EPSRC Centre for
Innovative Manufacturing in
LASER-BASED PRODUCTION PROCESSES

ANNUAL REPORT 2013 2014

www.cim-laser.ac.uk

Centre

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Introduction

Laser-based manufacturing is a global multi-billion dollar industry with significant business opportunities. The past 25 years have seen industrial lasers replace conventional tools in many diverse areas of manufacture, enabling increased productivity, functionality and quality.

The EPSRC Innovative Manufacturing Centre in Laser-based Production Processes aims to support an increase in uptake of laser-based manufacturing through a wide-ranging programme of coordinated research and network building activities, enabling significant business growth opportunities, stimulating the broader UK community, providing leadership in the development of UK public policy, providing access to infrastructure for SMEs, and education and training for industry.

Executive Summary

This Annual Review provides an overview of the EPSRC Centre for Innovative Manufacturing in Laser-based Production Processes. We highlight activities and achievements of its first year of operation, and our plans for future years.

Our vision is to *exploit the unique features of laser light and a world-leading team to unlock manufacturing innovation, and deliver ground-breaking industrial impact in key areas of the UK economy*. Our strategy to realise this vision is to focus on science-based research, drawing on the considerable breadth in physics, materials science, and mechanical/electrical/photonics engineering at the five universities to deliver innovative laser process and hardware solutions, thereby enabling the creation of high-impact laser-based production process and machine technologies.

The academic team currently consists of 16 academic staff, 14 RAs and 8 PhD students, and we expect this to grow in the next few months, as recently approved projects get underway. This team is supplemented by the excellent support and important advice we have received from both our industrial advisory group (11 core partners of the centre) and our independent steering group, which between them provide input from a total of 44 different companies and other independent organisations.

We have to date co-funded with our industrial collaborators a total of 11 projects, led by 8 different Principal Investigators. In particular, our research seeks to exploit and further develop recent major advances in laser technology in *two* key areas: (i) a new generation of lasers with ultra-high quality and reliability based on solid state (diode, fibre) technologies that have evolved from advances in the telecoms sector; and (ii) a new generation of high average power laser technologies offering controllable trains of ultrashort (ps-fs) pulses, with wavelengths in the IR-UV. Funded projects include the development of high energy amplifiers for ultrafast lasers; research into applications enabled by ultrashort pulsed laser processes including micro-joining of glass-to-metal and high speed glass machining; the development of sensors and key parameters to enable truly *smart* laser processes; and the development of multi laser selective melting machines to greatly improve the speed and efficiency of metal powder-based additive manufacturing processes.

Our geographic spread brings its own challenges but we maintain good communication via the use of video and teleconferencing, supplemented, of course by frequent visits between sites. In particular we have recognised the importance of providing the Research Associates employed by the Centre with appropriate networking opportunities and so have created a series of events for RAs from across the Centre to come together for 1-2 days at a time, to discuss their research, and interact with industrial collaborators. Furthermore, we have earmarked a funding stream for RA-led feasibility projects that will be developed in the course of these networking sessions.

Our outreach activity has in particular focused on the development of a roadmap for UK laser manufacturing, working closely with the Association of Industrial Laser Users, AILU. The primary objective of the Roadmapping exercise is to identify new and evolving manufacturing applications where laser processing may play a significant enabling role, e.g. for high-value-added components and systems and those fabricated from new/mixed engineering materials, or relating to new production techniques. In addition, the aim is to identify relevant areas where research and development would be required to facilitate future laser-based solutions to such production needs, for example in new laser-material process science and technology, new or enhanced laser source development, beam manipulation and delivery, and system integration/control issues. Once a final consultation process is complete, the report will be finalised and released in autumn 2014. Our plan is then to use this roadmap as the first step in the development of a National Strategy for Laser Manufacturing in the UK.

We have also exhibited at MACH 2014, three AILU workshop/seminar events, The Scottish Manufacturing Advisory Service conference in June 2014, the National Manufacturing Debate and Manufacturing the Future Conference. The Centre has hosted and/or chaired a range of events, including workshops on laser beam delivery, and EU H2020 and Technology Strategy Board funding opportunities.

Looking forwards, we expect to fund a further 6 projects in the next year, and as a result to expand the base of industrial collaborators actively involved in projects.

We gratefully acknowledge the support of all those engaged with the Centre, both the dedicated academic team and our highly supportive (yet challenging!) industrial partners.

Professor Duncan Hand
Centre Director

Professor Len Cooke
Chair of the Independent Steering Group

Micro-Machining

There are increasing manufacturing applications for laser processing at micron-scale resolution, including material removal, surface and bulk structuring, joining and surface texturing, smoothing and polishing. Research in this theme covers the fundamentals of laser ablation and melt flow on the micro scale on a range of different materials using pulse lengths from the nanosecond to femtosecond regime.

LASER FINISHING

Work is underway to investigate the feasibility of using laser processing for post-machining of parts manufactured by powder bed and wire based additive manufacturing processes. A range of different laser ablation and smoothing approaches are being tested for materials of interest for additive processes, including stainless steel, cobalt-chrome alloy, aluminium and titanium. The work to date has focused on post-processing, however it is planned to also explore in-situ inter-processing approaches. Many applications e.g. medical, require a reasonably polished surface finish (i.e. good micro-roughness), so there is a particular focus on laser polishing processes. An experimental optimization of pulsed fibre laser polishing on martensitic stainless steel surfaces has provided reductions in the surface average micro-roughness (*spatial* $\lambda < 10$ μm) of around 80%, however the meso- and macro-roughness (10 μm < *spatial* λ < 80 μm and *spatial* $\lambda > 80$ μm, respectively) have not been affected. A combination of laser micro-machining and laser is currently being explored to provide improved independent control of micro, meso and macro-roughnesses.

HIGH SPEED, LARGE AREA SURFACE STRUCTURING

Ultra fast (UF) lasers have particular advantages with brittle materials such as glass, avoiding the thermally-induced cracking problems observed with longer pulsed lasers. Initial research in this area has concentrated on the development of UF laser processes to generate controlled scattering features on glass surfaces, at a high speed and hence low cost, and comparisons made with more established and lower cost CO_2 laser systems. This has been driven in particular by the demands of the rapidly expanding organic light-emitting diode industry, where complex laminate solutions are currently used together with glass and/or metal encapsulation. Directly patterning the glass using a suitable laser provides the prospect of a simpler solution. Promising initial results have been obtained, however for commercial reasons the project is now focusing on more general applications of processing of thin flex glass (including through cutting). This glass provides the opportunity to create flexible packages without the hermeticity issues associated with polymer packaging. It has been demonstrated, for example, that picosecond laser pulses of 515nm wavelength can be used for drilling small (60μm diameter) holes in a 100μm thin glass sheet at a speed of 20 holes per second.

ULTRASHORT PULSED LASER WELDING OF OPTICAL MATERIALS

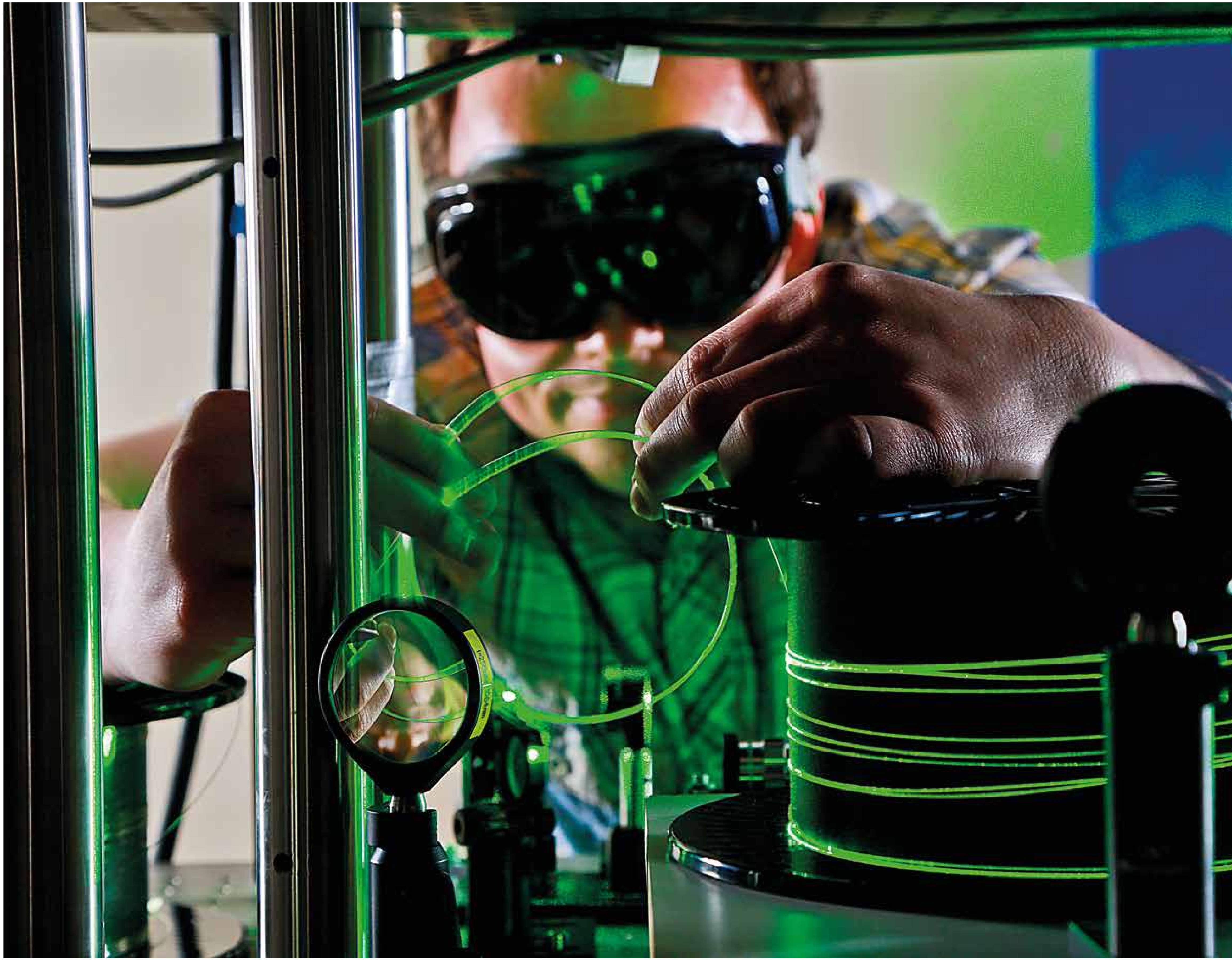
This work focuses on the development of industrially-relevant advanced laser bonding techniques for direct bonding of optical materials, including glass and crystalline materials to other optical materials and metallic components. Ultrashort laser pulses can provide a highly localised heat source, due to their nonlinear material interaction, and so are highly suited to such applications. This research is required in order to transform bonding demonstrations into robust high-yield manufacturing processes, including the development of strategies to avoid material cracking. Considerable progress has been made in developing the necessary knowledge and expertise including: (a) In the surface preparation of non-glass (e.g. metal) components, (b) techniques for ensuring the essential close contact between material surfaces during the laser welding process, (c) building up a knowledge of the parameter space for successful welding and (d) proof-of-principle examples in a range of industrially relevant materials. Detailed materials analysis has been carried out for a subset of parts, demonstrating the degree of inter-mixing during the welding process. We have also identified a number of suitable industrial processes to be investigated as the project continues.

Laser Development & Engineering

Research ongoing in this theme will underpin the development of technologies and components crucial to the hardware supply chain for laser-based machine manufacture. Research efforts concentrate on new laser device technologies, including solid state lasers pumped by diode laser arrays, with particular focus on the development of laser systems producing trains of ultrashort pulse pulses to enable significant expansion in novel laser processing applications.

HIGH ENERGY AMPLIFIERS FOR ULTRAFAST LASERS

Research in this area will further develop UK-based amplifier technology for ultrashort pulse laser systems with pulse durations in the 0.5 to 10 ps range. Work is on-going to develop new amplifier device architectures to scale to kW average powers, with design goals of high efficiency and minimising the cost of system production. New concepts that may prove instrumental in future high-power amplifier systems are being critically evaluated together with an industry partner.



Fusion Based Processes

The focus of this theme during the first year of the Centre has been additive manufacture applications where there is an urgent need to solve the unreliability and low efficiency of the laser-based process, concentrating on laser powder and laser shaped wire interaction and fundamentals. Outputs will feed into improved powder bed technology and a new laser-based additive manufacture process combining a very high power laser with wire strip.

FUNDAMENTAL LASER MATERIAL INTERACTION PARAMETERS IN POWDER MELTING

Work to define a set of interaction parameters that controls the fusion characteristics and profile of build layers in powder bed systems is ongoing. The aim of this research is to make the selective laser melting process more robust and transferable between different powder bed systems. These fundamental parameters can also be used for optimisation of the laser powder bed system in terms of process efficiency and scale-up to higher powers and build rates. The first phase will develop the relationship between the fundamental laser material interaction parameters and powder melting characteristics.

SMART LASER TECHNOLOGY FOR WELDING AND CUTTING

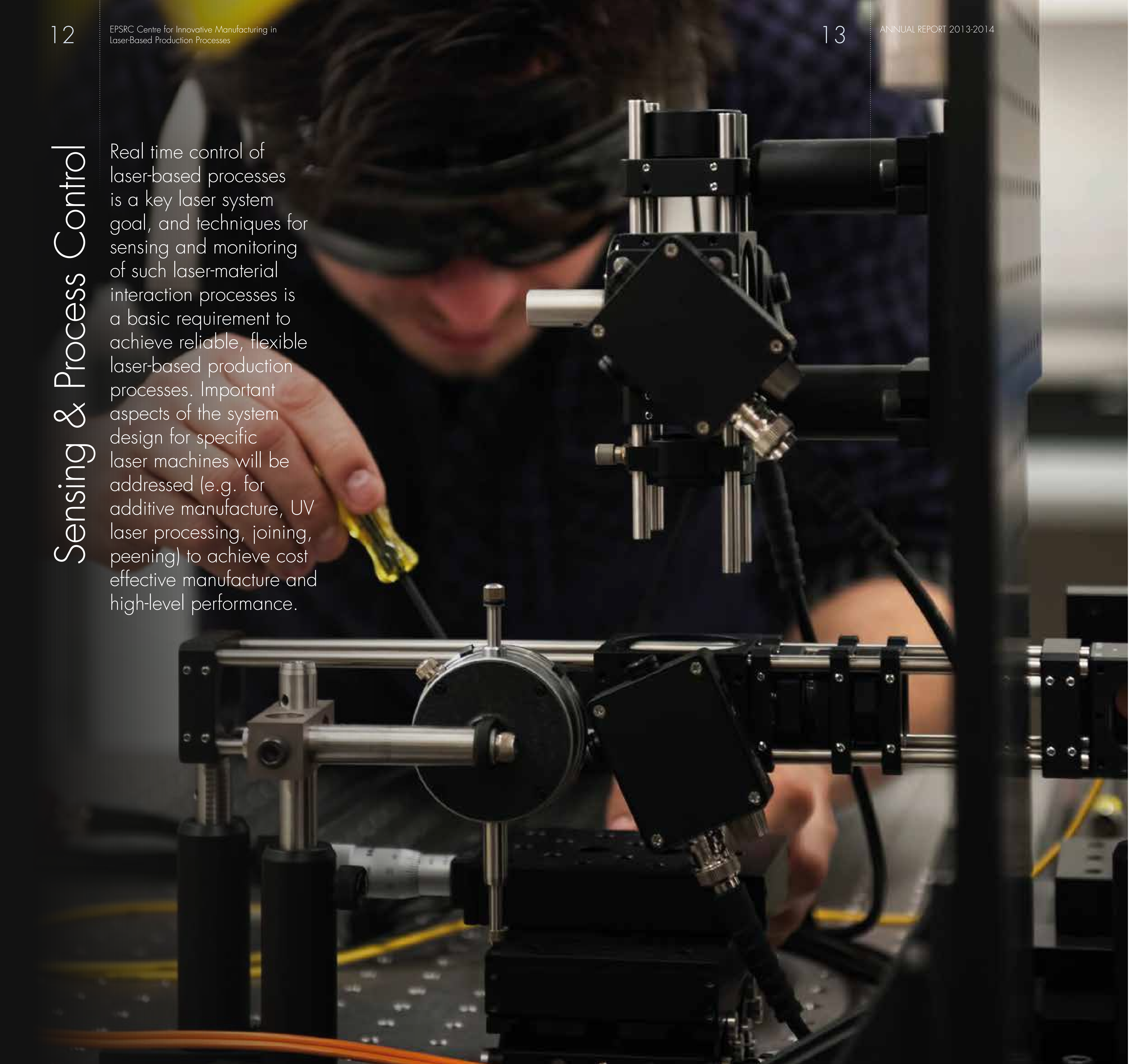
Laser processing is currently highly dependent on user knowledge and experience to choose correct or optimum parameters to obtain a reliable high quality process. Alternatively, for every new application or different laser system, expensive process development is required. Furthermore continuous human monitoring is often required to ensure smooth defect free production. The combination of these two factors is greatly limiting the potential exploitation of laser based production process in industry. To tackle this we are developing two approaches: (I) an Expert Laser System (ELS) which aims to greatly simplify the selection of laser welding parameters. The user only needs to set the requirements for the laser process (i.e. productivity, fit-up tolerance, penetration depth etc.); and (II) sensing based on back reflected light (BRL) which is ideal for process monitoring and control of laser processes being entirely non-intrusive. The Centre is investigating the use of analysed BRL as a laser process monitoring tool for cutting.

MULTI-LASER SELECTIVE LASER MELTING

Additive Manufacturing methodologies are beginning to achieve commercial uptake due to the advantages they bring in terms of part complexity, design freedom and material economy. Selective Laser Melting (SLM) is one such technology which utilises a scanning galvanometer system to divert a process laser across a metallic powder bed in order to create complex 3D components. In order for the uptake of this technology to continue improvements in build speed and material microstructure coupled with reduction in part defects and process uncertainties must be achieved. As affordable high power fibre lasers become available their integration into such systems should allow for some of the stated issues to be resolved. However the current optical configuration utilised will not readily accommodate increases in optical energy. The Centre is developing a proof-of-concept high power multiple laser scanning SLM system to allow for increased build rates and novel scanning strategies aimed at improving surface finish and reducing component residual stresses.

PROCESSING OF REFRACTORY METALS BY SELECTIVE LASER MELTING

There are currently no commercially available Selective Laser Melting (SLM) systems able to process refractory metals reliably. Refractory metals have high strength, are able to function at high temperature and have excellent corrosion resistance making them applicable to high strength medical devices, rocket nozzles and support hardware in the nuclear industry, while their ability to absorb radiation is useful in medical imaging devices. There are a number of challenges associated with processing refractory metals, including the high temperatures and strengths at temperature. Work in this area will develop processing parameters for a minimum of three refractory metals, identify any barriers that may limit the effectiveness of SLM processing and evaluate the performance. An initial study is being conducted that will evaluate the impact of cellular refractory metal structures for industrial applications. The results of this work will give UK industry an advantage in this high value manufacturing sector.



Sensing & Process Control

Real time control of laser-based processes is a key laser system goal, and techniques for sensing and monitoring of such laser-material interaction processes is a basic requirement to achieve reliable, flexible laser-based production processes. Important aspects of the system design for specific laser machines will be addressed (e.g. for additive manufacture, UV laser processing, joining, peening) to achieve cost effective manufacture and high-level performance.

CONTROLLED LASER MILLING

Research in this area is developing laser based methods for the specific removal of thin metallic protective layers from a metallic substrate material with integrated process monitoring. Laser Induced Breakdown Spectroscopy is an established tool for the identification of metals in laser plasmas and the Centre is developing the use of the spectral emission as a process monitoring tool to detect complete removal of the protective layer material.

PROCESS CONTROL FOR LASER-HYBRID ADDITIVE MANUFACTURE OF METALS

Additive manufacture of metals can produce fully-dense, near-net shape, free-form components directly from a CAD model. Wire feedstock (compared to powder) provides higher deposition rates, higher efficiency of material use, lower porosity, cheaper feed material, simpler feed mechanism and less surface roughness. Centre work in this area is investigating the laser-hybrid AM process in order to introduce build-height control for the first time, thus reducing the aggregation of height errors between layers. We will also introduce simultaneous height and temperature control, and investigate whether this approach enables control of the height-to-width ratio of the deposited bead, again for the first time. Both control approaches will reduce process variation: the serial production of parts in the future will require these assurances of process reliability and output material quality, particularly for aerospace applications.

ADD, REMOVE, MEASURE OR REPAIR

Development of a novel 3D freeform fabrication laser based manufacturing platform will provide a flexible platform combining the ability to construct, build and add material to freeform shapes with metrology of the created part and the ability to remove material to achieve a high level of form fit and low tolerances in excess of that achievable in freeform manufacture on its own. By integrating fibre delivered laser sources into a parallel robot device we will produce a flexible system capable of a number of concurrent engineering processes. This combines new product development and/or fabrication steps for novel customised parts or repair of damaged high value components with the ability to monitor the process and measure the component.

Centre Outreach

A core aim of the Centre is to stimulate a vibrant and coherent lasers-in-manufacturing community with a strong cross-boundary structure, forward-looking programmes, and the resource base to promote commercial growth through knowledge generation, technology promotion and exploitation activities.

During our first year the Centre has delivered joint workshops and seminars with our outreach partners, sponsored and participated in conferences, and initiated, in partnership with the Association of Industrial Laser Users (AILU), the development of a road map and UK strategy for laser-based manufacturing.

Selected Outreach Activities

HIGH-THROUGHPUT LASER-BASED MANUFACTURING WORKSHOP

The Centre worked in partnership with SU2P (a partnership between 6 Scottish Universities, Stanford, Caltech and industry partners) to deliver a workshop aimed at identifying opportunities within Horizon 2020 to partner with SMEs in the area of high-throughput laser-based manufacturing.

INTERNATIONAL SYMPOSIUM ON ADDITIVE MANUFACTURE

Organised by the British Trade & Cultural Office (BTCO), Additive Manufacturing Association of Taiwan (AMAT) and National Taiwan University of Science and Technology (NTUST), the 1st Additive Manufacturing and 3D Printing International Conference was held at NTUST in Taipei. This conference convened international academic representatives and AM vendors together to present the most up-to-date technology, application and market trends. Chris Sutcliffe participated to represent the Centre and the University of Liverpool, increasing the Centre's international links.

SCOTTISH MANUFACTURING ADVISORY SERVICE CONFERENCE

The Centre sponsored a workshop and stand at the Scottish Manufacturing Advisory Service (SMAS) Conference to promote laser-based manufacturing to business in the manufacturing sector. The Centre is offering SMEs the chance to work on feasibility studies with the Centre at no cost to themselves.

AILU'S POWER BEAM DELIVERY AND MANIPULATION CONFERENCE

AILU's Power Beam Delivery and Manipulation conference was sponsored by the Centre for Laser-based Production Processes. Chaired by Duncan Hand, Centre Director, the event held presentations and exhibitions from a range of companies and speakers followed by a tour of Cambridge University's Centre for Industrial Photonics Institute for Manufacturing.

2015 INTERNATIONAL YEAR OF LIGHT AND LIGHT-BASED TECHNOLOGIES

In 2015 the Centre will be running events in support of the International Year of Light and Light-based Technologies. **www.light2015.org**

INTERNATIONAL YEAR OF LIGHT 2015

UK Roadmap & National Strategy for Laser-based Manufacturing

A key aim of the Centre and its partners is to generate a coherent strategy document and technical roadmap for the UK that will be used to influence UK policymakers, trainers, educators and industry. The aims of this activity are:

- To stimulate the implementation of laser-based manufacturing processes across a much broader range of UK manufacturing.
- To develop suitable support mechanisms to support and further develop the UK laser sources, photonic components and machine integration manufacturing industry.

The development of the National Strategy is ongoing and incorporates input from AILU/ BIS Laser Materials Processing Strategy Workshop (February 2012) and the AILU/Centre roadmapping workshop (March 2014). After consultation with the wider manufacturing community the strategy will be led by a group of key stakeholders, including trade bodies, industry independent research organisations, funding agencies, and universities. This working group will draw both on their own wide range of experience and knowledge, and on a broad evidence-base including Photonics21, US laser manufacturing strategy and other relevant manufacturing strategy documents.

The UK Laser-based Manufacturing Roadmap-2014 Report was presented at the EPSRC Manufacturing the Future Conference in Glasgow on 23rd & 24th September 2014. The National Strategy Working Group will be formed by the end of 2014.

SME Seedcorn Projects

In order to demonstrate the potential value of laser-based manufacturing to industry the Centre is offering 2 weeks of researcher time to companies via our Seedcorn projects.

Seedcorn projects allow SMEs to work with the Centre on 2 week feasibility studies or pump-priming projects at no cost to themselves. Each project will be awarded up to 2 weeks researcher time with input from members of the Centre academic team to develop or test laser-based production processes that could benefit the SME involved.

How to apply:
For more information on this scheme and details of how to apply please email **LbPP@hw.ac.uk**.

Facilities & Equipment

The Centre has a range of state of the art facilities and equipment available across all University partners that enable comprehensive manufacturing research programmes. Our academics and researchers work across all sites and with industry partners to ensure the Centre produces cutting edge, industrially relevant research.

HIGH POWER LASER APPLICATION LABORATORIES

The High Power Laser Application laboratories at Heriot-Watt are well-equipped, including various high average/peak power lasers across a wide range of pulse lengths (millisecond, nanosecond, picosecond and femtosecond plus continuous wave) and wavelengths from the UV through to the infrared (355nm, 532nm, 1.06μm, 2.94μm, 10.6μm). These laser systems are coupled with high precision motion systems, including high speed galvo scanners and high precision air bearing and cross bearing stages. The laser processes that can be provided encompass micromachining, optical modification, polishing, cutting, joining, and microwelding.

WELDING AND LASER PROCESSING LABORATORY

The Cranfield laboratory is an industrial scale facility dedicated to the study and development of joining, laser processing and large scale metal additive manufacture. Lasers available include an 8 kW IPG fibre laser, 200 W Synrad CO_2 laser, SPI pulsed fibre laser, TEA CO_2 laser and a JK 300 W average power pulsed Nd-YAG system. The lasers are supported by an extensive range of manipulators including robots, a 3m linear slide and traditional precision XYZ linear slides. For very large scale parts we have the 5m x 3m x 1m Hi Value Engineering system which is equipped for welding, machining and rolling. There are three environmental chambers for operating in controlled at atmosphere including vacuum and up to 250 bar pressure for hyperbaric studies. For hybrid processing there is a host of state of the art fusion arc welding power sources with the latest variants both in gas metal arc (e.g. surface tension controlled metal transfer) and gas tungsten arc welding (e.g. TOPTIG). The laboratory is equipped with 20 tonne cranes for management of large parts.

For process analysis we have a range of cameras (IR and high speed), beam diagnostics and thermal/electrical measuring systems. For material characterisation there are electron microscopes (with EBSD and EDS) and mechanical testing with Digital Image Correlation.

ADDITIVE MANUFACTURING

Additive manufacturing facilities at Liverpool consist of three MCP Realizer Selective Laser Melting machines, used for the development of new optical systems, powder handling systems and general building work. These machines are highly modified and can be reconfigured with reasonable ease allowing rapid development of optical, mechanical and materials systems. They are also able to produce solid, porous and combinations of solid and porous structures, suitable for the orthopaedic industry. There are also two Renishaw AM (Laser Melting Additive Manufacturing) machines, which are being developed to incorporate new technologies. An E-beam additive manufacturing machine will be installed soon. These machines all use metal powders and full safe powder handling systems are incorporated. Other work in the area is on Laser Cladding and Direct Fabrication using wire feed systems that give compositional control and in the use of technologies normally associated with semi-conductor manufacture to improve the ink jet printing of metals. The University also has a full range of analytical techniques that can be used to analyse and quantify the experiments carried out. These include optical and electron beam microscopy (SEM, TEM, STEM), X-ray based techniques (EDS,XRD) and mechanical testing facilities.

Additional equipment is available at Heriot-Watt (Realizer 250) for 3D printing of stainless steel components from metal powders. An extensive suite of testing and measuring instrumentation and facilities for fibre optic sensing and fibre optic handling. Cu-vapour laser for basic fibre Bragg grating writing.

LASER DEVICE PHYSICS AND ENGINEERING

Heriot-Watt University hosts the laboratories and facilities that support the research of new laser technology. We focus on developing, characterising and applying novel ultrafast lasers, near- and mid-infrared solid-state laser devices, as well as semiconductor diode laser systems. We have a track record of developing a wide range of laser systems, many of which are available for application testing. These include 1 μm wavelength ultrafast oscillators (Yb:YAG, Yb:KYW and mode-locked semiconductor lasers), ultra-fast amplifiers (Yb:fibre and Yb:YAG slab architectures), 1350-4000-nm optical parametric oscillators, 1530-nm femtosecond fibre lasers and 450–1500-nm supercontinuum sources. The Centre has the capability to develop bespoke laser systems, and as such we have the expertise, equipment and capability to fully characterise laser systems (e.g. beam profiling of high power laser beams up to kW-level; precision ultrafast pulse characterisation; as well as laser wavelength measurement in the visible, near-, mid- and far-infrared).

CENTRE FOR INDUSTRIAL PHOTONICS LABORATORIES

The laboratories at Cambridge encompass a range of both high average power lasers (including fibre lasers up to 4kW) and ultrashort (femtosecond) pulsed lasers, together with a suite of analysis equipment, such as beam analysers and a FLIR thermal camera.

ANALYTICAL FACILITIES

Based at the University of Manchester we have a suite of 20 electron microscopes, comprising 12 scanning electron microscopes (SEMs), two dual beam Focused Ion Beam (FIB) microscopes, and five transmission electron microscopes (TEMs). This includes the recently installed state-of-the-art FEI Titan G2 80-200 scanning transmission electron microscope (S/TEM) with ChemiSTEM™ technology, the first of its kind in the UK. TEM preparation of complex specimens and serial sectioning is possible with the two dual beam Focused Ion Beam (FIB) microscopes: an FEI Nova 600i, equipped with an HKL electron backscattered diffraction (EBSD) system, and an FEI Quanta 3D FIB. In addition to our dual beam FIBs, we also have an FEI Quanta 250 FEG SEM dedicated to 3D imaging at the nano-scale using a Gatan x-ray tomography and ultramicrotome capability (Gatan 3View and XuM). The FEI Magellan FEG-SEM has a resolution of 0.8 nm, and is equipped with Oxford Instruments Xmax80 SDD system, EBSD detector and an AZTEC integrated analysis system. We have 5 FEG-SEMs equipped with EBSD analysis systems. In addition to the Manchester facilities there is high quality analysis equipment (SEMs, optical microscopes, Raman microscope, mechanical testing) available at the other institutions.

Leadership Team

Professor Duncan Hand

Centre Director, Precision Laser Processes

Duncan Hand, Centre Director, has been a member of staff at Heriot-Watt University for over 20 years, following a PhD in fibre optics at the University of Southampton. Duncan's work on lasers in manufacturing includes laser precision machining; the use of adaptive optics in laser manufacturing processes; and laser micro-joining processes. In this work he collaborates with a range of companies including SPI Lasers, AWE, Renishaw and M-Solv. He has further research activity, in collaboration with the University of Bath, on the delivery of high peak power laser light through novel microstructured optical fibres, with applications in manufacturing and medicine.

Professor Len Cooke

Chair, Centre Independent Steering Group

Professor Cooke graduated in Physics from Queen's University Belfast. Following completion of a PhD in Laser Plasma interaction he joined the laser group at AWE Aldermaston where he worked on the development of X-ray diagnostic equipment and the commissioning of the HELEN high Power Laser. He joined the Optics and Laser technology Department of BAe Systems in 1984, becoming Department Head in 1989. The dept comprised ~35 research scientists and was responsible for the development of Photonics and Laser Technology for defence and Aerospace applications. He retired in November 2010. He was a cofounder of the AILU and is also chairman of the Steering group of the CIM in Photonics at Southampton University.

Professor Stewart Williams

Fusion Based Processes

Stewart Williams has nearly 30 years' experience in research of laser material processing for manufacturing applications. This has been both in industry and more recently in academia. Topics have covered welding, cutting, drilling, micromachining and surface treatments. The main focus for his current research is elimination of black art in laser processes. This is being tackled by understanding scientific fundamentals in processes and then working how to apply them. The objective is to increase the industrial use of laser based production processes. This has approach has already been proven in laser keyhole welding and is being extended further.

Professor Bill O'Neill

Process Monitoring & Control

Bill O'Neill is Professor of Laser Engineering within the Cambridge University Engineering Department and Director of the Centre of Industrial Photonics. He has written over 170 research publications and scientific papers on the subject of laser-matter interactions, optical engineering, laser based manufacturing technologies, and micro/nano fabrication techniques. He is a member of the international advisory panel of the National Laser Centre of South Africa, a Director of the Laser Institute of America, and advises industry on a number of laser based manufacturing technologies.

Professor Daniel Esser

Laser Engineering

Daniel Esser is a professor in Laser Device Physics & Engineering at Heriot-Watt University, focussing on diode-pumped solid-state lasers and devices in the near and mid-infrared spectral range. His research background include key demonstrations of Nd-doped systems for 1 μm operation, Tm-doped systems at 1.9 μm and Ho-doped lasers and amplifiers for high energy 2 μm operation. His research interests include power and energy scaling modern lasers, as well as the myriad applications where these lasers are used. Daniel has a relentless passion to see new technological developments in diode-pumped solid-state lasers to be adopted by industry.

Dr Chris Sutcliffe

Powder Bed Additive Manufacturing

Dr Chris Sutcliffe has worked in a range of fields including laser processing using short pulse duration lasers, cold gas dynamic manufacturing, stereolithography of anatomical phantoms, selective laser sintering of medical devices, the production of controlled release oral dosages and selective laser melting. He is now recognised as an expert in the field of selective laser melting; in particular in the design of production manufacturing equipment and the development of next generation orthopaedic, trauma, spine and CMF implants for which he holds base technology and device design patents which have been licensed internationally. He has extensive industrial experience including being R&D Director at MTT Technologies.

Professor Phil Prangnell

Material Characterisation

Phil Prangnell's research activities are focused on studying advanced thermomechanical processing and joining techniques for light alloys (mainly aluminium and titanium). In particular, he is interested in understanding and modelling interactions between phase transformations, deformation microstructures, and industrial processes. He has worked extensively with the aerospace industry on developing welding techniques for aerospace alloys. In recent years his welding research had focused on joining dissimilar metals and friction welding, as well as variations on the friction stir welding process (e.g. FSSW, static shoulder FSW, USW etc.). He is also actively engaged in understanding relationships between microstructure and properties in additive manufacturing.

Professor Denis Hall

Outreach Co-ordinator

Denis Hall is the Centre's Outreach Co-ordinator. As Professor of Photonics at Heriot-Watt University he conducted research on laser device physics and applications his group pioneered ultra-compact high power planar waveguide lasers, exploiting concurrent research in RF discharge physics and optical waveguides to develop new laser concepts based on 2-D laser power scaling and novel laser resonators. Such lasers are now successful industrial products for several global companies. His work, part of a general industrial orientation involving partnership in many industry/university collaborative research projects, has produced a series of commercial laser products and industrial laser-based systems. He has co-founded three successful start-up companies producing lasers and photonic systems.

Veronica Ferguson

Outreach Officer

Veronica Ferguson is the Centre's Industrial Outreach Officer. Her experience has been in the development of partnerships between industry and partners from other sectors, including Higher Education. Skills include written communication skills, the ability to build effective working relationships, organisational skills and managing successful delivery of objectives for the partnership. Veronica has organised many conferences, networking and training events, and has an interest in Organisational Development.

Key People

Professor Howard Baker

Laser Engineering

Dr Klaus Metzger

Lecturer in Laser Engineering

Dr Robert Thomson

Reader in Applied Optics & Photonics

Dr Supriyo Ganguly

Lecturer in Welding Science

Professor Andrew Moore

AWE William Penney Fellow, Optical Diagnostics

Dr Peter Fox

Lecturer in Additive Manufacture

Dr William MacPherson

Lecturer in Applied Optics & Photonics

Professor Derryck Reid

Ultrafast Optics & Director of EPSRC CDT in Applied Photonics

Alex Peden

Centre Co-ordinator

Dr Robert Maier

Research Fellow in Sensor & High Power Laser Applications

Dr Jonathan Shephard

Reader in Applied Optics & Photonics

Researchers

Dr Rainer Beck

Dr Sonia Meco Martins

Dr Peter Schemmel

Dr Richard Carter

Dr Jinesh Mathew

Dr Wojciech Suder

Dr Christine Crombie

Dr Aldara Pan Cabo

Dr Usani Unoh Ofem

Dr Tavi Ciuca

Dr Krste Pangovski

Dr Krystian Wlodarczyk

Dr Filomeno Martina

Dr Goncalo Rodrigues Pardal

EPSRC Centres for doctoral Training

The Centre for Laser-based Production Processes has links to several EPSRC Centres for Doctoral Training that complement and augment the research effort of the Centre.

EPSRC CENTRE FOR DOCTORAL TRAINING IN APPLIED PHOTONICS

The Centre can fund up to 10 new Research Engineers each year, including a stipend of £20,100 for 2010/11 intake plus fees paid. The Centre currently has 45 Research Engineers ranging from those in their 1st year to those who are in the final stages of writing-up their thesis. Projects range from fundamental research aimed at developing company technical capabilities to applied research and development of product prototypes.

www.idcphotonics.hw.ac.uk

EPSRC CENTRE FOR DOCTORAL TRAINING IN ADVANCED METALLIC SYSTEMS

The Centre was set up to address the critical shortage of doctoral level metallic material specialists in the UK. Graduates from physical science and engineering disciplines over a 4 year period are trained in fundamental metallurgical science and engineering as well as undertaking an industry sponsored multi-disciplinary cutting-edge doctoral project.

www.metallicscdt.co.uk

EPSRC CENTRE FOR DOCTORAL TRAINING IN ULTRA PRECISION

Many emerging sectors and next generation products will demand large scale ultra precision (nanometre level tolerance) complex components. Such products include: next generation displays, plastic electronic devices, low cost photovoltaic cells, energy management and energy harvesting devices and logistics, defence and security technologies. Their product performance is set to advance and the innovative manufacturing based on ultra precision technologies for these products defines the scope for the EPSRC Centre.

www.cdt-up.eng.cam.ac.uk

EPSRC CENTRE FOR DOCTORAL TRAINING IN RENEWABLE ENERGY MARINE STRUCTURES

The Centre of Renewable Energy Marine Structures (REMS) will train fifty Engineering Doctorate (EngD) students over an eight-year period, admitting ten new students each year for five years starting in October 2014. This is a collaborative partnership between Cranfield University and the Department of Engineering Science at the University of Oxford in which the Centre for Laser-based Production Processes is a partner.

www.rems-cdt.ac.uk

EPSRC CENTRE FOR DOCTORAL TRAINING IN ADDITIVE MANUFACTURE

The primary objective of the Centre for Doctoral Training in Additive Manufacturing and 3D Printing is to produce research leaders to tackle the major scientific and engineering challenges over the next 10-15 years in enabling Additive Manufacturing and 3D Printing to play a prominent role in manufacturing, providing the people and talent to fuel this new industrial revolution.

www.nottingham.ac.uk/additivemanufacturing