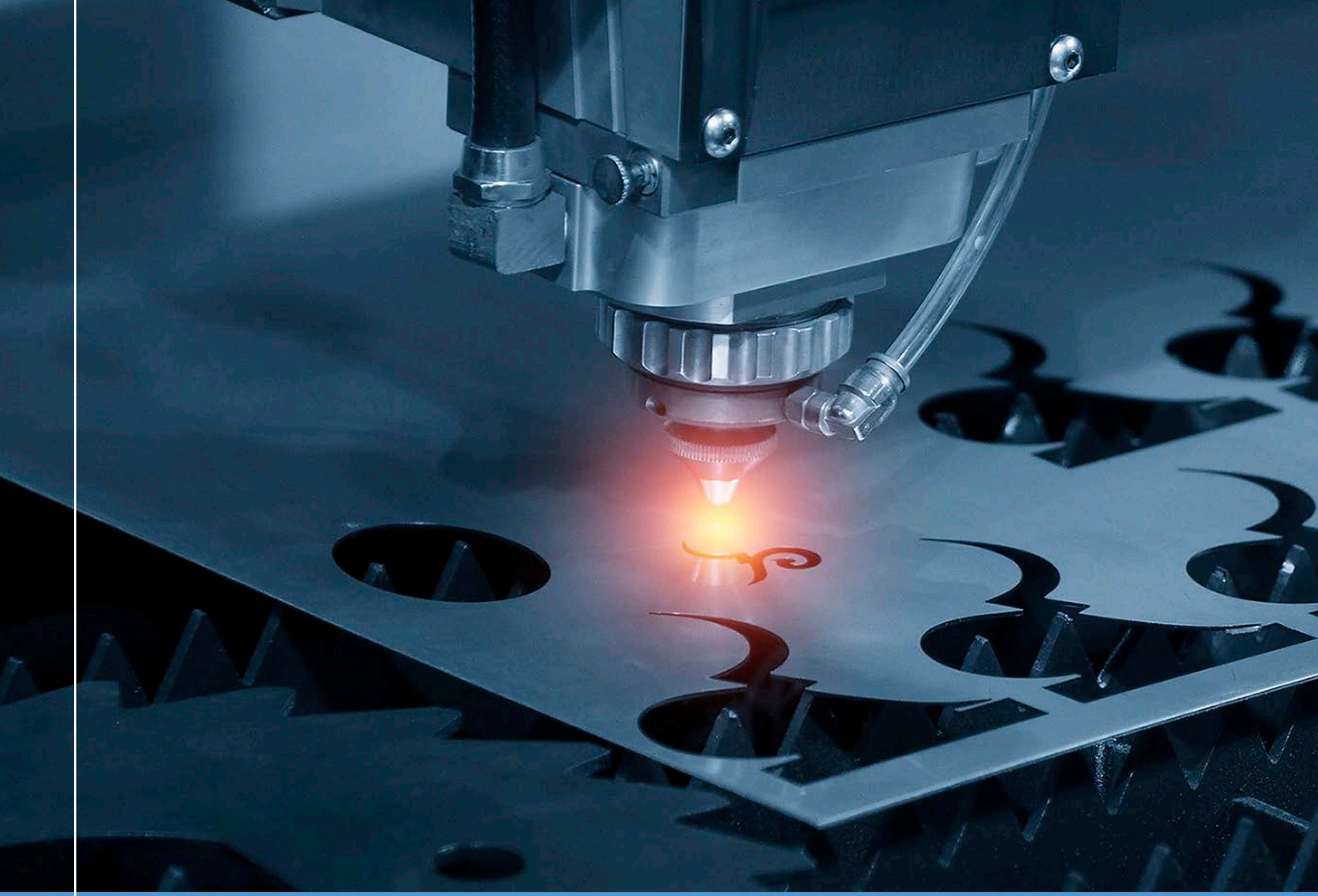
EPSRC Centre for Innovative Manufacturing in
LASER-BASED PRODUCTION PROCESSES

Lasers for Productivity

A UK STRATEGY

Innovate UK
Knowledge Transfer Network

AILU
ASSOCIATION OF INDUSTRIAL LASER USERS



CONTENTS

EPSRC Centre for Innovative Manufacturing in
LASER-BASED PRODUCTION PROCESSES

Ensuring all manufacturers have the skills, finance, knowledge and confidence to deploy lasers in production

This strategy has been developed by industry with input from a broad cross-section of UK manufacturing sectors and in collaboration with:-

- Industrial manufacturers, sub-contractor manufacturers and suppliers
- UK laser and system manufacturers and supply chain
- Association of Industrial Laser Users (AILU)
- Knowledge Transfer Network (KTN)
- EPSRC Centre for Innovative Manufacturing in Laser Based Production Processes (CIM-Laser).

FOREWORD

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Laser technologies have been at the core of an impressive range of ground-breaking manufacturing advances across multiple sectors of modern industry. Lasers have not only replaced 'conventional' tools in diverse areas of product manufacture thereby driving increased productivity, quality and functionality; they have also enabled completely new 'laser-unique' production processes, which have facilitated the manufacture of key strategic products.

However, while laser-enabled production processes are revolutionising manufacturing productivity and functionality in industries as varied as microelectronics, packaging and auto manufacture, the UK faces significant challenges if it is to match the breadth and depth of laser-system penetration that has been achieved by the leading manufacturing nations.

To address this problem, the UK Association of Industrial Laser Users (AILU) and CIM-Laser, the multi-university industrial laser R&D Centre, have worked with the community to develop a strategy to facilitate a significant growth-upturn in the exploitation of laser technologies across the UK manufacturing sector. Under the guidance of experienced laser industry leaders, the team has engaged with the UK industrial laser community including both laser processing system users and laser-machine manufacturers, along with their supply chains. More than one hundred industry colleagues have been involved via workshops, detailed online surveys and focus groups in contributing their assessments, ideas and suggestions and these have been analysed and are captured in this document.

In the context of the UK Government's recent Industrial Strategy Green Paper, there is wide-ranging agreement that investment in a coordinated UK action plan to expand the industrial adoption of laser-enabled manufacturing processes presents a major opportunity to increase our lagging manufacturing productivity and to underpin the development of high value-added products across multiple significant sectors of UK industry.

Photonics processes such as Lasers are compelling examples of the fast evolving Digital Manufacturing capabilities. The 'digital thread' runs all the way through the concept design of the laser equipment, the manufacturing definition of the product and its associated process modelling, the design of the closed-loop manufacturing process and the deployment of a fully proven production ready application in a 'state-of-the-art' facility.

Lasers have matured quite rapidly from their humble origins in the laboratory and are now widely regarded as capable, flexible and energy efficient manufacturing technology. Their unique non-contact processing capability and energy efficient applications make them an ideal choice for a growing number of manufacturing applications.

UK Manufacturing is continuously striving to improve its competitive position through better Quality and Productivity. The photonics technologies in general and Laser processing in particular, provide enormous opportunities to drive down manufacturing costs and improve the overall quality and efficiency of the manufacturing value chains. In many instances the application of Lasers enable greater design freedom as well as a step change improvement in cost.

However, the UK lags behind many of the other developed economies in the application of photonics-enabled manufacturing processes and risks being outpaced by our competitors who appear to have better grasped the business potential of these game changing technologies. This document highlights this concern and proposes a number of areas of focus to improve the situation going forward. These include, using the High Value Manufacturing Catapult and relevant university based research Centres as a foundation for experimentation and specialist knowledge, developing new R&D capabilities to better exploit the potential of this technology, establishing a deeper training landscape for operators and technicians and providing a structured network of support for the SMEs and 'middle market' companies to help establish a photonic-capable competitive manufacturing base in the UK.

1 EXECUTIVE SUMMARY

Laser light offers unique advantages for high value manufacturing and is revolutionising many mass production techniques.

Digitally controlled and remotely programmable, lasers can be seamlessly integrated with robotics and digital manufacturing to improve precision, increase manufacturing speed reduce down-time and expand design freedom: all critical to improving UK manufacturing productivity. Already having a major impact in aerospace, automotive, microelectronics and defence production, our vision for UK manufacturing is for laser processing to be the norm, rather than the extraordinary.

The impact of laser processing extends far beyond the £10bn annual global laser processing machine tool market. Comprising a whole suite of critical processes from precision marking, scribing and cutting, to welding and metal 3D printing, laser processing is adopted throughout the supply chain in markets as diverse as food processing, car assembly, aerospace, security and healthcare. The leveraged value is immense with £300m of laser components being integrated in lasers and systems enabling >$300bn of products globally.

However, UK manufacturers lag behind our leading competitors in the adoption of laser processing, purchasing fewer than 8% of the high-power laser processing systems bought by German manufacturing. This is in contrast to the UK being one of the leaders in laser and process development, with multiple globally-leading laser system manufacturers and research institutes spread throughout the UK. British laser systems are globally competitive, with laser producers exporting >80% of their output, providing the best laser solutions for manufacturers throughout the world. But the weak domestic market is symptomatic of the low adoption by UK manufacturing, albeit with notable exceptions. This strategy identifies the key barriers that are holding back adoption of laser processing in the UK. Overcoming these barriers presents one of the biggest opportunities for improving UK manufacturing productivity this century.

Our study shows that the greatest barrier to broader adoption of lasers in manufacturing is the shortage of skilled staff, most critically at the engineering and vocational/ technician skill level, where >75% of Industry canvassed report that they have serious difficulties recruiting. Supply of the highest skilled, PhD level, research engineers is only a little better with more than 50% of industry encountering difficulty hiring. Skills and awareness of impact are the highest priority action areas identified in this strategy. A multiyear program is required to ensure those undertaking engineering apprenticeships and engineering courses at Further Education Colleges are exposed to, and have experience of, laser processing. To improve UK productivity, it is also vital that the next generation of engineers are inspired and taught how to design for laser manufacture at the earliest opportunity.

Access to finance to invest in laser processing is almost as much of a barrier as skills, with over 55% of firms finding it difficult, or impossible, to raise funding to invest in laser processing. Despite being used in various forms in manufacturing for over 30 years, private financiers and banks still see laser processing as a risky investment. Low adoption in the UK means that there is a lack of awareness (amongst finance institutions and non-technical management) of successful return-on-investment cases for laser processing. Action is needed to open-up innovative sources of financing for digital laser processing including the proposed Innovate UK loans.

Laser processing can be incorporated at multiple stages in manufacturing with differing functions. This diversity of impact is both laser processing's core strength and a weakness, as new users require full demonstration of capability, reliability and return-on-investment in each potential deployment. Action is required to support process demonstration and evaluation of realistic return-on-investment models. In time, improved adoption will lead to greater network effects and self-sustaining spread of success stories and best practice. To establish this critical mass, additional support is required to promote the productivity impact of laser processing to UK manufacturing.

High value manufacturing in the UK is, by necessity, a dynamic industry, continually adapting to produce the latest highest value products. This requires ongoing development of new processes capable of manufacturing new materials, into new formats, often at ever higher precision. The precision and control in lasers make them well suited to many of the challenges in digital manufacture, but action is still needed to develop new lasers, laser processing methods and knowledge of laser material interaction, for the next generation of materials, and to reduce capital and operating costs, with ever increasing flexibility, reliability and predictability.

As a high-value digital process, with an established, regionally distributed skills base, development of laser processing should be a key component of the UK's industrial strategy. The UK laser processing industry welcomes the opportunity to work with government to integrate this 'Lasers for Productivity' strategy into the broader UK industrial strategy outlined in the government's 2017 green paper. The UK laser processing industry will work with government to develop a fit for purpose technical training and awareness infrastructure that can support laser processing in the UK, support improved access to capital investment, help spread adoption to reduce the productivity gap and increase engagement with this key digital technology.

With these barriers addressed, laser processing offers key opportunities for the UK economy in:

- automotive, with lighter weight, stronger more fuel efficient vehicles
- healthcare, especially in 3D printed medical implants and low cost health monitoring.
- aerospace, with lighter weight stronger parts and 3D printed solutions.
- energy, especially recycling in offshore Oil and Gas and both Nuclear power construction and decommissioning
- defence and security with ever more novel functionality

The economic value of these future opportunities will be measured in £billions in each market, as laser processing becomes the only viable manufacturing solution. Adoption of our recommendations included in this strategy will result in the creation of an additional 5,000-10,000 high-value jobs in the UK within 10 years and indirectly support more than 100 times this number of other jobs in key UK industries from aerospace to car production.

Realising these benefits requires addressing the barriers to adoption of laser processing in the UK. Without overcoming hurdles in skills, finance, demonstration and customisation the UK will continue to lag behind its competitors in the adoption of laser processing, further dragging productivity down and jeopardising the long-term competitive future of high value manufacturing in the UK.

2 VISION FOR UK MANUFACTURING

Light does its work remotely making it perfect for manufacturing. Products of all sizes can be processed using laser light without any physical contact between the laser and the part being manufactured. Lasers can travel large distances in flexible optical fibres providing highly focused light beams, able to precisely mark, modify, machine, build and join parts without ever touching them.

Laser processing is a point and go process, with no bespoke tooling to wear-out (drills, stamps, etc.) and without hazardous, environmentally-unfriendly chemicals. The ability to modify and process materials remotely with precise digital control means lasers are easily deployed on robots, frequently leading to joint deployment of both technologies.

For modern production, laser processing is the perfect embodiment of the new age of digital manufacturing that is so vital for increasing productivity. Laser beams can be precisely computer controlled, digitally steered rapidly over parts and follow predetermined processes. They can be remotely optimised in advance for maximum yield and the data stored for future use. The modern laser manufacturing workstation seamlessly integrates lasers and robotics and can be configured to mix multiple parts from many customers to maximise the use of raw materials and reduce the overall capital equipment investment. Laser marking can give traceability to all parts from the smallest electrical component to the largest aircraft wing without paint or chemical treatment.

Acting remotely, lasers give flexibility to product flow, minimise process creep, eliminate down time for tool replacement and exploit online monitoring to achieve maximum up-time. Laser manufacturing

Figure 1: Laser integrated with a snake robot for remote access cutting applications (Source: TWI)

has always been a precisely controlled digital process. Unseen, it has led the way in developing the framework for digital manufacturing from part visualisation, digital machining, yield optimisation, predictive costing and traceability. Laser processing is now revolutionising and making obsolete many of the mass production manufacturing methods developed in Britain during the industrial revolution.

Yet the UK lags behind other developed nations in the use of digital laser manufacturing processes. Without greater adoption of laser processing, UK manufacturing will go backwards becoming less competitive and less productive, unable to manufacture at the level of precision, cost and customisation that is becoming standard throughout the world. Manufacturing centres that were previously low cost, especially in China, are now heavily investing in laser processing as a key component of manufacturing automation, widely regarded as essential to keep their manufacturing competitive. This international demand is delivering excellent export growth for UK laser and production-system manufacturers. However, as China digitises its manufacturing with lasers, they are gaining the ability to lead on precision and control in their manufacturing rather than cost, just as Germany, the world leading adopter of precision laser manufacturing, does today.

Our vision for UK manufacturing is for laser processing to be the norm and not the extraordinary - to ensure firms of all sizes have the skills, finance, knowledge and confidence to deploy laser processing rapidly and effectively.

Delivering this vision will raise productivity and competitiveness across large swathes of UK manufacturing, from the smallest SMEs to the largest PLCs. Increasing adoption of laser processing will also generate high value manufacturing jobs in UK photonics companies that produce laser processing machines together with their supply chain of lasers, optics, monitoring, software control, and robotics, thereby expanding the market for companies currently mainly reliant upon exports. Implemented successfully, this strategy will support UK economic growth for decades to come, acting as a launch pad for the digitising of UK manufacturing. If not implemented the UK will squander its competitive advantage in laser design and forever play catch-up in the digital manufacturing age.

Figure 2: UK produced laser micro machining systems (Source: Oxford Lasers)

3 STATE OF INDUSTRY

3.1

WHAT IS LASER PROCESSING?

Laser processing for manufacture is the use of lasers to mark, cut, scribe, build, join or modify components in any form[1]. Forming a £10bn global industry[2], multiple application segments are commonly identified: marking, drilling, micromachining, surface treatment, additive manufacture, joining (e.g. welding/soldering) and cutting.

As evidenced by the UK Laser Processing Industry Survey conducted during the development of this strategy, these processes can be deployed at multiple points in production for example:

- initial cutting of raw material e.g. plate steel, joining of parts during assembly, e.g. welding of car sub-frames
- surface treatment of completed parts
- marking of finished goods; maintenance and reuse – paint stripping of aircraft frames.

This versatility also means lasers are deployed throughout the supply chain in different ways and by multiple companies in the manufacture of a huge range of goods from mass market consumer electronics and food, specialist medical devices to aircraft and cars.

The materials processed can vary greatly from cutting flat parts in plate steel; to drilling nozzles in inkjet printer heads; additive (3D printing) manufacture of metal parts; serial numbering packaging; and security marking high value products. Although metals are commonly targeted, laser processes are not limited to metals and lasers are increasingly used on a wide variety of materials e.g. cutting mobile phone screen glass,

Figure 3: Diversity of production processes where lasers are applied (Source: Laser Processing Industry Survey)

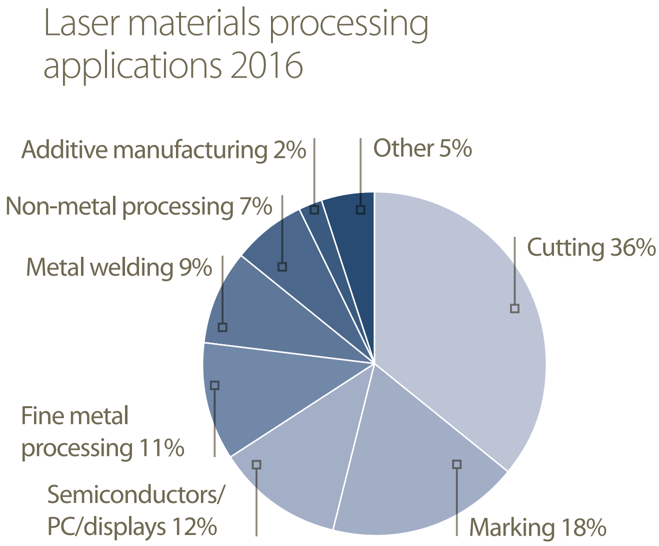


Figure 4: Global Laser processing applications 2016. (Source: Laser Markets Research / Strategies Unlimited ©Pennwell)

Figure 6: Laser processing of critical jet engine components (Source: Winbro)

marking food, annealing television displays, security marking diamond, and drilling micro-holes in printed circuits boards. Along with laser power, many other parameters, such as laser colour (wavelength), spot size, scan speed and pulsing of the laser are used to optimise the individual processes.

3.2

STATE OF UK INDUSTRY

The laser processing supply chain in the UK (and elsewhere) is broadly segmented between component and system developers; sub-contract manufacturing service suppliers and large scale manufacturers/users.

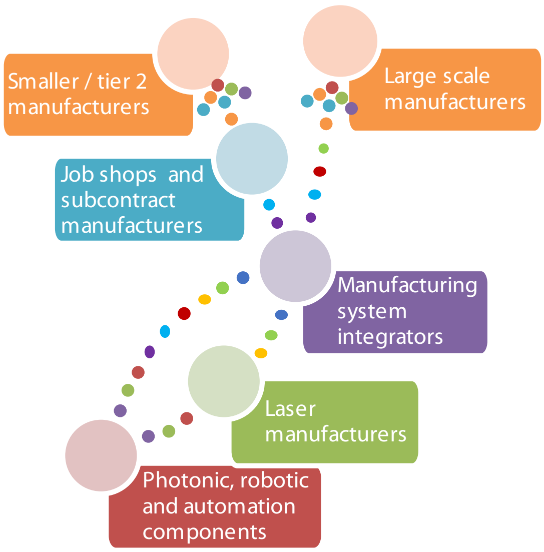


Figure 5: The laser processing supply chain

The UK is particularly strong in areas of components, laser system manufacturers and job shops, all areas dominated by SMEs. The AILU report *'Exploiting laser technology in 21st Century UK manufacturing'*[3] identified more than 130 applications for laser based processing with over 30 having strong links to sectors/products key to UK manufacturing. A further 2012 survey estimated that the UK is home to a vibrant community of ~400 laser sub-contract manufacturers (job shops), mostly SMEs, with >11 manufacturers of lasers, >19 manufacturers of laser processing systems and 16 university groups with significant activity in the area.

There are also many large scale manufacturers who extensively leverage laser processing in key sectors of the UK economy including aerospace e.g. Rolls Royce, BAE Systems, GKN; defence e.g. Leonardo, QinetiQ and Thales; and automotive manufacturing e.g. Nissan, Honda, Toyota, Jaguar, Land Rover and BMW Mini.

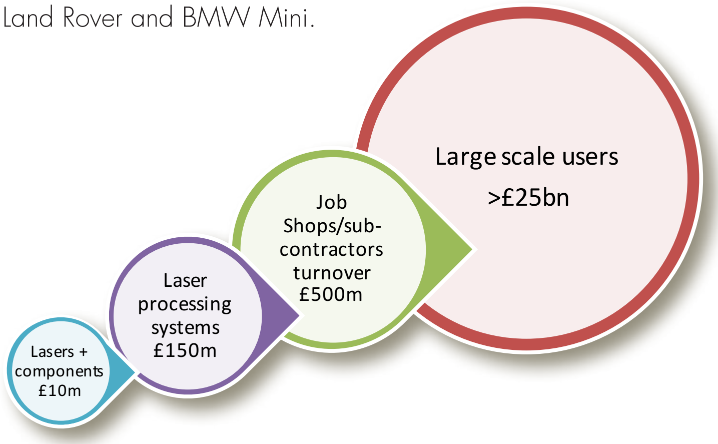


Figure 7: Value of laser processing to the UK economy

Figure 8: Laser in automotive production

The contribution of the top-level laser-enabled segments to the UK economy is significant. Large-scale end users in Automotive and Aerospace alone have an output of >£25bn combined.
As illustrated in the case studies that follow, laser processing is now critical to keeping the products from these companies competitive. The numerous laser sub-contract manufacturers around the UK also provide a critical point of access to laser processing for smaller scale manufacturers, and are estimated to contribute £500m to the UK economy in contract engineering services.

The UK is also a centre of excellence for laser research design and production. Over 50 years of internationally leading laser research at over 16 Universities and RTOs in the UK has produced a skill base that has grown multiple domestic laser manufacturers [e.g. Lynton Lasers (Manchester), Laser Quantum (Stockport), Palomar Technologies (Hull), Oxford Lasers (Didcot), Microlase (Glasgow), M Squared Lasers (Glasgow), SPI Lasers (Southampton), Midaz Lasers (London), etc.] and attracted inward investment from many of the world's leading laser companies. Often purchasing domestic companies, these billion dollar global operations have made numerous acquisitions in the UK over more than 2 decades (e.g. Coherent, Rofin-Sinar, Trumpf, Novanta). In recognition of the UK strength, these companies have invested in UK-generated technology and facilities post-purchase, making them major centres of their global production operations.

Relative exploitation of laser in manufacturing by competitor countries

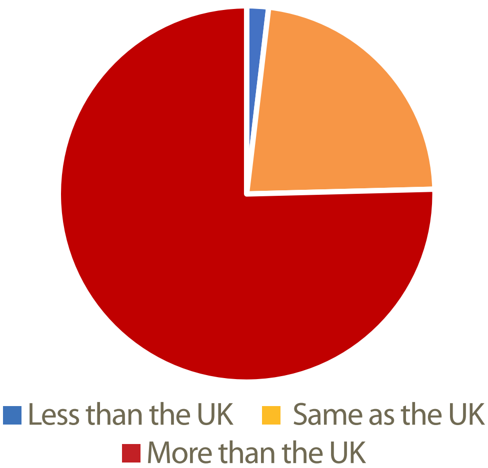


Figure 9: Adoption of laser manufacturing in competitor countries relative to the UK (Source: Laser Proc Ind. Survey)

Inward investment in UK laser manufacturing

The reputation of UK laser capability is underlined by multiple international merger and acquisitions over the last 20 years including:

- Coherent Inc (US) acquired Laser Applications (Hull Uni spinout), Midaz Lasers (Imperial College spinout), and Microlase (Strathclyde Uni spin-out) – now Coherent Scotland with 150 staff, Glasgow.
- Rofin-Sinar Gmbh (Germany) acquired Palomar Technologies (Heriot-Watt Uni spinout), now Rofin Sinar Hull UK, 150 staff;
- Trumpf Gmbh (Germany) acquired SPI Lasers (Southampton Uni spinout) and JK Lasers (ex Lumonics UK)
- Novanta Inc (US) acquired majority stake in Laser Quantum (Manchester Uni spinout)

However, the scale of exploitation of lasers in manufacturing is much lower in the UK than in the USA, Japan and Germany. According to the Laser Processing Industry Survey for this strategy and the previous AILU *'UK Laser Materials Processing Statistics'* report[4] there were more than 10 times more lasers used in Germany per unit of manufactured product than in the UK and that for high power laser systems, UK manufacturers purchased fewer than 8% of those purchased by German manufacturers.

This finding is confirmed by UK manufacturers of industrial lasers and laser systems who repeatedly report exporting 80-100% of their output, with few UK customers. Whilst this balance of trade puts UK laser producers at the centre of a global market, it also highlights the sustained under-investment in laser processing by much of the rest of UK manufacturing.

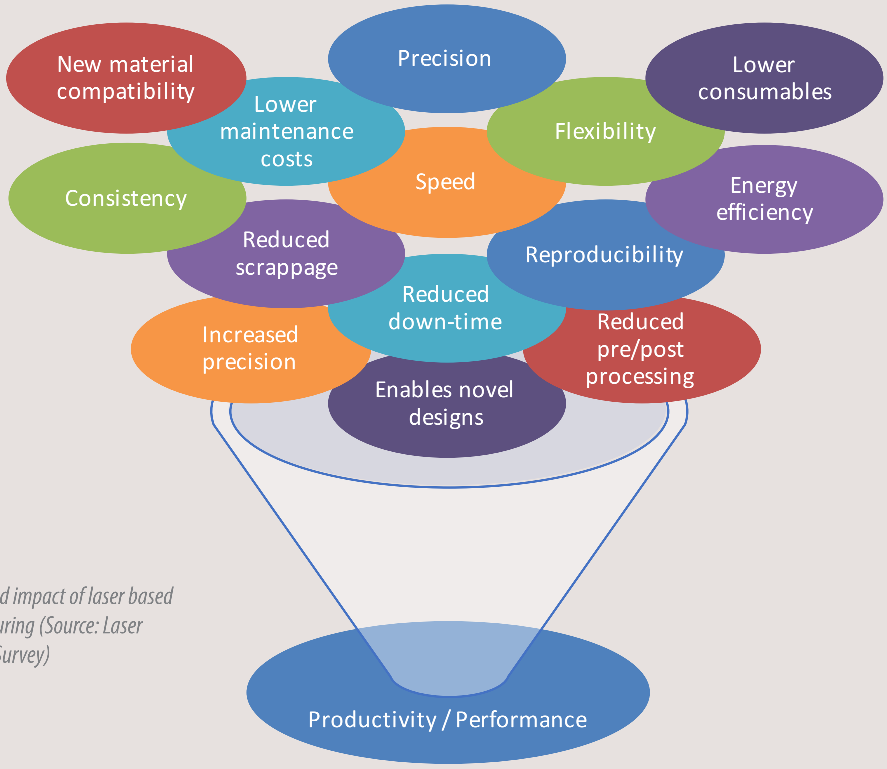


Figure 10: Benefit and impact of laser based process to manufacturing (Source: Laser Processing Industry Survey)

3.3

BENEFITS

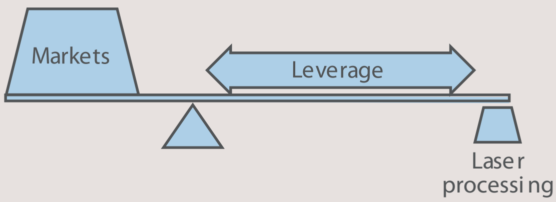
Laser processing delivers multiple benefits including manufacturing efficiency, cost reduction, product performance and quality enhancement – as confirmed by evidence gathered for this study.

The case studies that follow demonstrate how different combinations and manifestations of these benefits drive adoption in individual processes. For example, increased accuracy, lower maintenance costs and down-time, higher speed and digitisation all contribute to enhancing productivity and stimulating adoption. There are also many cases where adoption is driven by unique 'laser-only' outcomes where products cannot be manufactured by any other process. Indeed, the large variety of drivers for laser processing is one of the hurdles preventing more rapid adoption in UK manufacturing, since the benefits for one process/factory/company are often distinct from those relevant to a different process/factory/company.

3.4

MANUFACTURING LEVERAGE

The market leverage from applications of laser processing is extreme due to its breadth of functionality and the range of markets impacted. In multiple cases, sales of a few thousand lasers systems are used to produce 100's of millions of parts which enable multiple markets each worth >£8 billion: 500 -1000 times greater than the value of laser and laser systems sales into those markets.



Such high leverage is not achieved in a single market, but multiple diverse applications from mobile phones, ink jet printers, medical stents, blood monitors, displays, solar panels and lighting to automotive, aerospace and transport systems. In the future, this leverage will be even greater, driven not just by expansion of existing applications, but adoption in emerging markets ranging from point-of-care and consumer health devices, prosthetics, precision drug delivery to environmental monitoring and chemical free cleaning.

Focusing on just two of the application case studies presented below, (i) cooling holes in jet engine blades and (ii) touch screens and smart sensors, ~£160m laser sales globally enables >£160bn of sales of manufactured parts and at least 10X more in end products.

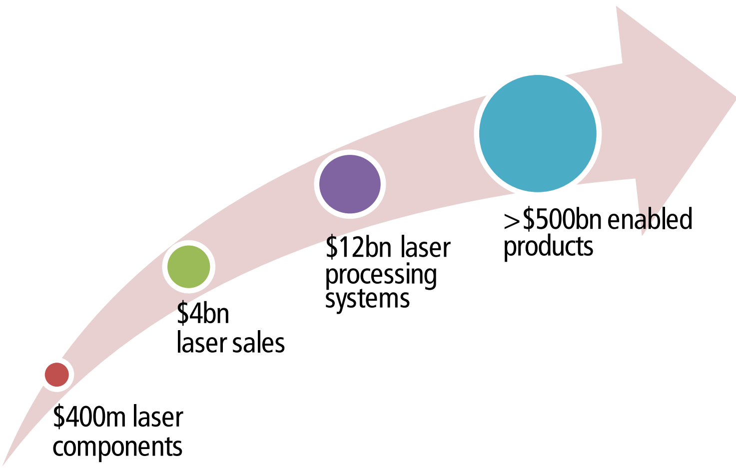


Figure 11: Leverage of lasers and laser processing through the laser system value chain.

This leverage is achieved from just a small sub-set of applications, adding more, e.g. including microelectronics and photovoltaic processing, would add much more leverage globally. The leverage is even higher if the value of services that operate on laser processing enabled hardware is also considered. How much more would airline tickets cost, or delivery charges be, if jet and truck engines had the efficiency of 20 years ago?

Looking to future markets where laser processing feasibility has already been demonstrated, especially in medical and sensing, shows that within the next 10 years £300m worth of laser systems are likely to enable the manufacture of over £400bn of products globally.

3.5

REGIONAL DISTRIBUTION

The laser manufacturing supply chain is distributed throughout the UK. Laser job shops and sub-contract manufacturers serve local industry in almost every region of the UK. Large scale deployments of laser manufacturing in big industry are distributed throughout industrial locations from car plants in Swindon and Teeside to aerospace manufacture in Bristol, Lancaster, Manchester and Yorkshire.

Similarly producers of laser and laser manufacturing systems are distributed throughout the country from Coherent Scotland in Glasgow, Rofin-Sinar UK in Hull, to SPI Lasers in Southampton and Rugby.

The UK research and technology base is also well represented across the UK, with particular strengths in the Midlands, the North of England, and Central Scotland, providing local and national support of the manufacturing industry. University research strengths cover both the development of industrial laser systems and laser manufacturing process development. The university research base is supplemented by organisations focused on higher Technology Readiness Level activity such as TWI (Cambridge and Sheffield) and the High Value Manufacturing Catapult Centres, in particular the Manufacturing Technology Centre (Coventry) and the Centre for Process Innovation (Sedgefield) – all of which have a focus on working with industry to develop truly industrial-scale processes.

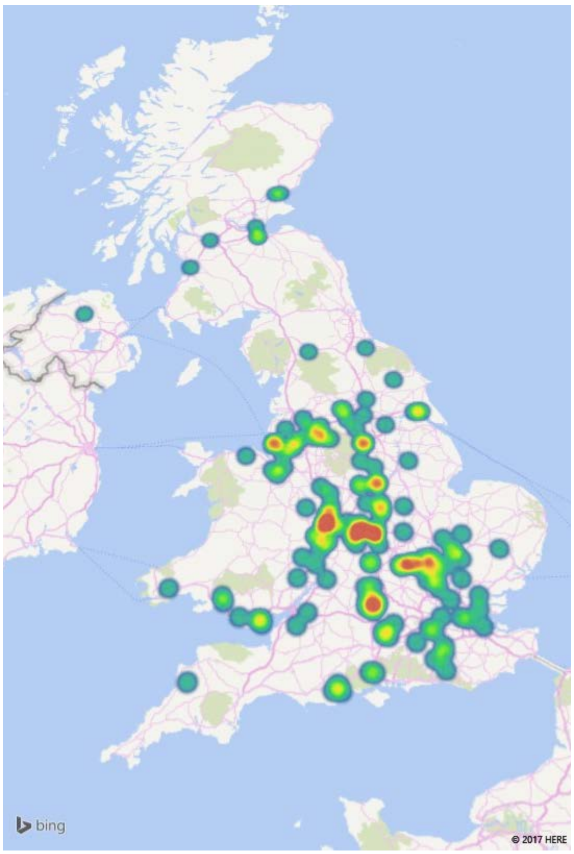


Figure 12: Distribution of members of the Association of Industrial Laser Users (AILU) around the UK (Source: AILU, Mapping Bing) (Note this is only a sample of locations using laser processing)

CASE STUDY

LASER CUTTING – MADE IN THE UK

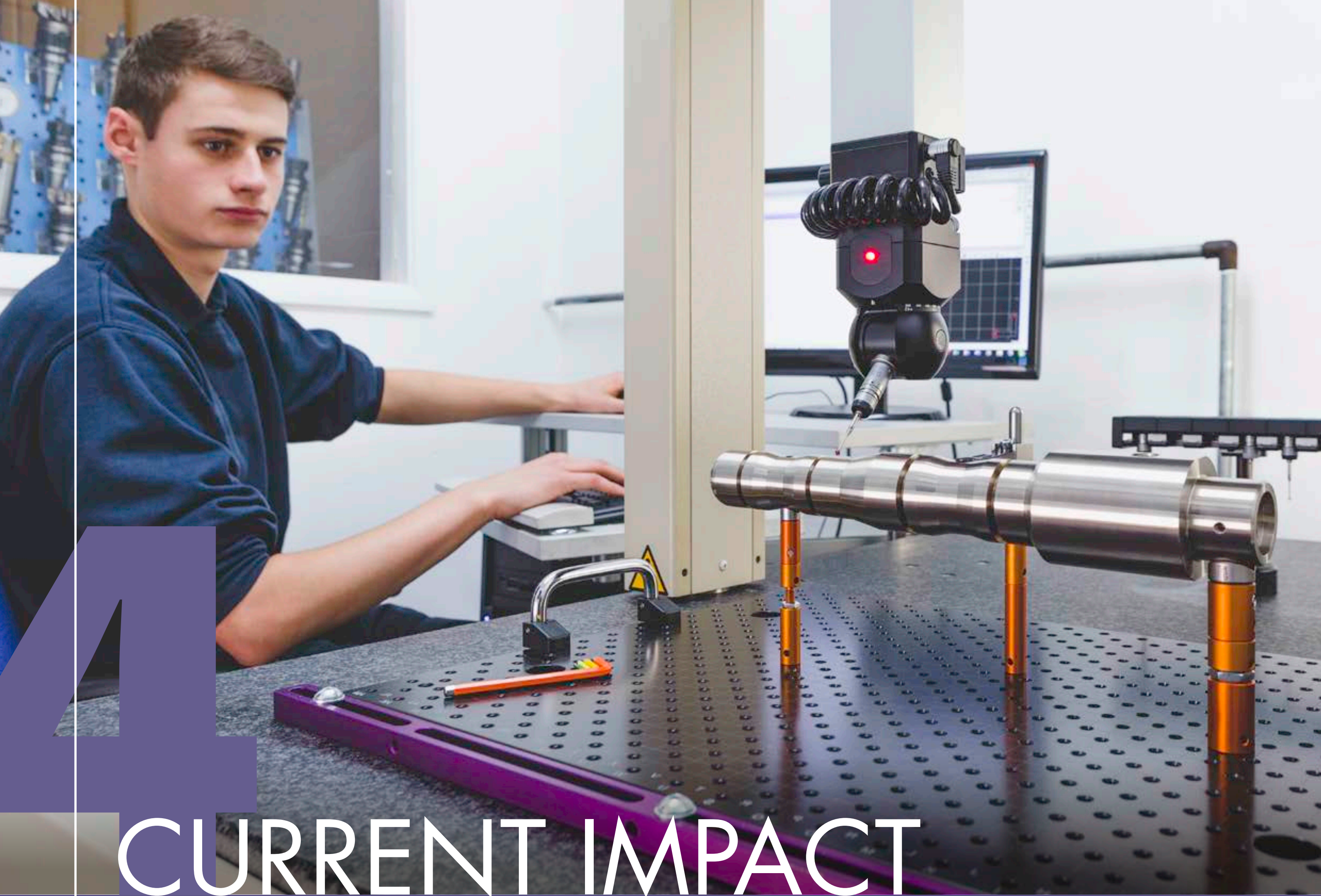
As can be seen clearly in Figure 4, laser cutting is still by far, the largest application of laser materials processing, notwithstanding its invention, here in the UK, 50 years ago. Early in 1967, Peter Houldcroft, from TWI, visited the UK car and truck manufacturer Leyland Motors, to discuss a problem they were having when trying to use a plasma cutting torch, mounted on an articulated arm robot, to cut out 3D pre-production body panels from pressed steel blanks in the process of developing exact trim lines for future press tools. The problem was that the process was not precise enough and the plasma torch produced burning of the edges of the thin car body material. On the drive back to Cambridge, Houldcroft thought that the combination of a focused laser beam and an oxygen gas jet, would produce a fast and precise cut, suitable for such an application. Later that year he was given the opportunity to test this concept when he was offered time on the UK's first operational carbon dioxide laser, built at the Services Electronics Research Laboratory, in Baldock. This 300W pulsed slow flow laser was operational, less than two years after the publication of Patel's paper describing the possibility of lasing action in a carbon dioxide molecule. Houldcroft was originally asked if he thought the laser could be used to weld metal.

Figure 13: The world's first gas assisted laser cut

Figure 14: The UK's first 5-axis laser cutting machine

After a quick calculation, he decided that the pulsed nature of the laser might not provide the necessary average power. However, it might be able to cut. The results of Houlcroft's experiment, conducted in May 1967, were published in the British Welding Journal in August of that year. The image in Figure 13, from the TWI archive, shows the world's first ever gas assisted laser cut being made.

In the 70's, the invention of the fast axial flow carbon dioxide laser, also at TWI, meant that the powers needed for commercial laser cutting could now be achieved, whilst maintaining a compact laser footprint and soon several companies were manufacturing such lasers and fitting them to two-axis flatbed cutting machines, to produce accurate, two dimensional metallic profiles. This technology has since grown into a billion dollar machine tool business and is also the primary technology in use in the vast majority of the UK's laser cutting jobbing shops. In 1983, Austin-Rover installed the UK's first five-axis laser cutting machine, for the application of trimming pre-production body panels, in its plant at Swindon. Today, every major manufacturer of automobiles in the world uses this process in the development of new car bodies.



4 CURRENT IMPACT

Laser processing already provides crucial benefits to a wide range of industries, with such a diverse impact that it is impossible to cover all the applications in detail here. Thus, a selected range of applications are highlighted in the following case studies to illustrate multiple processes underpinning many of the UK's highest value manufacturing industries.

4.1

COOLING HOLES IN JET ENGINE BLADES

Each turbine blade in a modern jet engine generates more power than a Formula One engine. Operating above the melting point of the metal each nozzle guide vane in the jet engine must be continually cooled by gas flowing through thousands of micro holes. These cooling holes are critical to enable advanced aero-engines to achieve the low emission levels and increased fuel economy required by fleet operators and regulators.

Cost pressures and design requirements (e.g. smaller and more complex hole shapes) for these critical parts have pushed the process demand beyond the capability of the previous non-laser solution (electric discharge machining). High peak power lasers and machine tools were specifically developed in the UK to process these "difficult to machine" super alloys and are now standard for drilling turbine blades throughout the world.

First developed in the UK by Rolls-Royce, this laser processing solution continues to give the indigenous aerospace industry a competitive advantage. Aerospace manufacturing is one of the UK's leading economic sectors with estimated

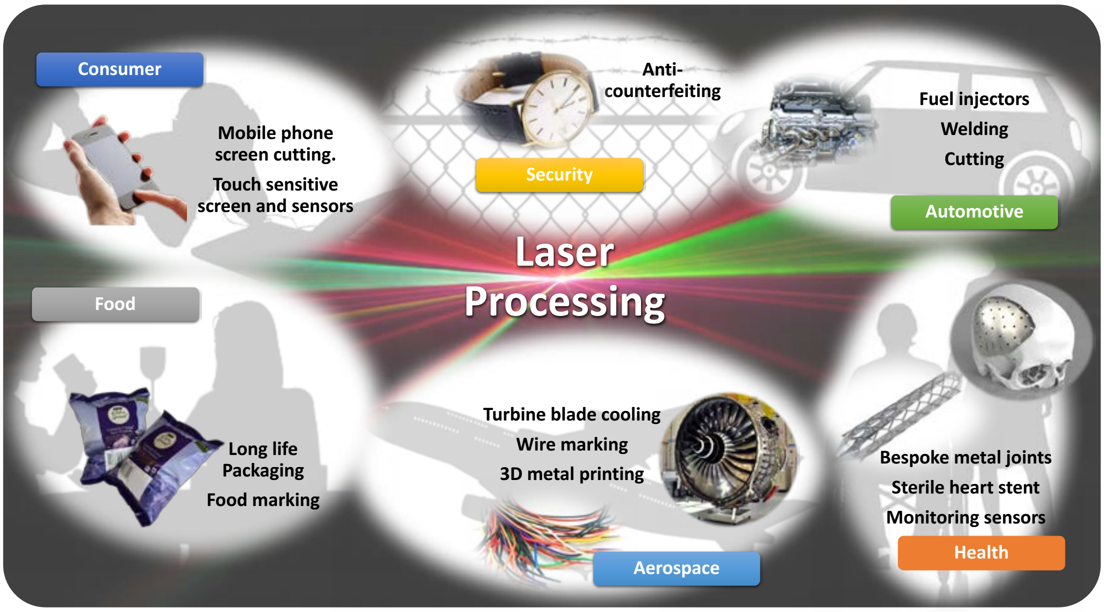


Figure 15: Illustration of the breadth of impact of laser processing into diverse end markets

revenues for 2016 of over £27 billion (including £11.2 billion in exports) directly supporting 85,000 high value jobs. Aero engine manufacture is one of the highest value segments of this industry in the UK. Laser processing is critical to enabling engine manufacturers, such as Rolls-Royce, to achieve their product performance, as well as opening-up new design options, allowing aero engines to run hotter and more efficiently.

Figure 16: Laser drilled jet engine high pressure vane (Source: Winbro)

This laser process has created and sustained thousands of jobs in UK companies, from the largest manufacturers to focused equipment suppliers e.g. multi-Queen's Award winning Winbro Ltd (Coalville).

4.2

AEROSPACE CABLE MARKING

Figure 17: Laser marking of aircraft wiring (Source: Spectrum Technologies UK)

Aircraft electrical wiring systems are large and complex comprising up to 300 miles of wiring per aircraft. To aid manufacturing and maintenance each wire is identified by an alphanumeric code printed every 75mm along its length; these must be legible, safe and permanent. Wires are made with thin (150 microns) non-stick fluoropolymer insulations. The previous industry standard of hot-stamp ink marking was non-permanent and caused serious safety concerns by damaging wiring. Consequently a replacement technology was urgently needed.

"Cold" UV laser marking has now completely replaced hot stamping for aerospace wire marking. Unlike standard laser marking it causes a colour change of the titanium dioxide filler of the fluoropolymer insulation and does not burn or change the mechanical or electrical properties of the wire. UV laser marking is non-damaging, safe and permanent. It also allows marking of twisted cables which could not previously be marked. This novel process, developed at BAE Systems, is now exploited in the UK by Spectrum Technologies (Bridgend), who manufacture laser cable marking systems. They have now supplied ~2000 systems across the global aerospace industry.

UV marking ensures the safety of critical electrical systems and brings huge cost benefits in production. It reduces set-up time in manufacture from many minutes to zero; increases marking speeds and enables new capabilities e.g. incorporation of bar codes further increasing downstream productivity in aircraft assembly. This now vital laser process also enables marking of cables which could not previously be directly marked, replacing heat shrink sleeves, which added many kilogrammes to the weight of wiring systems. This process has provided savings equalling tonnes of fuel used and reductions in global emissions.

4.3

FOOD PACKAGING FOR INCREASED SHELF LIFE

Figure 18: Laser pierced Viridiflex food packaging (Source: Coherent- ROFIN Baasel UK)

Consumers are buying increasing amounts of pre-packed foods including meat, bread, fruit and vegetables. To reduce waste, modified atmosphere packaging ensures food remains fresh for as long as possible by regulating the levels of oxygen, carbon dioxide, nitrogen and other gases inside the pack. However, individual food products vary significantly, and the packaging must be individually tailored to the product type, the mechanism of decay and the respiration rate of food content.

Lasers, including those made by Rofin-Sinar (Hull), are used to achieve flexible long-lived food packaging by high speed perforation of holes at predetermined intervals across the packaging film. With sensors integrated in the packaging machinery, the hole size can be monitored continuously and adjusted 'on the fly'. The film can thus be perforated accurately and reliably, and adjusted to fit the needs of the food product.

Laser-perforated food packaging has been proven to increase shelf life of fruits and vegetables by several days, when compared with unperforated or mechanically perforated films as well as preserving colour, taste and nutrient content in the food. Mould growth is inhibited, the ageing process is effectively slowed down and shelf-life increased in a controlled and predictable manner. This allows distribution territories to be extended, restocking frequency and associated labour costs to be reduced while waste is cut dramatically. Such advantages have seen laser perforated food packaging deployed across Europe and North America e.g. by Ultimate Packaging (Grimsby) under the Viridiflex trademark.

4.4

TOUCH SCREENS AND SMART SENSORS

Screens and sensors are made touch sensitive by patterning thin, invisible layers on top of the screen or sensor. To increase sensitivity new finer conductive lines are required. A solution has been

Figure 19: Hybrid inkjet laser printing of electronic touch circuits (Source: M-Solv)

to combine inkjet printing of wide (1-2mm) tracks with nano-particle metallic inks on the sensor bezel area and then locally sinter printed metallic ink to create high conductivity 'wires'. A pulsed infrared laser is then used to ablate fine trenches in printed ink to form isolated high density conductive tracks.

This hybrid printing/laser process is fully digital so no masks or screens are required. Tooling costs are zero and lead times are ultra-short compared to conventional screen printing/lithographic based processes. New sensor designs can be manufactured and tested rapidly allowing fast product development. The process is applicable to touch, bio & other sensors as well as large smart windows and displays. The technique has been developed and implemented at M-Solv's production line in Oxford with global sales of manufactured products.

4.5

ANTI-COUNTERFEITING

Fake or counterfeit goods have always been a problem for producers of valuable items and high quality brands (e.g. banknotes, credit cards, watches, clothing, perfumes, jewellery, etc). Whilst some fakes are obvious from their low quality, counterfeiting has become increasingly sophisticated making it much harder for the customer (or even, for example, a specialist jeweller) to confirm that a product is the real item. Various types of marking including laser micro marking and holographic stickers are used, but these often only provide a moderate level of security.

Figure 20: Laser embossed holographic security marking (Source: Heriot-Watt University)

A new approach based on laser processing now enables holographic structures to be digitally 'embossed' onto the surface of metals. This hard to-replicate laser process uses highly controlled melting and melt flow to generate patterns of sub-micron deep optically-smooth 'dimples' on the metal surface, with depths controlled to 10-20 nanometres. Only with a laser is it possible to create such a controlled melt flow process and create an optically-smooth dimple pattern so that the light reflected from them adds coherently to create an image – the hologram. The response of the laser irradiated metal is strongly dependent on the precise material properties and even small amounts of impurity, as often found in fake goods, will significantly affect the results, changing the appearance of the security pattern.

Developed at Heriot-Watt University, this novel laser security-marking process is currently in final stage commercialisation with a specialist manufacturer of laser marking systems for the jewellery industry.

4.6

DRILLING OF AUTOMOTIVE FUEL INJECTORS

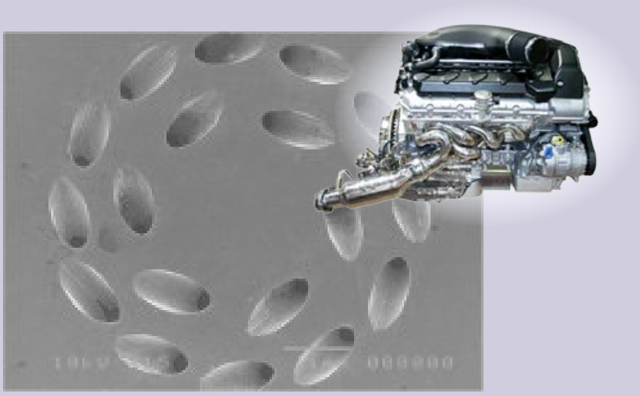


Figure 21: Laser drilled holes for racing car petrol fuel injector. (Source: Oxford Lasers)

Direct fuel injection is vital to achieve efficient combustion in the modern automotive engine. One of the original drivers for volume production of lasers for micro-machining, laser drilling of fuel injection nozzles remains an essential part of the drive to increase fuel efficiency and reduce emissions in the automotive sector. For example, laser drilled petrol spray holes are now deployed extensively by companies such as Bosch who in 2012 first introduced them for the Audi A3.

The fuel injection market, which alone is worth over £40bn[5] globally, is vital to the UKs £50bn automotive manufacturing sector. Enabling this application for more than 20 years, Oxford Lasers (Didcot) has provided customers in Europe, USA and Asia, multiple production and R&D laser systems for drilling both diesel and petrol fuel injectors.

Figure 22: 3D laser-printed bespoke cranial implants (Source: Renishaw)

4.7

3D PRINTING (ADDITIVE MANUFACTURE)

3D printing is increasingly recognised as a critical part of the future of manufacturing, allowing designers and engineers to manufacture incredibly complex components under full digital control. 3D printing of metal parts has significant potential for making lightweight structures with minimal use of high value materials e.g. tungsten alloys. However, this requires efficient precision melting of metal powders (requiring very localised high temperatures) and even first generation lasers were unable to achieve the required performance.

Figure 23: Bike frame with 3D laser printed joints (Source: Renishaw)

To enable 3D metal printing a new generation of high power lasers based on specialised optical fibres were required. First pioneered at the University of Southampton in the UK, these lasers have been commercialised by companies including SPI Lasers (Southampton and Rugby) in the UK, and IPG Group in the USA and others globally. Fibre lasers can now deliver high power 1 micron wavelength light with excellent beam quality and power. These have enabled Renishaw (Staffordshire) to develop machines which make 3D metal printing of parts a commercial reality, with the support of research groups at the University of Liverpool and elsewhere.

3D printing in metals allows designers' inspiration to run free, for example enabling:

- superlight-weighted automotive sport components
- custom fitted titanium and carbon fibre mountain bikes
- individually tailored replacement hip joints and hearing aids
- customised dental implants
- on-demand fabrication of discontinued parts
- recreation of historical artefacts.

Laser enabled 3D printing is proving to be an exciting, powerful and essential part of our manufacturing arsenal.

4.8

DECOMMISSIONING RADIOACTIVE MAGNOX WASTE FUEL CONTAINERS

There are thousands of steel containers that have been used for storing and transporting spent radioactive nuclear fuel (Magnox) for reprocessing. Recognising that most of the radioactive contamination resides within the first millimetre of the container wall, such contaminated containers need to be disposed of. Since long-term storage costs are proportional to volume, efficient ways to size-reduce these containers are essential. The baseline method to achieve this has been to employ manual techniques using reciprocating saws and grinders.

Recently, novel remote laser cutting techniques have been developed in the UK by TWI (Cambridge) to size-reduce the geometry of the containers to five flat pieces. The innovation lies in the large tolerance to stand-off distance offered by the specially-designed laser cutting head, which allows completely remote laser cutting with robotic manipulation of the beam for the complex shapes on the sides of the containers. The resulting cut pieces are then transferred to an automatic milling machine which removes about two millimetres of material from each surface. The result is the production of a few kilogrammes of radioactive material for safe storage with the remaining container steel recycled.

The main benefits of using laser cutting relate to significant productivity gains and considerably reduced radiation received dose, when compared to manual size reduction. Overall, the use of laser cutting results in a five-fold increase in productivity, while achieving a 90% reduction in the radiation dose uptake for the staff involved. It is estimated that, in addition to the major reduction in operator health risk, application of laser-enabled cutting technology to decommissioning all Magnox container skips would provide a cost saving of approximately £30m, compared to the use of mechanical techniques.

Figure 24: Laser dismantling of redundant nuclear waste container (Source: TWI)

5 BARRIERS TO FUTURE UK GROWTH

The full productivity gains from laser processing can only be realised by UK industry if the following barriers in skills, finance, standards, feasibility demonstration, risk and health and safety perceptions and automation are addressed.

5.1

PRIORITY BARRIERS

The root cause of the barriers which are slowing adoption of laser processing by UK manufacturing can be summarised as:

- access to finance throughout the value chain from system developers to would-be adopters
- shortage of manpower with relevant skills and experience in using laser processing
- asymmetry in industry size, between UK SMEs developing laser processing solutions, and key global customers, who drive adoption, leading to the gap in feasibility demonstration and qualification.

Industry expert sub-groups and the Laser Processing Industry Survey highlighted serious difficulties in recruiting staff at all levels. In the most extreme cases globally leading automotive companies have had to move laser manufacturing technicians from Germany to support UK car production. The shortage is most acute at lower skill levels, but persists everywhere from operator technicians to research engineers. This presents a significant barrier to growth since the skills level where shortages are highest are also those identified in the survey as those most important to enabling growth. Modest variation between sectors was also apparent, with laser micro engineering reporting the highest numbers of firms (>90%) having difficulty in obtaining technician grade staff, whilst the same sector found it easiest to recruit

BARRIER	DESCRIPTION	UNIQUE ASPECTS TO LASER PROCESSING	SOLUTION
Skills	Skilled staff are needed at three levels:- • operators / technicians • graduate engineers • research, development and design engineers	8 out of 10 companies report difficulty in finding technician level staff with experience of laser based manufacturing. Additional shortage of qualified graduate engineers with adequate laser manufacturing knowledge.	More industrial placements with laser processing in vocational courses, and support for apprenticeships in companies using lasers. More laser processing equipment in further education colleges and schools.
Finance	Over 55% of companies find it difficult or impossible to obtain funding to invest in laser processing solutions.	System costs can vary significantly from £20k to £500k depending on process and level of automated part handling. Financing provided by system suppliers ties users to a small number of venders.	Developing leasing models with independent financial providers. Government support of loans e.g. via Innovate UK, to implement new manufacturing solutions.
Standards & Consistency	Many newer processes are not standardised and are not always consistent, preventing pure "plug and play" digital manufacturing.	At smallest feature sizes controlling variation can be critical to maintaining end part performance. The current understanding of laser material interaction outside common sheet metals is insufficient.	Active feedback, closed loop control. Increased focus on the material science of high power light material interaction. Development and promotion of standard processes.
Feasibility demonstration & process qualification	End users require full demonstration of laser processes and reliability. Adoption often requires requalification of existing process or product.	Higher investment requires greater levels of confidence in process performance. Laser processing is often material and application specific, requiring bespoke process development.	Application-specific demonstration facilities for laser processing to inform return-on-investment. Fast track SME funding for process development and production qualification.
Risk perception	Conservative approaches to the adoption of new technology and unwillingness to adapt current processes. Insufficient senior management support.	Perceptions of laser processing as risky based on lack of experience or knowledge of relevant case studies. Industrial secrecy on deployment of laser processing, restricting open access to relevant examples.	Sustain promotional campaign of productivity benefits based on established case studies. Support for wider dissemination of best practice examples.
Health and Safety concerns	Deploying new processes requires changing existing procedures potentially outside the knowledge base of many potential users.	Laser processing can create different hazards to traditional manufacturing process e.g. laser safety, requiring additional H&S knowledge.	Increase dissemination, availability and certification of standard safety solutions and protocols.
Automation and Scale-up	Access to complementary technologies, e.g. robotics, to enable processes to be scaled up and integrated with automated part handling for high volumes.	Lasers have high costs and low down time, often processing small features relative to part size. Return on Investment is maximised by scaling up processes to high utilisation rates & integration with manufacturing flow & part handling.	Support for system and manufacturing integration engineering and demonstration.

The table summarises the key barriers and suggested solutions to the adoption of laser processing in the UK identified in this study.

research level staff. A reflection of the relative recent transfer of these processes from research to production, the effectiveness of UK graduate programmes (e.g. doctoral training centres) in developing new photonics technologies, contrasted with the ineffective training of engineers capable of implementing new processes.

Skill shortages are also compromising the quality of potential hires, with 40% of industry reporting the level of skills in laser processing in technician and graduate level job seekers as weak or very weak. In contrast ~90% of industry surveyed viewed quality and skill level of engineering researchers as good to very strong, a further reflection of the strong UK research base.

Adoption is also being hampered by the lack of design for laser-manufacturing skills in broader industry. Given the strong correlation between laser manufacturing and improved productivity this means the UK is missing out on efficiency gains as design engineers throughout broader industry lack the knowledge to design new products for the most efficient laser-based production methods.

Considering the full cross-section of barriers, it is the level of investment required that is seen by industry as the most significant barrier to the adoption of more laser based processes by UK manufacturing. However, perception of risk, lack of management support and conservativism to the adoption of new, and displacement of existing processes also play a major role in slowing adoption. Resistance to change, short term investment horizons and macroeconomic uncertainties are a powerful combination suppressing investment in laser processing technology which is widely regarded to be critical for improving manufacturing productivity.

Barriers to adoption of laser processing in UK

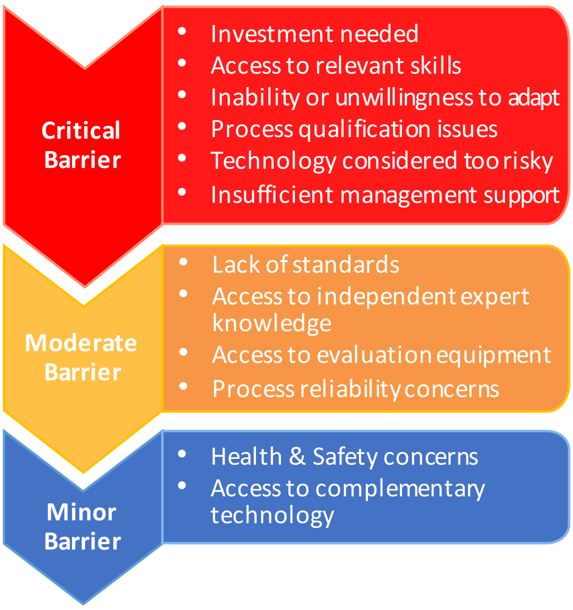
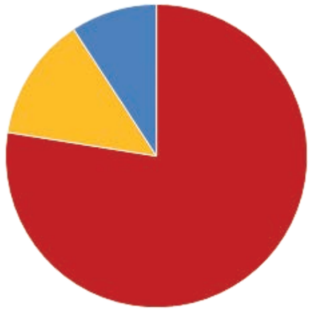


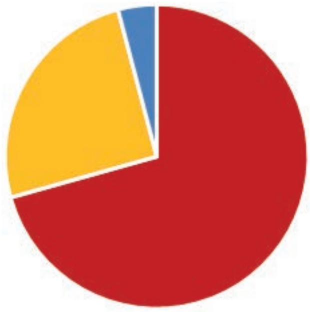
Figure 25: Relative importance of barriers preventing leverage of laser processing in the UK (Source: Laser Proc Ind. survey)

Figure 26: Medical hip reamer being laser cut on 5-axis machine (Source: Coherent Rofin)

Availability of Machine Operators/Technicians



Availability of Qualified Engineers (BEng, BSci, MEng)



Availability of Research Engineers (PhD, EngD)

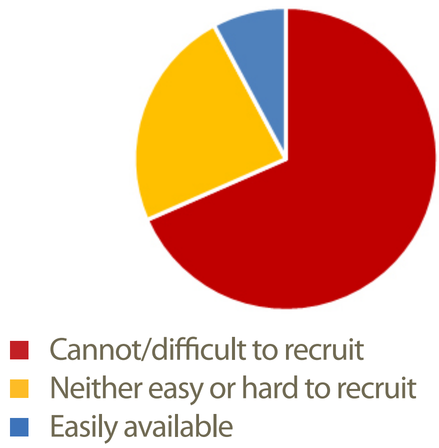
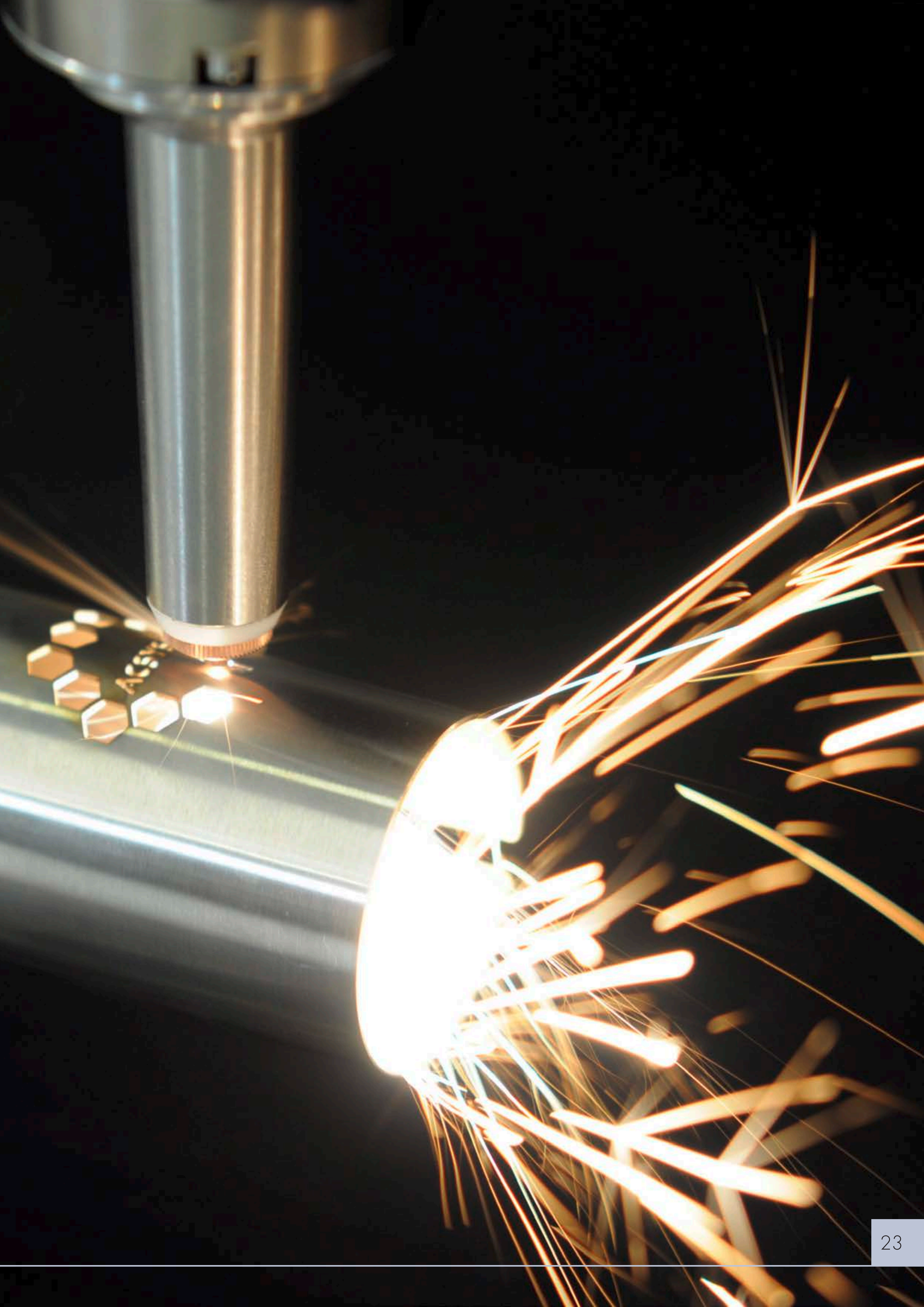


Figure 27: Perceived relative difficulty / ease of recruiting different skill levels in laser based manufacturing (Source: Laser Proc Ind. Survey)



6 OPPORTUNITIES

6.1

FUTURE MARKET IMPACT

The impact laser processing delivers and the drivers for adoption vary between different vertical market sectors. In Healthcare and Medical equipment the greatest impact is seen by industry to be in improved quality, reliability and durability in products from medical implants to diagnostics instruments. In Defence and Aerospace, it is in the ability of laser manufacturing to enable new features and functionality that is seen as having greatest impact e.g. Airbus is investigating the use of additive manufacturing (known as 3D printing) for greatly reducing material cost, waste and weight in the manufacture of airframes. In the Energy sector, lasers reduce the cost of manufacturing solar cells while improving their efficiency. In the Nuclear, Oil and Gas industries, the laser's ability to cut concrete and metal remotely will be crucial in the decommissioning of power stations and off-shore oil rigs. In Automotive, it is the laser's contribution to flexibility and decreasing costs that drive adoption.

Take up in these different vertical markets will depend not just on the technical potential, but also awareness of that potential within those industries. Some sectors, such as Aerospace and Defence, already have very high awareness of the potential for laser manufacturing due to their early adoption of laser solutions, often as the only way of achieving required performance. The Automotive industry also see lasers at the core of future manufacturing, with most major manufacturers forecasting the number of laser welds in a car increasing six-fold over 10 years.

Figure 28: UK produced production platform for advanced laser processing of thin films (Source: M-Solv)

Future impact of laser manufacturing by sector

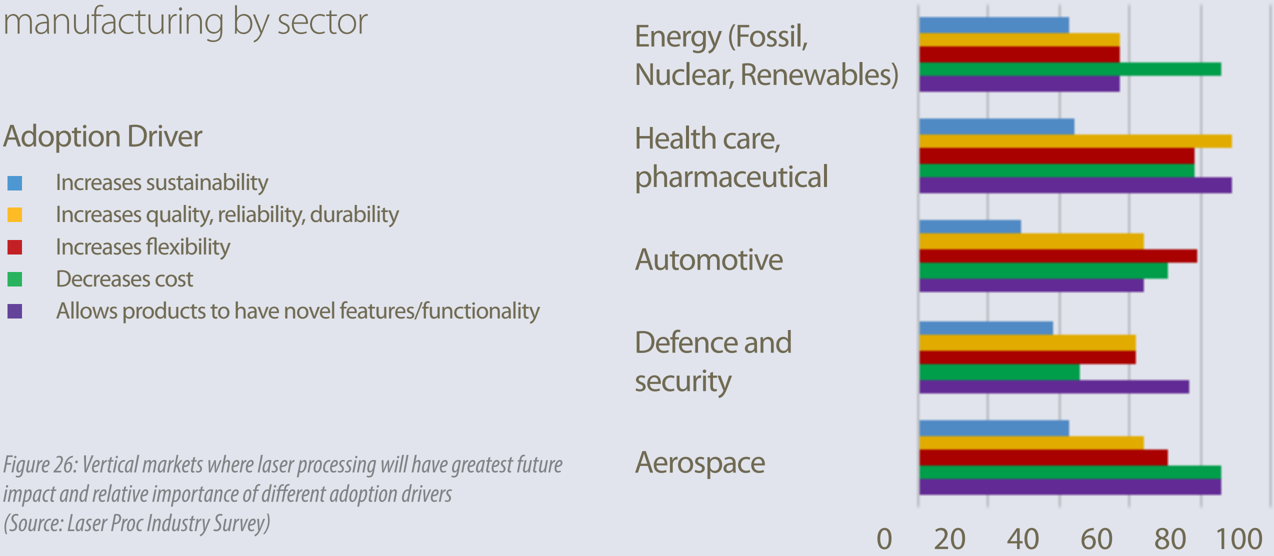


Figure 26: Vertical markets where laser processing will have greatest future impact and relative importance of different adoption drivers (Source: Laser Proc Industry Survey)

Figure 29: Renishaw laser enabled 3D printing/Additive Manufacturing production system (Source: Renishaw)

However, in Medical and Pharmaceutical applications awareness is polarised, with much of industrial laser industry believing that the Medical industry has little awareness of the potential of laser processing, whilst a key subset see awareness as high. This reflects the binary nature of adoption in Healthcare and the difference between adoption within medical procedures and use within medical manufacturing. For example, lasers are commonly used for surgical procedures such as tumour necrosis, welding detached retinas, corneal sculpting in vision correction, cataract and glaucoma treatments. This demonstrates a strong awareness of the impact of lasers in surgery, especially in ophthalmology. Industrial experience also shows, when adopted, lasers rapidly become the de facto standard manufacturing tool, e.g. in heart stent production. Yet this has only occurred in a small number of medical device areas and there are significant opportunities to increase adoption in medical device manufacturing.

6.2

FUTURE PROCESSES

The diversity of manufacturing processes where lasers add value, the current low rates of adoption in the UK and the continual emergence of new laser processes means there is huge potential for growth in the use of lasers for high productivity and precision manufacturing. Asked to identify the areas of greatest opportunity, over 90% of the Laser Processing Industry Survey responders see 3D printing as offering the biggest potential for growth, closely followed by surface structuring, micro or nano machining. These are all relatively new areas

only emerging as mainstream commercial options in the last 5 years. They are also areas where there are UK leaders in the development and production of laser based machine tools and production systems e.g. Renishaw (Staffordshire), Oxford Lasers (Didcot), M-Solv (Oxford), OpTek Systems (Abingdon), Thinklaser (Redhill), Tykma-Electrox (Letchworth), Spectrum Technologies (Bridgend).

As some of the newest laser processes, these areas also have most to gain from additional process development and understanding to improve consistency, reduce implementation time and enable process customisation. For example, while rapid advances have been made in metal 3D printing with lasers, further development of the metal powder/wire-laser interaction, material metrology and process control is required so that it is a truly digital transferable process producing parts fit for use without additional processing.

Well established processes such as welding, cutting and marking, which are at the core of the existing laser manufacturing market, have also been identified by industry as having significant potential for additional growth in the UK, e.g. in

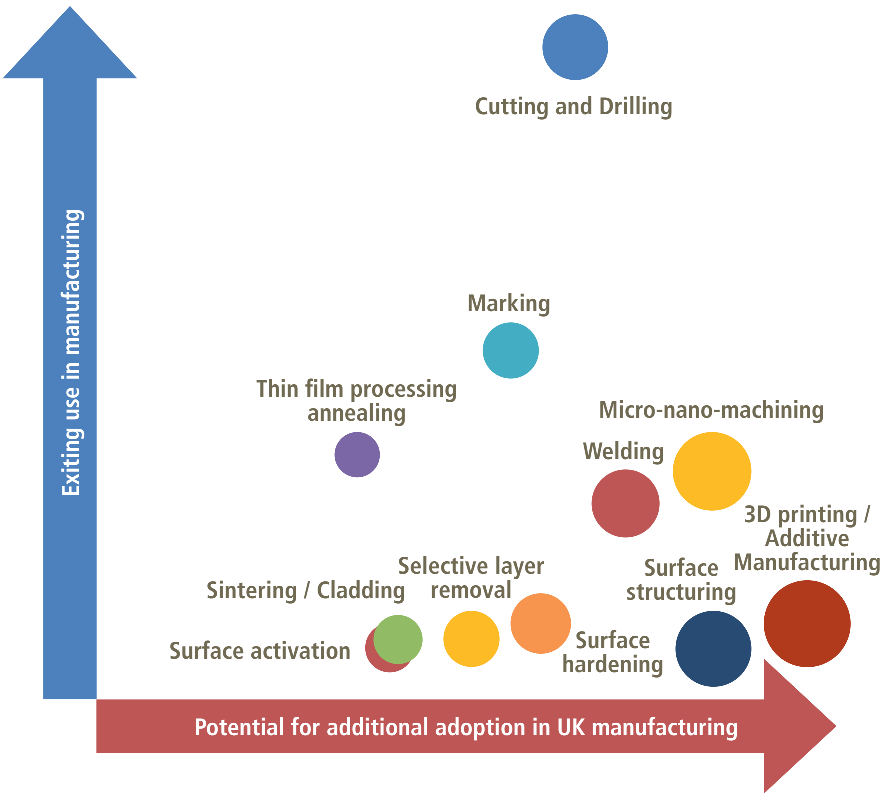


Figure 30: Laser processes offering the biggest potential for future impact in UK manufacturing vs current global adoption (latter based on 2016 laser processing equipment market, Strategies Unlimited).

decorative and security marking. This growth will be delivered primarily by enabling greater take-up of proven processes e.g. uniquely marking all of the 3 million parts in an aircraft so all fragments can be identified in extreme air accident investigations. Growth will also come from new processes, such as laser machining features in high-value parts so wear can be tracked, invisible-to-eye security markings, chemical free cleaning and marking, or fabrication of disposable point-of-care medical sensors.

6.3

DETAILED OPPORTUNITIES

Within the major markets to be impacted by laser processing in the future, UK industry has identified specific technical opportunities where they anticipate progress within the next 5 years. Collaborative Laser Processing development programmes in these areas are foreseen by industry to be capable of opening up significant new markets in the UK and internationally for sales of laser manufacturing systems and components. Also, when adopted in the UK, these present major opportunities for high value UK manufacturing in the indicated industries.

These are all industries where the UK already has significant strength, as identified in the UK's industrial strategy. However, awareness of the impact of these new laser processes varies from high in Defence and Aerospace sectors to low in the Energy and Healthcare sectors, and substantially more support is required to initiate collaborations and realise the benefits of laser processing for manufacturing in sectors where current awareness of laser impact is low.

Figure 31: Technical developments in laser processing with potential to be developed within the next 5 years by impacted market

Energy

- Renewables: Improving solar cell efficiency with laser surface texturing and annealing
- Oil and Gas: Dismantling offshore platforms with remote robotic-guided laser cutting
- Nuclear: high reliability welding in new nuclear build, safe decommissioning old nuclear facilities with remote laser cutting

Health

- Diagnostics: Laser transfer printing of ultra-low cost paper based disposable flow assays for point-of-care and home diagnostics
- Monitoring: Low cost health monitoring sensors
- Treatment: 3D 'bio-printing' of bespoke prosthetics, replacement joints and other body parts

Automotive

- Enabling increased range electric vehicles with laser annealing of next generation batteries.
- Mass production of position sensors for autonomous vehicles
- Increase fuel efficiency with laser surface modification for improved strength and reduced engine friction

Defence and Security

- More accurate threat detection with multifunctional cameras enabled with laser structured lens surfaces
- Additive Manufacturing of stealth surface structures
- Tamper-proof security marking laser-etched direct onto product

Aerospace and Space

- Lighter weight stronger aircraft with laser joining of dissimilar composite materials e.g. carbon fibre and steel
- Additive Manufacturing of light weight airframe components for better fuel efficiency
- Laser paint stripping of commercial aircraft
- Antennae directly scribed with lasers into the airframe
- Laser drilled holes in wing leading edges for Hybrid Laminar Flow Control for reducing drag and fuel consumption

7 RECOMMENDATIONS AND ACTION PLAN

Action is required in five key areas to accelerate the adoption of laser based manufacturing processes in the UK, to enhance productivity and ensure the long-term sustainability of UK manufacturing. These action areas are fully aligned to five of the key pillars of the UK Governments latest industry strategy.

A detailed plan for addressing these actions will be developed and led by industry. In return the UK laser processing sector calls on Government to work with its industrial leaders to develop a Sector Deal for laser manufacturing in the UK as a key part of digitising UK manufacturing and delivering higher manufacturing productivity throughout the UK.

7.1

SKILLS AND TRAINING

The UK has successfully invested extensively in high level skills for the development of laser processing training through Research Council supported Doctoral Training Centres, Centres for Innovative Manufacturing and Manufacturing Hubs. These initiatives are successfully increasing the supply of the highest level of skills in the workforce at PhD level and above, who can develop new processes and expand the field of laser processing.

Whilst the supply at the highest skill level is being addressed (and it is vital that this continues), it has exposed a serious shortfall in the availability of skills to implement and operate laser based manufacturing processes on a day-to-day basis. For every PhD level employee, 10-20 skilled workers are required to implement and operate laser processes on a day to day basis[6].

Urgent action is required to increase vocational training of laser processing. A multi-year program is required to ensure those undertaking Engineering Apprenticeships and Engineering courses at Further Education Colleges are exposed to, and have

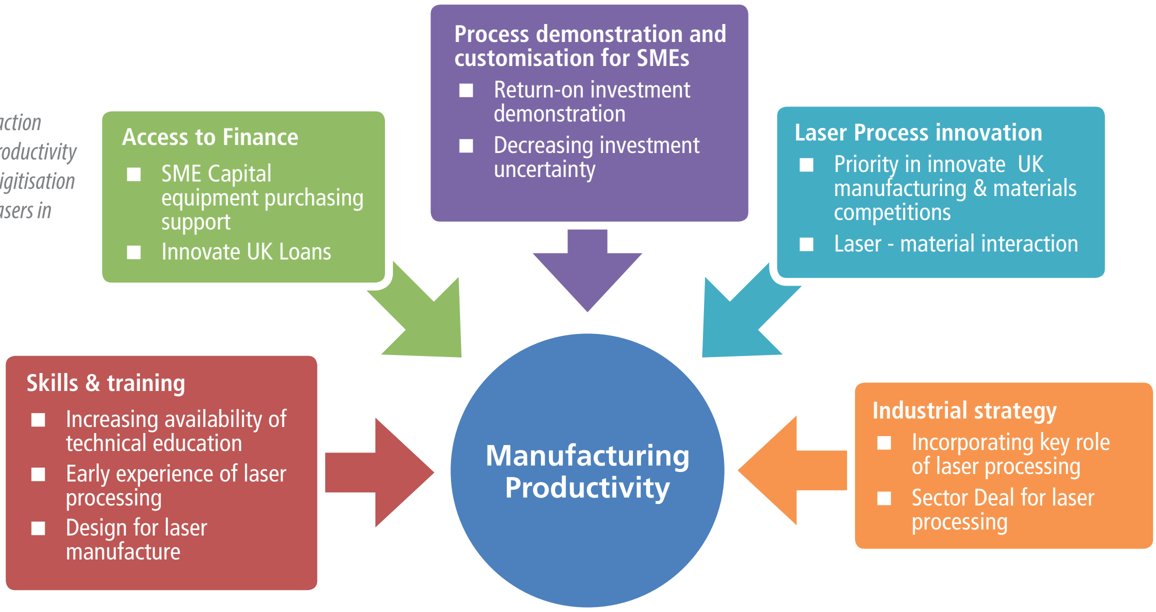


Figure 32: Five point action plan to increase UK productivity and manufacturing digitisation by increasing use of lasers in manufacturing

experience of, operating digital laser processing machinery, including cutting, marking and welding. To achieve maximum productivity gains, it is also vital the next generation engineers are taught how to design for laser manufacture and mechanical engineering courses need to be adjusted to incorporate this training.

Lasers fascinate the young. Increasing their availability in schools and their use in Design and Technology at GCSE, A-level and equivalents will help inspire the next generation of engineers, and through practical experience, increase STEM education participation.

The move to employer-led apprenticeships has compounded the skills shortfall since the speciality laser job shops are mostly small firms, unable to commission a full apprenticeship on their own. The rapid development of laser processing, and restrictions on capital spending, has also left many Further Education Colleges significantly short of laser based equipment and thus unable to provide suitable training or exposure to laser processing.

The Laser Processing Industry Survey also indicates that management knowledge (and even basic awareness) of the capability of laser processing is much lower in the UK than Germany. In the UK, manufacturing managers are less aware of the latest developments. The lack of exposure of apprentices and trainees to laser processing means the next generation of employees are not able to gather this critical knowledge. The closure of the Manufacturing Advisory Service has further reduced routes to spreading manufacturing best practice.

Currently, UK manufacturing faces a multi-generational gap in its awareness of laser

Figure 33: Training and demonstration of laser processing equipment (Source: TWI)

processing in manufacture: a critical productivity enhancing technology. If unaddressed, this gap will constrain UK manufacturing growth for decades.

The proposal for a 'simplified system of technical education' in the latest industrial strategy is welcomed by the laser processing industry. However, to be effective this needs to include training and qualifications in laser processing. The UK laser processing industry look forward to working with government to identify if the current training infrastructure is sufficient[7] or new institutions focused on training of laser processing are required in the UK.

As potential employers of those with vocational level technical skills, the UK laser processing industry looks forward to informing the development of new technical education initiated by the Industrial Strategy. In return for increasing relevant training the UK industry commits to taking on 200 new trainees a year by 2020, with job creation of 5000-10,000 new positions in laser processing in wider UK manufacturing.

7.2

FINANCE

Access to capital finance remains a serious hurdle to the adoption of digital laser manufacturing in the UK, particularly for SMEs. Despite being well established and a manufacturing standard, banks interpret laser processing as a risky hi-tech investment. This is in part due to the futuristic association of lasers, and part due to a lack of network effects in the UK. The greater the number of laser solutions that are implemented, the more sources of loan and other finance will become familiar with them as secure investments, which will lead to a positive spiral of investment and realisation of productivity gains, enhancement of profits and evidence for further investment.

To overcome this problem some of the largest laser system suppliers offer their own financing. But with little competition from traditional finance suppliers the terms are not always favourable. The need to provide finance acts as a significant barrier to new UK laser processing equipment suppliers entering the market. Lack of independent finance also means equipment choice can be determined by the finance package available from different suppliers rather than the most suitable machine for the task or the one with lowest capital and operating costs.

Urgent action is therefore required to open-up the financing of digital laser processing systems. Solutions are required which can address a large range of system costs which can vary from £25k to >£500k and are available across all UK regions.

The proposed introduction of loans from Innovate UK would encourage just the type of investment in digital laser manufacturing that is required. The modern, forward looking disruptive nature of laser processing would, presumably, be seen positively, rather than negatively as it is currently by UK banks. However, despite initial promise, Innovate UK loans appear stalled in implementation and action is urgently required to make them available for development and investment in new digital manufacturing laser processing equipment.

7.3

PROCESS DEMONSTRATION AND CUSTOMISATION FOR SMES

To invest, companies need to understand their return on investment (ROI) i.e. for a given investment how soon will the capital cost be recovered and what profit will eventually accrue from the investment. The ROI the company management and their backers may accept as reasonable may vary, but without information on production impact, no investment will proceed. The larger the investment the more certain and more detailed the data on productivity is needed.

Laser processing is a technique characterised by many different processing parameters using different laser types in different ways. The parts handled can vary in material, size and complexity from aircraft wings to silicon chips with processes ranging from subtle marking to rapid cutting.

There are many process parameters, with differing impacts on productivity and with optimal values that vary between applications. The more laser processing is implemented, the more the productivity impact can be deduced from similar processes and the more production managers will have confidence in those projections. However, the low take-up of laser processing by broader manufacturing in the UK means these network effects are limited and lack of confidence in projections of production impact and thus ROI is constraining investment.

Figure 34: Laser coaxial brazing processing development as installed at MTC/HVM Catapult Coventry (Source: Precitec)

Action is required to support process demonstration and development with the specific aim of underpinning ROI decisions, especially for SMEs. Whilst manufacturers of lasers and systems are often happy to support the generation of such data, the market can be sceptical that supplier generated figures are over optimistic. Hence managers from potential end-user companies seek independent clarification of production impact, a role well suited to the High Value Manufacturing (HVM) Catapult and other research organisations. However, grant funding for such proof-of-process studies is scarce and vital for providing the data needed to unlock further investment by industry. Proof-of-process projects for manufacturing should be given the same weight as proof-of-concept studies looking at new product development from Innovate UK and other agencies. Additional access models to the HVM Catapult should be provided, particularly for SMEs, for both process and skills development.

7.4

LASER AND LASER PROCESS INNOVATION

In parallel with raising its manufacturing productivity, it is vital that the UK is ready and able to develop the next generation of laser manufacturing processes. Increasingly this means engineering new laser systems that can process new materials, in more exotic formats and in more complex combinations, all which must be cut, joined, built-up and marked.

The flexibility of laser processing to deal with different materials and multiple manufacturing processes is one of its great strengths, but the development of optimum process conditions for efficient interaction of selectable (new) laser beam features with new materials is complex. Action is thus required to support the development of new laser processing techniques particularly around the processing of new materials, material combinations and novel manufacturing processes. To facilitate this also requires continuing research and development on new laser and laser system technologies, particularly in pushing the laser performance envelope in wavelength (UV and mid IR), pulse duration, peak/average power and repetition rate. Of prime importance for UK growth in manufacturing usage of lasers is the development of new manufacturing designs/techniques to enable reduced capital/operating costs, predictable outcomes and increased reliability.

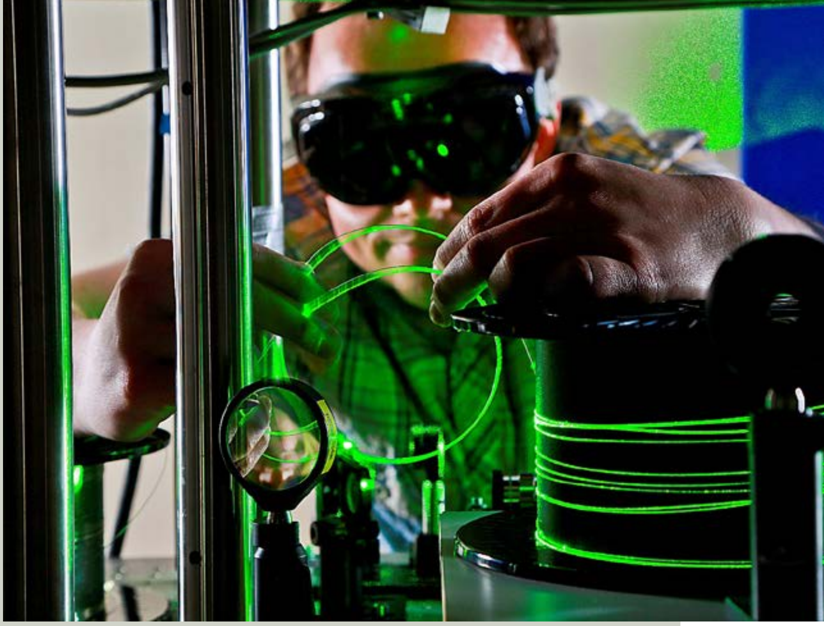


Figure 35: Development of next generation lasers and laser processes is critical for keeping UK manufacturing competitive in the future (Source: Heriot-Watt University)

Such investments should be a priority for Innovate UK's regular Manufacturing and Materials competitions, and for Research Council funded university/industry collaborations, to exploit the excellent links between strong academic research teams and laser/laser system manufacturers. The regularity of these competitions and their collaborative nature is welcomed by industry. However, significant gains would result from encouraging applications at the intersection of laser processing, novel combination of production materials, manufacturing processes and robotics.

7.5

INDUSTRIAL STRATEGY

A forward looking modern industrial strategy has been identified as key to the UK rebalancing its economy and shaping the UK future. Released as a Green paper in January 2017 the latest UK industry strategy aims to "build on our strengths and extend excellence into the future" in all regions.

As an inherently high value digital process, increasing use of laser processing should form a core pillar of the UK's future industrial strategy. The hugely diverse markets using laser processing, as illustrated by the case studies included here, show the gains across the whole economy that could result. The regional spread in laser processing expertise and where it can be implemented in manufacturing, means fostering the further deployment of laser processing will benefit all regions. However key skill gaps are evident and the industry looks forward to working with the new body tasked in the industrial strategy with identifying such skill gaps, and helping inform those early in their careers of the opportunities in laser processing.

Laser processing and laser development have long been UK strengths. Time is now overdue to leverage these science and innovation strengths into major gains in UK manufacturing productivity. Supporting the uptake of laser processing will deliver long term, diverse and sustainable benefit to the UK in all manufacturing sectors from food and medical, to aerospace, automotive and many other sectors yet to be realised. Some leading manufacturers, in defence, automotive and aerospace, have already adopted laser processing. Fostering wider adoption will play a vital role in closing the gap between the productivity in these early adopters and the rest of UK industry.

Measures to increase access to growth finance, outlined in the industry strategy, are welcomed by the laser processing industry. This is especially needed for long term capital investments of the type typically needed to implement laser processing. The industry welcomes the opportunity to work with government to ensure proposals are relevant to investment in laser processing for productivity.

Finally, as a core productivity enabler, the UK laser processing industry wishes to extend the hand of collaboration to the Productivity Council in order to support engagement with digital laser processing technology and support exchange of best practice within the wider manufacturing industry on how it can be adopted to maximum impact.

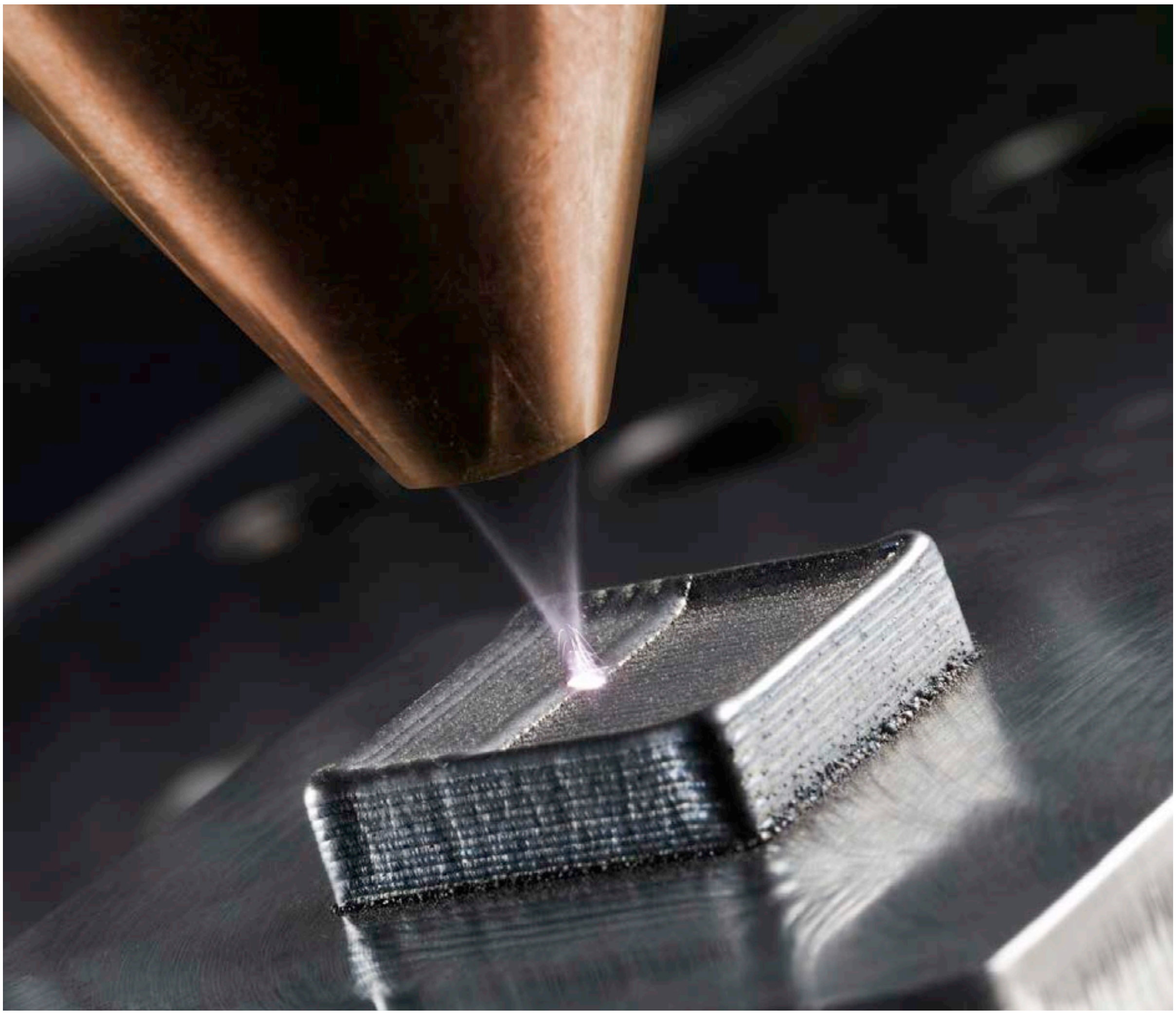


Figure 36: Laser additive manufacturing / 3D printing (Source: Trumpf)

8 APPENDIX - METHODOLOGY

The UK Association of Industrial Laser Users (AILU) and the EPSRC-Industry funded Centre for Innovative Manufacturing in Laser-based Production Processes (CIM-Laser) have together teamed with key industry experts to form a Strategic Working Group with the aim of developing a strategic growth plan for the exploitation of laser-enabled production processes across UK manufacturing industry.

This manufacturing strategy has been developed under the overall guidance of a Chair, Dr Malcolm Gower (Nanophoton Technologies) and Co-Chair, Dr Paul Hilton (TWI), and with the support of the Organising Team, drawn principally from AILU and CIM-Laser.

In order to generate the evidence needed to underpin the development of its proposals, a Strategic Working Group was convened comprising ~50 experienced experts drawn from laser-user companies active in key sectors of UK manufacturing industry, companies operating in the laser machine tool manufacturing supply chain, and leading industry-oriented academics, active in laser manufacturing product/process technology R&D.

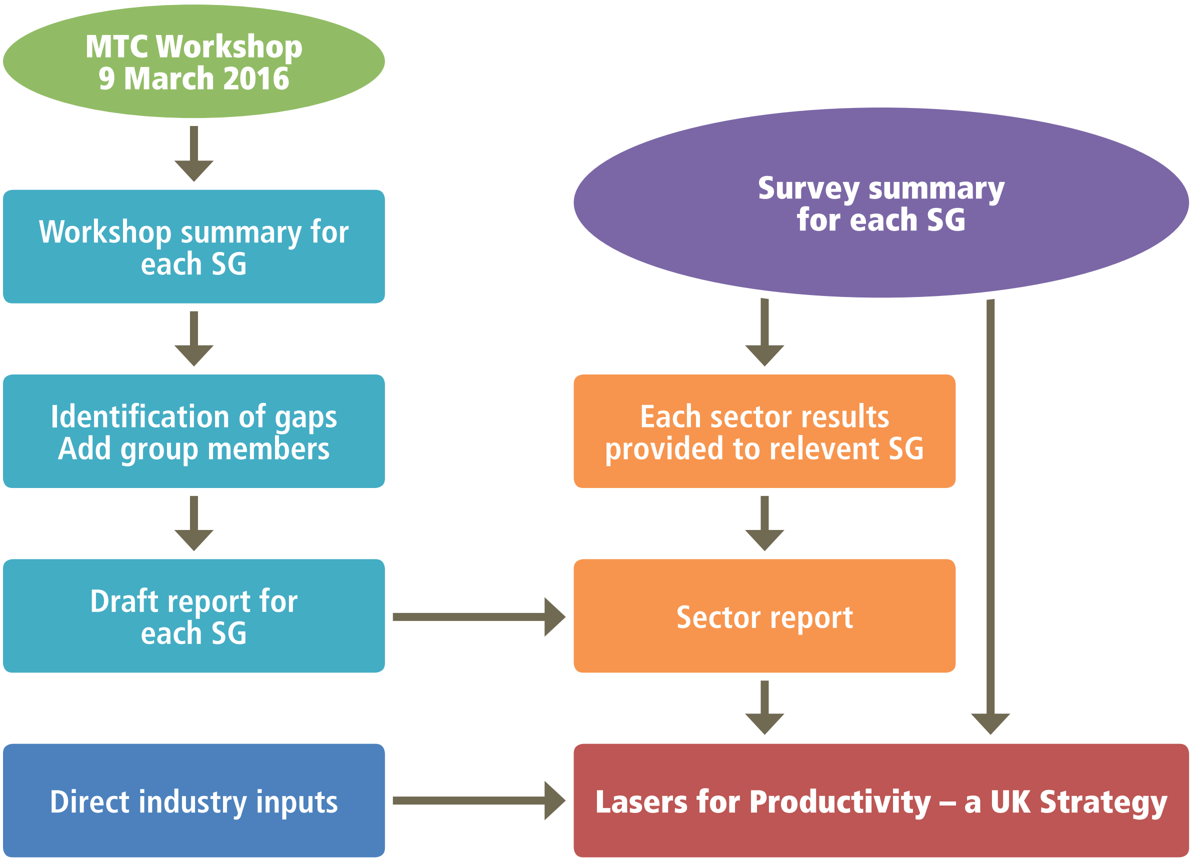


Figure 37: Process flow used to generate laser for productivity - UK strategy

To manage effective coverage across the key relevant sectors of UK industry, the Working Group was split into six Sub-Groups (SGs) each with sector responsibility, an industry Chair, academic Coordinator together with a senior postdoctoral researcher from CIM-Laser as assistant/facilitator.

The strategy was developed based on evidence gathered from across the user and supply base through 4 key instruments:

- Strategy Working Group: expert workshop held at MTC
- activity of Industrial Sector-Expert Sub Groups
- Laser Processing Industry Survey
- direct inputs from key industrial players both in the UK and further afield

Contributions from each of these channels were developed and combined to provide the core evidence-base from which the National Strategy was developed during the period March 2016 to January 2017, while also building on the prior report - *UK Roadmap-2014: Laser-based Manufacturing Applications*[8].

8.1

WORKSHOP

The development of the strategy was initiated at an all-invitation Workshop held at the Manufacturing Technology Centre (MTC), Coventry on 9 March 2016. Supported by 47 participants from across the user and supplier base, the Workshop provided the forum for the initiation of the activities of the expert Sector Sub-Groups that provided input over the subsequent 10 months.

The Workshop was split into Sub-Groups who worked together to provide a summary of:-

- current status of laser-enabled processes in each of the Sub-Group sectors, and suggestions for case studies illustrating strong/transformative manufacturing impact
- opportunities for future growth in laser enabled manufacturing applications
- opportunities for future growth in laser enabled manufacturing application
- perceived barriers to growth

Figure 38: Participants in March workshop

After an initial brainstorming of opportunities, Sub-Groups voted on the top priorities in each sector and results were reported to all in a Workshop Plenary Session. This process was repeated to identify barriers to growth in each sector.

A senior CIM-Laser postdoc was assigned to each Sub-Group, and was responsible for recording the outputs at each session, which became the basis for individual Sub-Group workshop reports prepared in concert with the sub-group Chair and Coordinator in the days following the meeting. The outputs from the Workshop were provided to each expert sub-working group as a starting point for their subsequent analysis and provided direct evidential input to the final report.

8.2

SECTOR-EXPERT WORKING GROUPS

The Strategic Working Group experts were organised into a series of Sub-Groups covering vertical sectors of UK manufacturing strength where laser-based production processes have significant commercial impact i.e. aerospace, defence and automotive, and key horizontal sectors of the laser processing industry i.e. micro-engineering, laser equipment manufacture and laser sub-contract manufacturers (job shops). Any individual laser manufacturing process may be relevant to multiple vertical sectors and any sector may leverage a range of processes, equipment and suppliers.

Beginning with its outputs from the workshop, each Sub-Group was responsible for covering a

SUB-GROUP	CHAIR	COORDINATOR
1- Aerospace, Avionics and Space	Clive Grafton-Reed (Rolls-Royce)	Stewart Williams (CIM-Laser, Cranfield University)
2- Defence and Security	Philip Cooper (De La Rue)	Daniel Esser (CIM-Laser Heriot-Watt University)
3- Automotive and Yellow Goods	Clive Buckberry (Quanta Fluids)	Bill O'Neill (University of Cambridge)
4- Laser Micro-engineering	Mike Osborne (OpTek Systems)	John Lincoln (Future Photonics Hub, University of Southampton)
5- Laser Equipment Manufacturing	Andrew Kearsley (Oxford Lasers)	Martin Sharp (Liverpool John Moores University)
6- Laser Sub-Contract Manufacturers	Neil Main (Micrometric)	Lin Li (University of Manchester)

specified Industry Topic or Market Sector, providing their analysis of key sector issues, including:

- current global/regional market scale and dynamics in that Sector
- relative UK status - strengths and weaknesses
- current and future opportunities (commercial and technical)
- market growth prospects
- supply chain issues
- new process and new hardware technology opportunities and challenges
- develop a set of recommendations for action and investment.

Within each Sub-Group, the Chair drawn from industry was tasked to provide leadership and to take the main responsibility for the outputs from the Sub-Group, along with a Sub-Group Coordinator, who also provided overall logistical support.

8.3

CALL FOR EVIDENCE SURVEY: UK LASER PROCESSING INDUSTRY

To supplement the input from the expert working groups, an industry-wide Call for Evidence on-line survey focused on the usage of laser-based production processes in UK manufacturing was conducted. Hosted by the University of Cambridge's *Institute for Management (IfM) and facilitated by Dr Charles Featherstone (Science Technology and Innovation Policy ,IfM)*, an invitation to complete the survey was sent to industry-wide professionals drawn from the membership of AILU, the contact base of CIM-Laser and contacts of the Organising Team.

The survey sought information and respondents' views in relevant topic areas including:

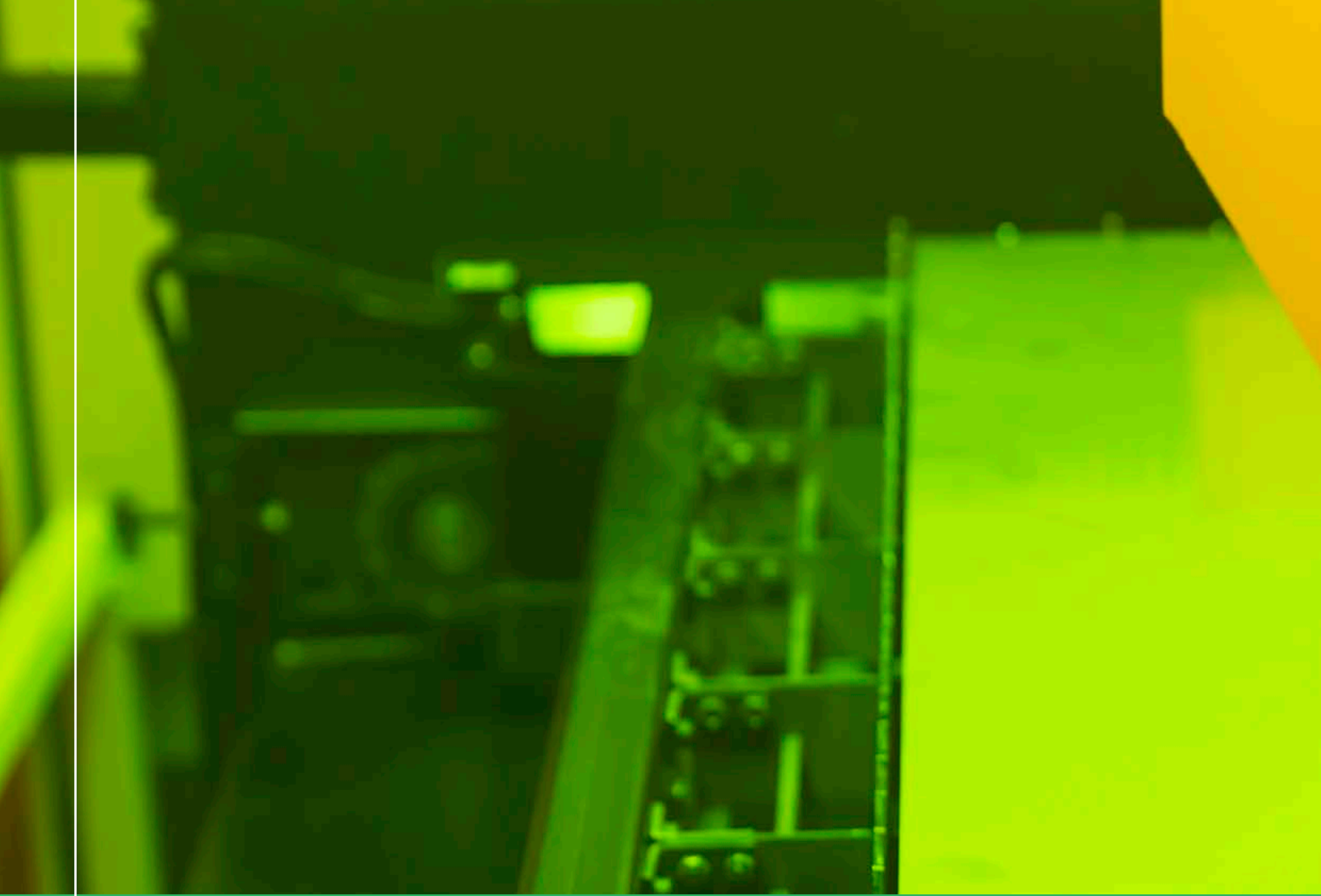
- background information covering the type of organisation and sectoral expertise of each respondent
- outline detail of respondent's company current extent of exploitation of laser processing
- overall UK exploitation of laser processing in manufacturing, and views on how it compares with manufacturing competitors
- current UK availability of key resources needed for effective utilisation of laser processing in manufacturing including qualified staff and equipment investments
- assessment of current level of awareness of opportunities for manufacturing productivity gains through usage of laser processing technologies
- future UK opportunities for market growth based on the exploitation of laser-based machines and laser-enabled manufacturing processes
- assessment of the industrial capabilities and resources including skills, access to expertise and machinery and other investments needed to achieve productivity gains
- barriers that exist in the UK that hinder growth in widespread adoption of laser processing in UK manufacturing.

The results of the survey indicated that those that replied had significant knowledge of and engagement in all relevant industry sectors including Aerospace, Defence and Security, Automotive and Yellow Goods as well as Healthcare/Pharmaceuticals and Energy generation.

8.4

DIRECT INPUT

To provide further clarification on a range of issues covered in the Report, direct input was sought from key industrial players; both users and suppliers of laser - based manufacturing processes. This input provided invaluable clarification and verification of the evidence generated by the other processes.



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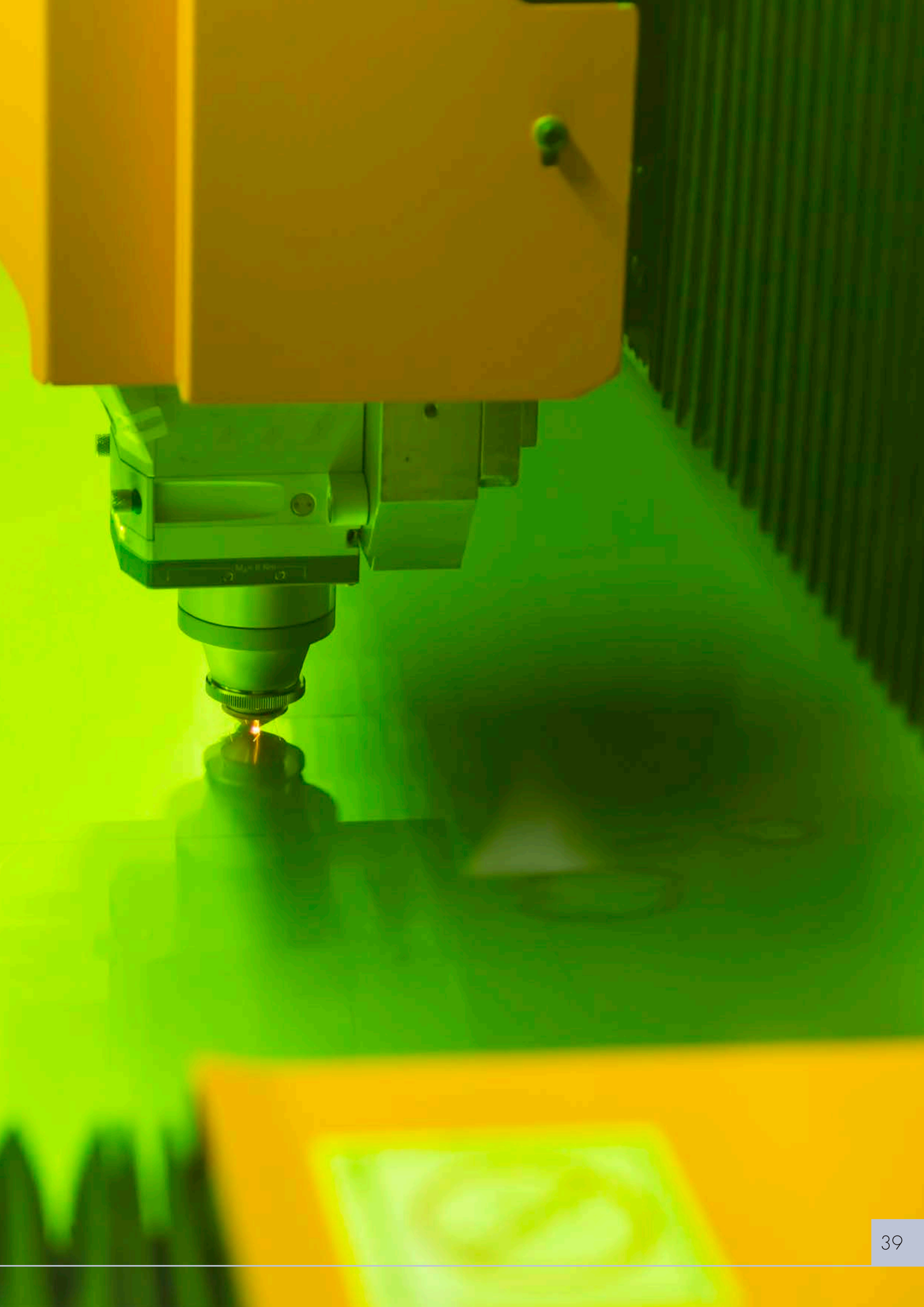

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- Philip Cooper, Large Area Electronics
- Charles Dean, Fimark Ltd
- Peter Dickinson, Spectrum Technologies plc
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- Steve Espino-Byrne - Gestamp Tallent Lt
- Daniel Esser, CIM-Laser, Heriot-Watt University
- Malcolm Gower, Nanophotontechnologies
- Clive Grafton-Reed, Rolls Royce
- Mark Greenwood, SPI Lasers UK Ltd
- Denis Hall, CIM-Laser, Heriot-Watt University
- Duncan Hand, CIM-Laser Director, Heriot-Watt University
- Paul Hilton, TWI
- Louise Jones, KTN
- Andrew Kearsley, Oxford Lasers Ltd
- Lin Li, University of Manchester
- John Lincoln, Harlin Ltd/Photonics Leadership Group
- Ken Lipton, Rofin-Sinar UK Ltd
- Anke Lohmann, KTN
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- Neil Main, Micrometrics
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- Stephen Morgan, BAE Systems
- Cormac Neeson, Crown Packaging UK
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