from medical technology to industrial production.

Lasers applied to joining processes

Another reason for the laser being a preferred tool in the e-mobility industry is its flexibility when it comes to joining dissimilar materials. In the applications mentioned we talk about joining copper to aluminium, copper to steel or aluminium to steel [9, 10]. SPI Lasers UK Ltd has demonstrated that, with short pulsed lasers, there is a stable process window for joining which can be driven with photons (Figure 3) [10].

When joining copper to other materials, intensive activities have been deployed to investigate the use of visible laser sources with green (515 nm) or blue (450 nm) radiation. Looking into the physical properties, especially the absorptivity under ambient conditions, you find this value multiplied tenfold in comparison with IR lasers [12, 13] which does not mean that stable process windows also exist with the pure use of IR beam sources [14]. Currently laser beam sources of 450 nm wavelength are available with an output power of up to 2 kW, which allows the processing of laser micro-welding with heat conduction welding, as well as deep penetration welding [15-17]. The absorptivity, and

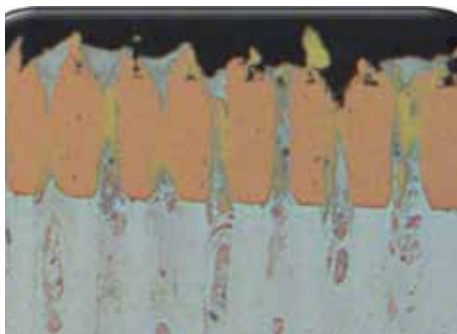


Figure 3: Metallurgically interesting material flow after joining copper to aluminium with ns laser pulses. Courtesy SPI Lasers.



Figure 4: Smooth and extremely stable 450nm laser weld of copper sheet prepared with three different surface conditions (etched, oxidised, polished). Courtesy Laserline GmbH.

therefore the energy input, during the process increases from 1070/1030 nm to 515 nm and 450 nm wavelengths. Local fluctuations during the process decrease, which indicates a more stabilised energy input (Figure 4).

In the context of energy input, a new degree of freedom has opened up, application specific intensity distribution. As research institutes increasingly help to understand beam-material interactions, the most profitable intensity distribution can be selected for the best result. Let us name it 'the GPS system for photons' (Figure 5). Basic research underlies this GPS system, comparable to a route planner. System developers like Precitec ensure that the photons can propagate without interference on their way to the workpiece. New devices for a flexible design of the intensity distribution have already been presented and applied to welding applications in the context of e-mobility [18, 19].



Figure 5: 'The GPS system for photons' - application specific intensity distribution.

Take away messages

This article has only been able to scratch the surface in highlighting the overlaps between photonics and the requirements for efficient production tools for tomorrow's mobility. Further interconnections with respect to Industry 4.0 and artificial intelligence have not been explored, but it is easy to find more examples that underscore the uniqueness of the laser in the context of e-mobility.



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MULTI-BEAM PROCESSING

MULTI-BEAM PROCESSING WITH HIGH INTENSITY ULTRASHORT PULSES

DANIJELA ROSTOHAR

Since the first laser application in May 1967, it became obvious that lasers were opening a new chapter in material processing. Today we can find laser applications in nearly all materials and industries. Pulsed lasers, especially ultrashort-pulsed, contribute to high quality laser material processing: low Heat Affected Zone (HAZ) cutting, drilling or surface structuring of even very sensitive and thin-film materials became possible.

Despite significant improvements in the operational stability of ultra-short pulsed lasers, their real industrial breakthrough is still limited to a very small amount of very specific applications. This is due mainly to the cost of lasers and low process efficiency. While the market price for these lasers depends on many factors, the recent demonstration of ultrashort-pulsed lasers with high average power may solve the problem of low processing efficiency.

Pulse and repetition rate

In the case of pulsed laser systems, the average power P_{avg} is equal to energy per pulse E_p multiplied by repetition rate Q .

Based on this relationship, it is clear that there is a trade-off between pulse energy and repetition rate. Due to limitations in laser physics and heat extraction from the active laser medium, high power laser systems can normally only provide two combinations of energy per pulse E_p and repetition rate Q :

- Low energy per pulse E_p (μJ level) and high repetition rate Q (MHz).
- High energy per pulse E_p (mJ) and lower repetition rate Q (kHz).

In the case of cutting, marking or Direct Laser Patterning (DLP) it is important to move the laser spot over the treated area while keeping a certain overlap between the two succeeding laser pulses. If d is the laser spot diameter, s is the scanning speed for a given repetition rate Q , the overlap of two laser spots is correlated to the laser spot diameter, scanning speed and laser repetition rate.

The overlap of two laser spots is correlated to the laser spot diameter, scanning speed and laser repetition rate.

For a laser system operating in MHz repetition rates, to have overlaps in the range of 50% -

80%, the scanning speed (> 10 m/s) is already beyond the capability of standard scanners. Additionally, it is well known that the upscaling of ultrashort pulse laser micromachining by increasing laser repetition rate is limited by the heat accumulation and shielding effect [1]. Consequently, a lot of attention is currently paid to the development of polygonal scanners to redistribute faster laser pulses over a treated area. However, those scanners are still in development, and they are currently expensive and bulky. Despite processing of roll-to-roll 2D parts using a polygonal scanner being promising, processing of 3D parts is looking very complex if not impossible.

At the HiLASE Centre ultrashort (< 2 ps) pulsed lasers of up to 1000 W are developed [2] following the second combination of high energy per pulse E_p and repetition rate Q in kHz range (some of the possible combinations of those parameters are listed in the table below for PERLA commercial laser systems). PERLA lasers (Figure 1) are diode pumped Yt: YAG thin-disk lasers operating at a nominal wavelength of 1030 nm. So far two families of laser systems are under development, low and mid-repetition rate (1-10 kHz) and high repetition rate (50-200 kHz). Recently, based on in-house knowledge, HiLASE started offering customised laser systems (see Table 1).



Figure 1: HiLASE ultrashort laser system (PERLA laser).

P_{avg} [W]	E_p [mJ]	Q [kHz]
70	0,35	200
100	1	100
50	10	5

Table 1: Parameters for some customised commercially available PERLA lasers

Damage threshold and specific removal rate

Other important parameters in laser micromachining are damage threshold and specific removal rate. The damage threshold is characteristic of each material and depends mainly on laser wavelength (absorption of material at a certain wavelength) and pulse duration. The most common way to determinate the damage threshold in the short pulse regime for the Gaussian laser beam is described in [3] and corresponds to minimum laser fluency.

Laser fluency is proportional to the ratio between energy per pulse and the area to be ablated. Typically, damage threshold values for metals in the air for wavelengths around $1 \mu\text{m}$ under ultrashort laser pulses are in the range of up to 1 J/cm^2 for metals and 10 J/cm^2 for dielectrics. This means that for a laser spot size of $50 \mu\text{m}$ (a typical value for wavelengths around $1 \mu\text{m}$ and a telecentric lens with $f = 100$ mm) initiation of ablation of the materials discussed is less than $20 \mu\text{J}$ per pulse.

The increase in pulse energy (or fluence) can improve the material removal rate to a certain extent. In a high fluence regime, the specific removal rate (ablated volume per time and power) is saturated and further increases will not improve the processing efficiency [4].

Logically, one would expect that increasing energy per pulse (and consequently fluency) would lead to an increase of efficiency in material removal, measured by specific removal rate. Unfortunately, the specific removal rate, besides dependence on pulse duration and in some case on laser spot size, also shows a saturation after a certain level of fluency: further increase of fluency will not lead to an increase in the processing efficiency.

Consequently, for the efficient use of available E_p of the laser system, new processing approaches would need to be developed. In the first approach, for micro-drilling, we use multi-beam processing which recently caught the interest of several research groups [4].

Multi-beam processing

In this approach, the initial laser beam is divided by a beam-splitting module (from the company Meopta) into more than 700 beamlets for parallel processing (see Figure 2). Recently, using the module in combination with one of HiLASE's laser systems and a scanner, 784 identical

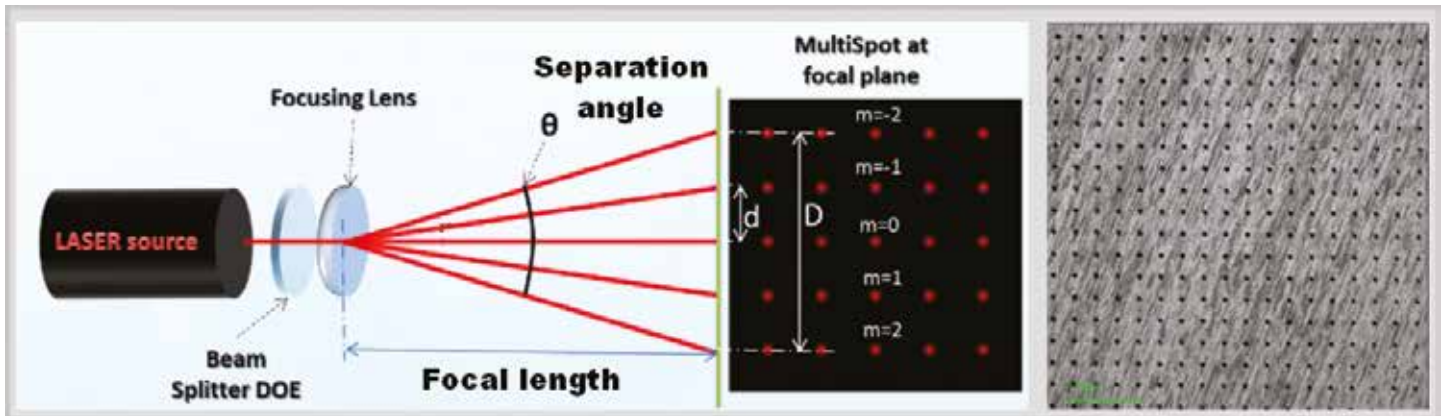


Figure 2: Basic principle of multi-beam processing (left) [5] and sample with multiple drilled holes (right).

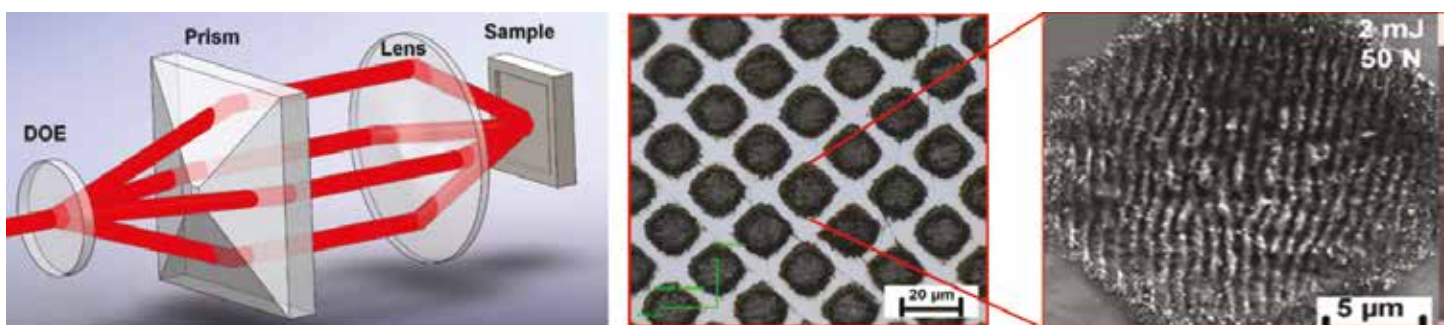


Figure 3: Four-beam DLIP setup (left) and part of samples with multi-spots. Each spot, depending on processing parameters, is filled with LSFL or HSFL LIPSS structures.

microholes were drilled in 20 μm thick invar (FeNi36) foils.

The Meopta module consists of a beam splitter (Diffractive Optic Element), focusing and monitoring elements. To minimise heat accumulation in the treated area, a sample was held in a specially designed holder with active cooling.

Surface structuring of complex 3D shapes is highly demanding for creating specific functionalities (e.g. self-cleaning, anti-bacterial, anti-icing, tribology, etc.). Taking into account the high quality of PERLA lasers ($M^2 < 1.2$), using multiple elementary cells DOEs (where cells are designed according to specific required functionality), a large area can be covered with just a few laser pulses.

Direct laser interference patterning

In order to tackle efficient surface structuring, we have recently started to investigate the direct laser interference patterning (DLIP) approach, which to date is the method providing the highest processing efficiency.

Four-beam DLIP system in combination with PERLA system recently demonstrated a capability to produce Laser-Induced Periodic Surface Structures (LIPSS) over a large area with significantly improved productivity (see Figure 3). By selecting processing parameters (fluence in the range of 0.1 to 0.17 J/cm² and several pulses per area) both low-spatial frequency

LIPSS (LSFL) and high-spatial frequency LIPSS (HFSL) were fabricated.

A redistribution of initial laser energy per pulse by a DLIP technique allowed the fabrication of ~1520 spots with HSFL in 50 ms and ~1016 spots with LSFL in 5 ms.

Future improvements

Most of the results were obtained with a low repetition rate (1kHz), so a further increase of processing efficiency is possible by using a higher repetition rate. Nevertheless, special attention should be paid to minimise heat accumulation.

Another possible improvement is the development and optimisation of Diffractive Optic Elements in order to minimise losses.

The development of a DLIP system with a top-hat beam will also be one of the next steps towards rapid production of large surfaces with LIPSS structures.

All of these improvements, in combination with further laser developments, will potentially lead to more efficient micro-processing under ultra-short laser pulses.

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BEAM MANAGEMENT

ADVANCED BEAM MANAGEMENT WITH HIGH POWER FS LASERS

JOSE RAMOS-DE-CAMPOS ET AL.*

Ultra-short pulse (USP) lasers extend cutting and drilling to micro applications with excellent results. Despite recent developments in this type of laser, it is not always possible to fully utilise the power they provide, which limits their commercial exploitation. USP lasers are being developed with higher average power, increasing the energy per pulse or increasing the repetition rate. This requires more sophisticated solutions for laser beam management, beam shaping, beam splitting, fast scanning, or a combination of these.

With increased maturity and reliability, and a better understanding of laser-matter interactions [1], USP lasers are rapidly penetrating the market, producing quality components. Market analysis indicates that this expansion will continue [2,3]. Most future industrial applications will require not only high processing quality, but also higher throughput and productivity [4], for example with higher average power. At present, several research projects in the EU's Horizon 2020 program already demonstrate an average power of the kW range, such as HIPERDIAS [5, 6] or POLAROLL [7].

However, a USP laser alone does not guarantee superior results if all other elements of the laser system are not properly selected and managed. For example, at high average powers, the residual thermal effects become significant and can degrade the quality of processing and optical components, posing specific new challenges. Therefore, new treatment strategies must be applied based on laser applications and specifications: laser beam shaping, high-speed scanning, parallel processing, or a combination of these.

For many laser applications, it is necessary to select differing laser beam parameters. This is well known, for example, with laser surface treatment where a homogeneous beam provides better results than that of Gaussian type, taking into account the effect in the material [8].

Laser beam shaping can be defined as the transformation of a laser beam to give a new beam with more suitable parameters (e.g. irradiance, radiating exposure, intensity, phase, divergence) for the application.

At LASEA we have developed a solution for higher productivity using commercially available fs lasers in the range of 100 W average power, for cutting and drilling roll-to-roll (R2R) or batch-to-batch applications, by integrating advanced beam management solutions. This takes into

account the more general definition of laser beam shaping, for taper control during cutting and drilling, taking advantage of the laser beam polarisation, and a concept of an optical system that reduces the final costs [10].

The taper problem

When micromachining with fs lasers, it is almost impossible to obtain the same dimensions on the input side and on the output side because the laser always produces a certain taper - of 3° to 7° - depending on the type of material and its thickness. The solution to this problem is to have an angle of attack and precession so that the beam is continuously rotated or synchronised with other motions. In addition to the experimental results, we are able to simulate this effect using software called LS-Plume [11].

This precession movement is achieved through the use of precession or trepanning heads. Most precession/trepanning heads drill a hole and then move the part with low speed stages, taking advantage of the cooling of the gas under the nozzle but having the disadvantage of a high pulse overlap, which leads to thermal problems. Alternatively, the galvo scanner allows the processing of large fields at higher speeds, allowing a much smaller overlap, but without gas cooling. In both cases, it is difficult to use powers greater than 20 W on a tiny part, which

results in relatively low productivity.

Parallel processing is one option to increase throughput by dividing a 100 W laser into multiple heads and processing multiple parts at the same time, but it is not cost effective because of the high investment cost of these heads (\$100k each). The only way is to divide the beam after the precession movement and this is the solution chosen by LASEA.

LASEA has precession technology [12] that is suitable for both drilling and cutting, with a conventional galvo head, no gas nozzle, and easier process development. We consider the precession module as a "beam shaping module".

Thanks to the precession movement perfect control of the cone is obtained [12], a scanning field of $25 \times 25 \text{ mm}^2$ for a focal length of 100 mm and, if the conicity is too negative, we simply reduce the angle of attack (diameter of the donut).

Increasing power

The feasibility of dividing the precession beam into as many scanners as required [10] can be demonstrated, as shown in Figure 1.

Many precession systems (e.g. rotating prisms of Dove, rotating cylindrical lenses) apply a proper rotation of the beam, which causes a rotation

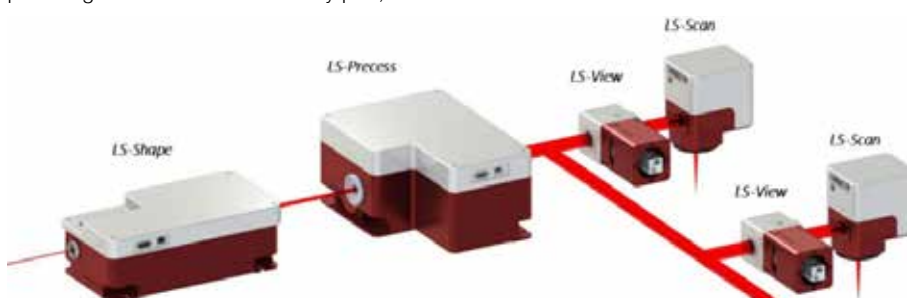


Figure 1: Representation of modules allowing a controllable precession movement in combination of two or more galvo heads.



Figure 2: Images of the practical demonstrator built, the back with the Tangor® laser (left); details of the different beam management modules (centre); detail of the two heads galvo from the front (right).

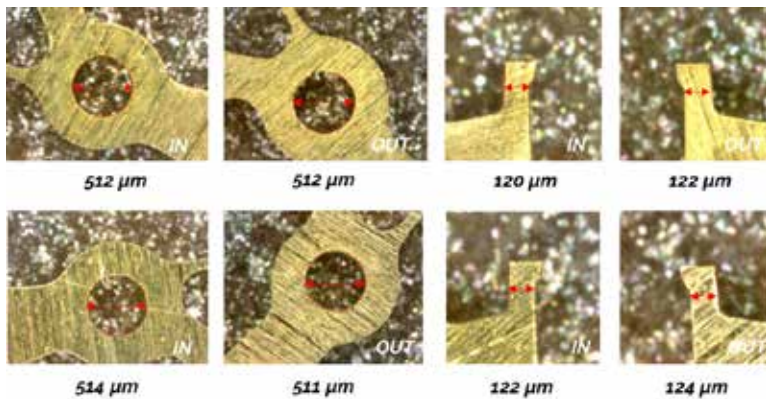


Figure 3: Comparison of practical results on two different samples, one in the top row and the other in the bottom row.

of the polarisation. The main advantage is that the circular drilling is carried out even with an elliptical spot, but the beam cannot be divided by polarising optics, which allows a precise adjustment of energies per beam. Instead, the LS-Precess does not apply a proper beam rotation [12]; therefore, the polarisation is not turned and we can convert it into a circle when needed. This requires good beam quality but has the advantage of being able to use polarising optics for beam splitting.

Practical demonstration

In order to validate the concept, we have built a prototype [10] of a double galvo head machine with a 100 W fs laser (Tangor® from Amplitude Systems®) as shown in Figure 2.

The splitting was carried out through polarising optics and the power balance is obtained from a rotating half waveplate. The power of the laser beam on the target was set at 15 W (+/- 100 mW) under both scanners, which equates to having two laser sources of 20 W each.

The scanners were driven by a main control card and an additional slave card. In this way, each scanner has its own lens calibration, the positioning controls are on the same clock as the master microprocessor and only one gate is sent to the laser. Even at high speed (3 m/s), there is no significant positioning delay (<2 μm) between the two scanners. The difference in path length causes the beam to hit both surfaces with a delay of 2 ns, which is negligible even at 100 m/s.

The difference in path length also causes a difference in the working distance because the waist position varies between the two paths. The beam profile was measured under both scanners and a focus offset of 20 μm was measured for a 600 mm path difference. This is difficult to measure because of the Rayleigh length of the beam of about 400 μm.

Finally, we compared the simultaneous mechanical gear cuts, made on a 400 μm thick brass sheet, with equivalent focal conditions, comparing the dimensions of the central hole and a tooth. The results showed that the dimensions are within acceptable tolerances

with equivalent quality and conicity, as shown in Figure 3.

Final concept

Finally, we designed a machine with 4 heads, with the precession movement generated at the rear, split above the 4 scanners, without additional motorised stages X, Y or Z, with manual adjustment in Z for opto-mechanical tolerances and suitable for XY stage systems or R2R systems, as shown in Figure 4.

We compared two approaches. The first was based on a 20 W fs laser cutting machine with 1 head, 1 precession module for an estimated processing time of 1 piece over 1 min and a depreciation over 5-years/1-shift. The second, presented before, with an 80 W fs laser cutting machine, with 4 heads, a single precession module, a process time for 4 pieces of just 1 minute and the same 5-years/1-shift payback period.

The result is a piece price almost three times lower with the second approach, of just \$0.54 compared to \$1.43 with the first one. Thus,



Figure 4: Representation of the design of the final four-head laser machine for a 100 W fs laser.



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demonstrating the increase in productivity of the proposed solution to be able to benefit from the power of the 100 W of the fs laser in its totality.

Future R&D developments

LASEA is currently involved in several Horizon 2020 R&D projects that deal with the average power of the kW range and their applications: LAMPAS [13], MULTIFLEX [14] and MULTIPOINT [15]. These projects propose different solutions to treat the beams of very high average power USP lasers, and to take advantage of the expected high productivity.

Summary

The USP lasers market is growing rapidly. USP lasers increase their average power, resulting in higher throughputs, but require improved technical solutions. Final applications define the most feasible strategy. We have shown an example of fs laser sources already commercially available in the 100W range. Others technical solutions will be developed in the coming years thanks to R&D projects and the development of new kW range USP lasers.

Acknowledgements

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OBSERVATIONS

3D PRINTING OF HYBRID METAL/POLYMER OBJECTS

YUAN-HUI CHUEH & LIN LI

Additive manufacturing offers so much potential for single materials it is sometimes easy to forget the massive additionality provided by combining different materials together. The techniques outlined in Yuan-Hui Chueh's article for physical interlocking of such extremely different materials is an excellent example of this. It is a very clever – and deceptively simple – idea, to use the structuring capability of AM to create interlocking features, and the layer by layer capability to change materials during a build process.

The results thus far are impressive, and I have no doubt that this will be developed to an extremely useful industrial process where disparate material joints are required.

Richard Carter, Heriot-Watt University

Additive manufacturing processes currently commercially available are classed single materials systems, i.e. each system is capable of processing one class of materials, for example metals, polymers, or ceramics. In this article, the authors combined laser powder-bed fusion (L-PBF), a metal AM technique, with Fused Filament Fabrication (FFF), a polymer AM technique to fabricate hybrid polymer-metal components. An interesting interlocking design coupled with the laser energy were used to realise good bonding between the metallic and polymeric sections of the printed structures. The system was equipped with multiple material deposition and removal mechanisms to enable multi-material printing, which paves the way for significant added multi-functionality, enabling further exploitation of the unprecedented degrees of freedom offered by AM technologies. As the technology readiness level of the developed system matures, it is expected to benefit a lot of sectors for applications in the electronic and biomedical fields.

Nesma Aboulkhair, University of Nottingham

TOPOGRAPHY & MORPHOLOGY OF LASER SHOCK PEENING ON Ti-6AL-7NB

XIAOJUN SHEN & PRATIK SHUKLA

It is good to see research in the UK on laser shock peening. Rolls-Royce introduced laser shock peening in fan blade production many years ago. There is, however, little study in the UK academic institutions on this topic, largely due to the lack of facilities.

This article reports an experimental investigation on the effect of laser parameters (pulse energy, pulse overlap) on the surface morphology generated through plastic deformation. I welcome more studies in this area. The author, having studied for his PhD degree in Professor Jonathan Lawrence's group, has several journal publications related to laser shock peening.

Lin Li, University of Manchester

LASER WELDING ALUMINIUM WITH AN OSCILLATING HEAD

ALEXANDRE PREVOST

Besides the advantages that Alexandre Prevost mentioned, I also would like to point out that a high brightness laser with small diameter spot will also improve the coupling of the laser radiation into highly reflective materials like aluminium and copper. In addition, beam oscillation using 2D patterns (i.e. infinity symbol) can also be used to preheat and post heat the material and reduce hot cracking. Oscillation techniques synchronised with power and mode modulation are used in production in order to successfully weld aluminium materials that typically need filler wire to reduce cracking. In order to take full advantage of these benefits it requires the use of an Adjustable Ring Mode (ARM) fibre laser with fast modulation capabilities.

Corinna Brettschneider, Coherent

I was very encouraged and interested to read Alexandre Prevost's article on welding aluminium with an oscillating head single mode, high brightness laser, and we have also found that using the wobble function has radically improved welding results in different materials.

We have been welding with a CW fibre laser for 6 years now, usually welding from 3 mm up to 10 mm, 3XX series stainless steel. Last year we were asked whether we could weld 0.5 mm to 0.5 mm titanium but not just as a butt joint. The parts to be welded had been hot formed in a way that the joint configuration lent the weld to be applied on the undulating 2 edges of the material that were also inconsistent to each other.

Running at low power (around 350 W) we had some level of success but as soon as the mismatch got above 0.5 mm, the keyhole became unstable and the weld would fail. Applying a linear wobble and increasing the power to 700 W solved our problem. As long as there were no gaps between the parts, our weld was now stable during welding and the finished results much improved.

Stuart Dutton, Graham Engineering

THE FULL POTENTIAL OF PHOTONICS IN E-MOBILITY: AN OVERVIEW

MARKUS KOGEL-HOLLACHER

Electric vehicles and their associated technologies are pushing the limits of the automotive manufacturing industry at a fast pace, opening the market to new and exciting opportunities for laser processing.

The battery system, for instance, is a key component in all electric vehicles in terms of performance, associated costs and safety aspects. Manufacturing processes should provide flexible but reliable solutions in line with these requirements. In this sense, laser processing is one of the main attractive manufacturing technologies currently considered to join different sub-components in a battery assembly, i.e. battery housing and contacting connections on a variety of welding geometries, thicknesses and material combinations.

Ensuring quality and integrity of every joint is of the utmost importance. A range of in-line monitoring tools are currently used for this purpose and some innovative solutions are in the process of being developed. It is a very active and proliferous field indeed, which contributes to the e-mobility evolution.

Anibal Di Luch, TWI

With the recent drive for low carbon propulsion technologies, the automotive industry is moving towards a net-zero future on the emission of the greenhouse gases. Issues like manufacturability and process control become vital. This article is a good example for addressing a variety of laser applications to support the current trend in e-mobility and highlighting the potential challenges. It shows the industrial shift from fossil fuel to battery electric vehicle where the battery pack and ancillary components can efficiently be manufactured using laser material processing.

The article not only shows the advantages of photonics within battery pack manufacture but also brings out the important aspects including uncontrolled penetration, leakage of harmful chemicals or risk of thermal runaway. This signifies the need for monitoring system and sensor technology. To address the challenges for dissimilar materials, various stack-ups and highly reflective materials, not only IR system but also green and blue lasers as well as distributed laser intensity are in the market. This is well described within the article with their potential uses.

Abhishek Das, University of Warwick

MULTI-BEAM PROCESSING WITH HIGH INTENSITY ULTRASHORT PULSES

DANIJELA ROSTOHAR

Within this article Danijela Rostohar makes some excellent points and provides a wide-ranging review of the current issues and barriers that industry has with the uptake of ultra-short pulsed lasers. There is also a neat description of the general misconception that increasing fluence always leads to an increase in efficiency, not taking into account any saturation threshold.

As a young research student, I was always amazed by Diffractive Optical Elements (DOEs) and it is very encouraging to see how beam splitting and DOEs are now being used to carefully control the laser-material interaction and control surface structuring of complex 3D shapes. Considering the fact that these systems can now cover large areas for such complex material processing, I can see them being attractive for industrial uptake.

The HiLASE approach of direct laser interference patterning (DLIP) is very interesting and extremely promising for further increasing manufacturing productivity of ultra-short pulsed lasers. The Laser-Induced Periodic Surface

Structures (LIPSS) that have been demonstrated within this article could be used for a number of applications such as biomimetics, adhesion applications and light guide systems etc. This is highly significant as many companies throughout many industries are now looking to micro-scale and nano-scale surface engineering for the development of their products.

The development of the HiLASE DLIP system is going to enhance what companies can do, especially considering some of the future work that Dr Rostohar and her team have planned in relation to controlling the laser-material interaction and upscaling for surface engineering of larger surface areas.

David Waugh, Coventry University

ADVANCED BEAM MANAGEMENT WITH HIGH POWER FS LASERS

JOSE RAMOS-DE-CAMPOS ET AL.

I see two themes being addressed in the article, firstly the availability of laser power and secondly

how to improve laser processing quality. Jose Ramos-de-Campos did a good job describing the benefit of using one laser and multiple scanners. For this vector job-based application, it definitely works. I also like the precession approach because, as addressed, the parts being used in watches need good cutting quality and straight edges.

Scaling up laser power is relatively cheap. So it makes sense to use one laser with a lot of power and split it up instead of using one laser for every scanner. That is because the USP lasers are much more expensive than the traditional galvo scanner.

When considering whether to implement beam splitting, the correct approach comes down to the application. From a cost point of view, the laser polygon scanner combination is much cheaper than using multiple galvos scanners. However, the application being addressed by Jose is not a polygon solution. The important question from a customer's perspective is clear, should I buy multiple lower power lower-cost lasers or one big laser and apply beam splitting?

Lars Penning, Next Scan Technology

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PRODUCT NEWS

SYSTEMS & SOURCES

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NEW FIBRE LASER WELDING TECHNOLOGY



The new Coherent HighLight FL4000CSM-ARM fibre laser enables more advanced welding capabilities for high thermal conductivity metals, and aligns to welding requirements for e-mobility, energy storage, and general electrical interconnects consisting of dissimilar materials, such as copper and aluminum, and foil stacks that require precise control. This new technology represents a significant improvement in simplicity, and overcomes the limitations of other joining technologies.

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LASER MARKER SHOWS EASE OF INTEGRATION

After 2 years of development, Laserax has released the LXQ Fiber Laser Marker series that redefines how easy and accessible laser system integration can be. The laser's features are not only aimed at reducing integration time and cost, but also at facilitating collaboration between system integrators and laser experts—a key factor for quick and easy laser integration.

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TLM Laser introduces the new AL-CROSS with 450 W fibre laser from ALPHA LASER. This provides robustness, mobility, user-friendliness and various storage options.

The high mobility of the laser arm enables a very flexible work area to weld, for example, a car roof or to carry out small overhead welding jobs. Work close to the ground can also be carried out.



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HIGH RESOLUTION AND SPEED FOR CAN MARKING

Macsa ID has launched a range of next generation fibre lasers specially designed to offer low cost of ownership, and maximum marking resolution and definition for high speed beverage can production lines. The company's latest SPA F-100 series is capable of coding up to 172,000 cans per hour, with guaranteed legibility, traceability and security.



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NEW DESKTOP LASER MARKER



The new Coherent EasyMark XL is a fully integrated, desktop laser marking system. Based on the successful EasyMark platform, the EasyMark XL offers an expanded working range and longer focal lengths. Marking fields are now available up to 240 mm x 240 mm.

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Prima Power Laserdyne announces the introduction of the LASERDYNE 811. This employs the most up-to-date hardware and software components for flexible precision laser processing in an affordable compact platform. This combination of workstation, controller, and laser means cost-effective, high speed, and reliable manufacturing machines for low and high throughput and takes full advantage of fibre laser technology.

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ANCILLARIES

NEW LASER PROTECTION CAMERA FILTERS

Brinell Vision has launched a range high precision laser filters specifically for the protection of cameras from exposure to scattered and reflected laser light. The range include an updated colour balanced 532nm filter along with Nd:YAG (1064nm) and Holmium (2,100nm).



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AUTOMATION SYSTEMS FOR LASER SYSTEMS



LVD introduces MOVit, a comprehensive range of automation systems, including a new Tower Automation System and Warehouse Automation System option for LVD Phoenix and Electra laser cutting machines.

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PHYSIK INSTRUMENTE LAUNCHES UK STORE

PI (Physik Instrumente) has recently launched its online shop for the UK, offering new and existing customers direct access to some of its most popular off-the-shelf products, as well as details of offers and pricing information.

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PRODUCT NEWS

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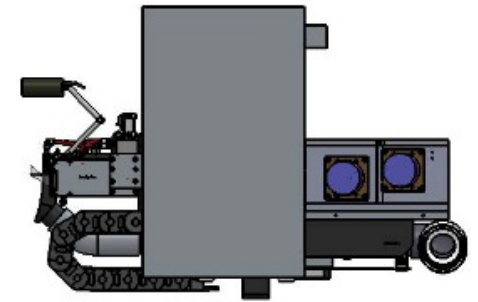
The Nitrogen Supply Company has been busy developing and formulating iMonitoring software and an OnDemand package for industrial laser users. iMonitoring helps customers manage their production cost by putting a price on gas usage per hour, per laser or per job. With OnDemand, customers have all the benefits of onsite nitrogen generation and only pay for the nitrogen they use.



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AH0219A-LPM

A CASE STUDY IN MOVING FROM YAG TO FIBRE LASERS

In 2019 SPI Lasers was approached by Pyramid Engineering to supply an evaluation laser for a new welding system being developed for a telecommunications customer. Pyramid designs and integrates high precision welding systems for the hermetic sealing of metal-can semiconductor and electronic packages, and was looking to replace its existing flashlamp pumped Nd:YAG laser sources with fibre lasers in order to offer its customers enhanced levels of speed, productivity and cost effectiveness as well as greater versatility.

A challenging application

The majority of Pyramid's laser welding systems utilise at least one glovebox, which allows for a controlled or conditioned atmosphere, and is particularly challenging for welding applications.

The YAG solution used a fixed optical weld path and a precise CNC motion-controlled welding table. SPI Lasers' solution was to introduce oscillation welding which uses a single-mode high-power laser with a scanner to rapidly move the laser beam to generate the weld pool. The high beam quality and small focused spot size creates a controlled key hole that minimises heat input into the part. The benefits of this process are that the weld depth and width can be controlled independently, and scanner parameters can be adjusted to control the weld shape. Control of the weld pool through oscillation can also greatly reduce weld spatter, resulting in higher quality welds as well as avoiding cracks in the weld.

It quickly became apparent that a fibre laser and the oscillation welding process was more suited to Pyramid's needs than their existing solution for a number of reasons:

Oscillation weld vs fixed optic weld

- 10 x faster welding speed from a fibre laser vs YAG.
- Part fit up 3x more forgiving in terms of seam gap and offset.
- Independent control of penetration depth and seam width.
- Better welds both structurally and visually.
- Cost savings from both laser source and beam/part manipulation.
- Lower heat input per unit length of weld vs YAG process.

Fibre laser vs YAG Laser

- 30% wall plug efficiency vs. circa 2% for lamp-pumped YAG.
- Cost savings as there are no flash lamps to be replaced.
- Maintenance operation is considerably reduced.
- Minimal spare part requirements – SPI Lasers



Figure 1: SPI Test station with enclosed bath and argon gas delivery tubes.

utilise 'Fit & Forget' technology.

- Reduced cooling and chiller requirements
- Substantial reduction in laser footprint
- No requirement for periodic alignment of the laser

The evaluation

A test station was created (Figures 1 & 2) and fitted with a redPOWER 2kW single mode laser (M^2 less than 1.1) with beam delivery optics of a 100mm FL collimator and a 255 mm FL scanner objective lens, which generated a $51\mu\text{m}$ ($1/e^2$) focal spot size.

The trial application was to successfully complete a hermetic fillet weld of an aluminium lid (grade 4047) onto a complex aluminium body (grade 6061-T6) which dictated a number of intricate and complex shaped welds.

Argon was used as a shield gas which was fed to the workpiece through 2 delivery tubes seen in the images below; the workpiece was enclosed in a 'bath' to hold the shield gas around the part.

Initial trials proved successful by identifying a range of parameters that could weld these materials with good quality.

The system was designed specifically to manufacture the customer's complex product, and two critical factors were specified:

1. Weld penetration was to be between 0.5 mm and 0.75 mm.



Figure 2: Set up of Laser Glovebox.

2. Heat input was to be minimised due to package containing delicate optical components.

Using the oscillating (wobble) welding head, the weld path and pattern can be configured - using a $50\mu\text{m}$ spot size the laser beam can be 'wobbled' to a width of 2 mm, in a configurable path such as circular, linear or infinity symbol. The pattern was optimised to meet the customers critical factors.

A high welding speed was maintained over the whole of the unusually shaped package as it fitted within the scanner's field of view, meaning that other than the scanner, there were no moving parts. An integrated vision system delivers pre-weld and, where required, post-weld verification.

Conclusion

The project showed that close cooperation on tackling the challenging requirements resulted in a successful outcome that has delighted the end customer (Figure 3). It has highlighted the significant benefits of using fibre lasers versus Nd:YAG lasers as well as the value of oscillation welding in tailoring weld profiles to meet specific requirements.

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Figure 3: The finished system.

A FUNNY THING

SUITABLY VACANT JOB SEEKERS

In the current climate, I am conscious of a lot of people being furloughed and made redundant. Hence, I imagine, there will be a lot of interviews taking place in the second half of 2020 as we hopefully see business pick up and some new jobs created. A few years ago, I was advertising for someone to join our team and I recognised that sometimes you need to make sure you filter out the ones that can't read or write in English to the required level – or have no relevant experience. In spite of this some filtering was needed!

To protect the guilty parties, I have changed the names below but the other facts are all 100% real – as they say fact is much more amazing than fiction, and I couldn't make this stuff up.

First impressions are very important as is accuracy, so Laura was out from the first word of her email, which was "Dead", instead of Dear Dave she wrote "Dead Dave"! Worst of all, she claimed that she was "completing qualifications in digital, social and hard marketing" (whatever that is, it can't be easy) as well as "proof reading". Oh Dear or should I say Oh Dead? On the subject of death, around the same time I had one of the briefest "CVs" that I have ever seen. The applicant, Bree, had no driving licence, no stated skills or job history, only one work experience placement at the undertakers in Abingdon – not really what I was hoping to find.

Buzz was an interesting case – perhaps a car crash waiting to happen – here is an extract from his application email:

"I am afraid that, due to the death of my former computer and a number of hard drives going missing, I can only show a limited amount of work. The works I have attached are those I was able to retrieve from emails. Not a very impressive exhibition, I know.

I am quite sure this spectacular display of clumsiness will preclude me from a position with you, however I send this email anyway, if only in the glee of human folly."



There was something quite well-spoken about Buzz, so I felt like I had to meet him – our short interview was fascinating but sadly drove home that he was not to be my next employee. After telling him this his reply included the words:

"I am sorry for my hesitation. That nervous space between decisions is where I seem to spend my whole life. It is a delicate weave between possibilities and has enabled me to avoid so much of that irksome business of living my life. I completely understand that you would want someone who is clear and sure of their desires and commitment.

Lasers are cool. Like drill bits or fax machines or telegraph poles are cool. My favourite geekery is with cameras. I love all geekeries though, as long as there is someone who will share the geekery with me. Humans are at their fullest as geeks run amok".

In the description of the job I made it clear that the office was in Abingdon and that people should be able to commute there daily. Studying one application, I noticed that he had a London

address, a mobile number with country code Sweden and a Sydney, Australia e-mail address. When I asked him to clarify his location, he started his reply with:

"Dave, Have you considered a career in private investigation? You are on the ball man, hats off!"

Finally there was Linda, who seemed to have a reasonable CV and nothing untoward about her application until the second email revealed that her email address was blissfulparanoia8@ - whilst this was encouraging (she could spell both "blissful" and "paranoia") I didn't think they were the two top characteristics I was seeking.

In the end, I did find someone suitable – albeit for a few months duration. What is the moral of the tale? Perhaps it really is important to do some due diligence before hiring if you are an employer – and if you are job seeking, check that your CV, covering e-mail and personality don't raise too many red flags before you get the chance of an interview. Good luck out there!

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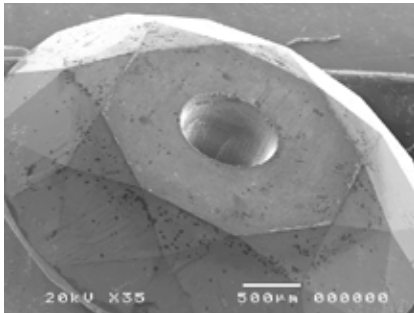


Image courtesy of Oxford Lasers Ltd.

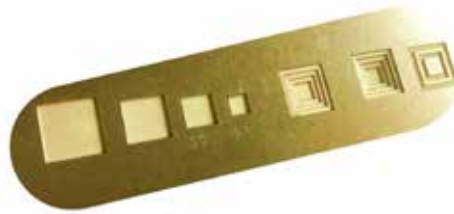


Image courtesy of Heriot-Watt University



Image courtesy of 3D-Micromac

PROGRAMME

WEDNESDAY 7 OCTOBER

13:30 - 15:00 BST Session 1 (Sponsored by SPI Lasers)

Welcome

Jack Gabzdyl, SPI Lasers

Ultra fast laser processing of high temperature superconductors

Bill O'Neill, University of Cambridge

Multibeam UV picosecond processing of PZT

Dimitris Karnakis, Oxford Lasers

TBC

Ulf Quentin, TRUMPF

14:50 Q&A

15:00 - 15:20 Break

15:20 - 16:30 Session 2 (Sponsored by Aerotech)

TBC

Eric Mottay, Amplitude Laser

Ultra-fast laser micromachining

Shireen Khanum, GF Machining

Laser microprocessing through 5-axis scan head coordination with servo stages

William Land, Aerotech

16:20 Q&A

16:30 Close

THURSDAY 8 OCTOBER

09:30 - 10:50 BST Session 3 (Sponsored by 3D-Micromac)

Direct Laser Interference Patterning: new ideas and concepts for high-throughput processing

Andres-Fabian Lasagni, Fraunhofer IWS

Roll-to-roll laser processing of flexible devices

Ronny Neubert, 3D-Micromac

High throughput scanning for ultrafast lasers

Lars Penning, Next Scan Technology

10:40 Q&A

10:50 - 11:10 Break

11:10 - 12:20 Session 4 (Sponsored by Cailabs)

Multi-Plane Light Conversion-based beam shaping for laser microprocessing

Pu Jian, Cailabs

Laser surface engineering for biological applications

David Waugh, Coventry University

High throughput, high quality laser engraving

Stephen Dondieu, Heriot Watt University

12:10 Q&A

12:20 Close

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Register at www.ailu.org.uk/events

DATE	EVENT	LOCATION
7-8 October 2020	AILU Webinar Micro/Nano Applications 	Online
19 November 2020	AILU Job Shop Annual Business Meeting 	IPG Photonics (UK), Coventry
25-28 January 2021	MACH 2021 rescheduled from 2020 	NEC, Birmingham
24-25 March 2021	ILAS 2021 rescheduled from 2020 	Daventry Court Hotel, Daventry