EPSRC Centre for Innovative Manufacturing in Additive Manufacturing

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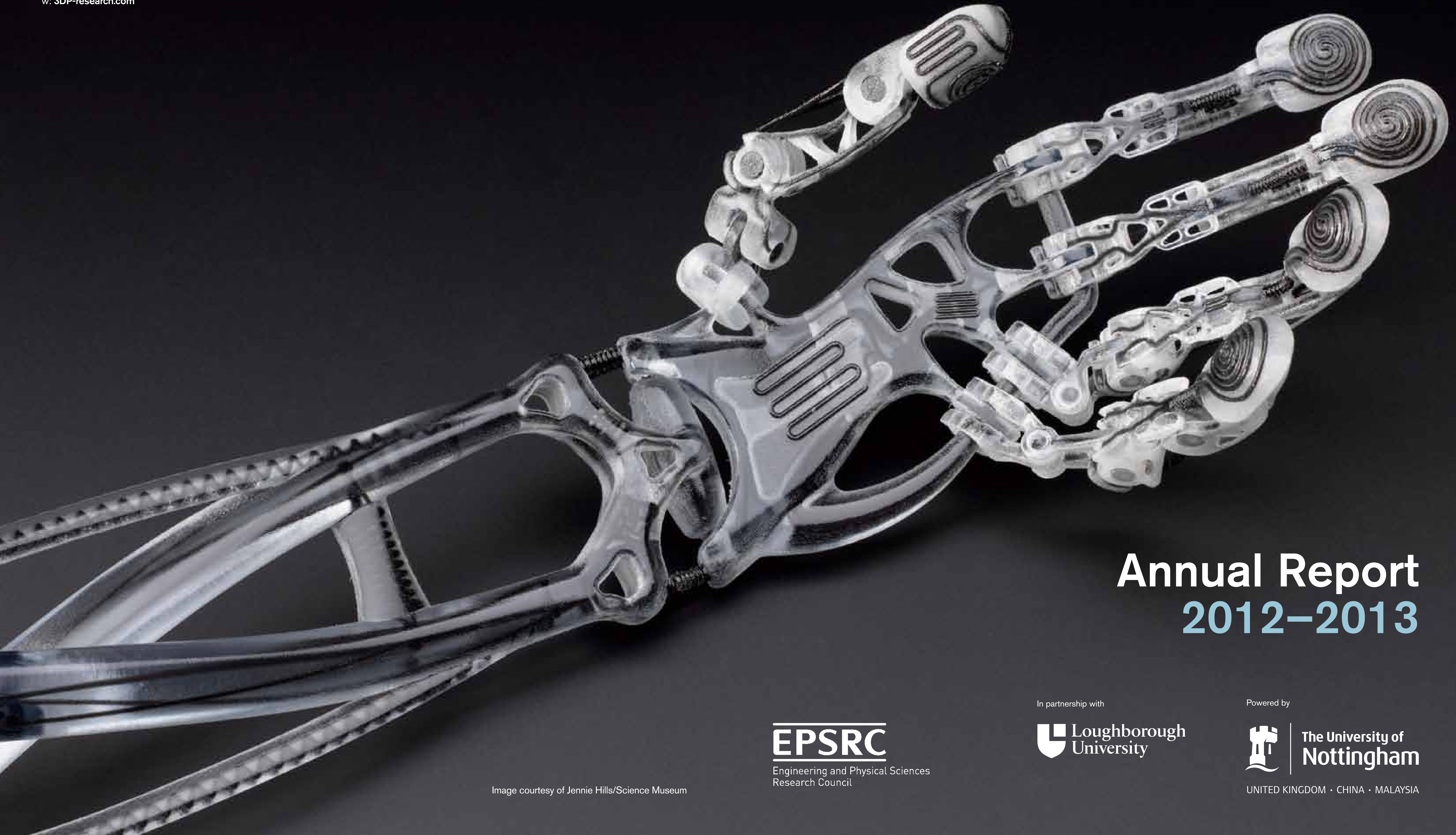

Image courtesy of Jennie Hills/Science Museum

Annual Report 2012–2013

EPSRC Engineering and Physical Sciences Research Council

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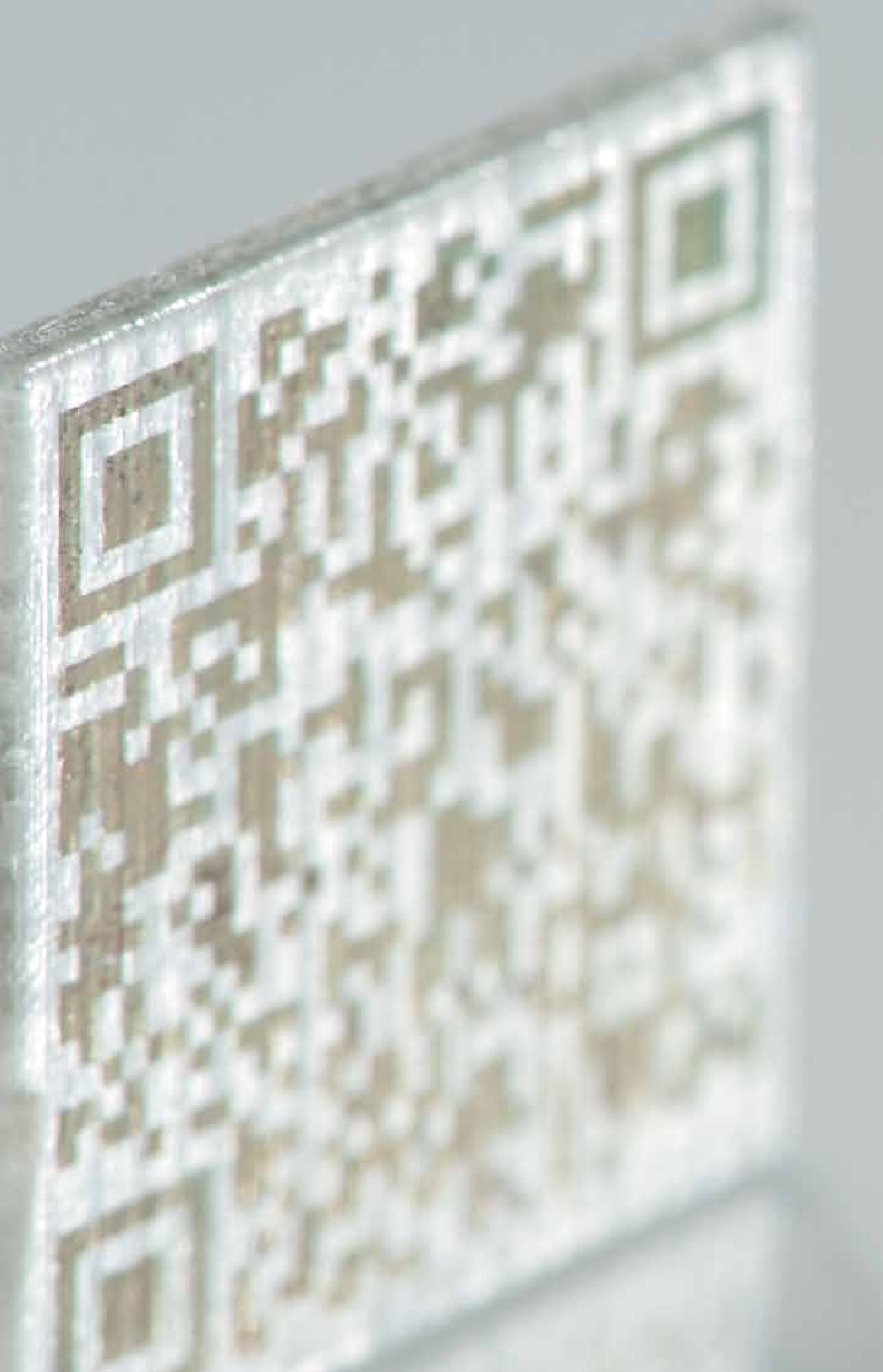

EPSRC Centre for Innovative Manufacturing in Additive Manufacturing
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An ink-jetted silver QR code on an ink-jetted polyacrylate substrate.

Vision

The EPSRC Centre for Innovative Manufacturing in Additive Manufacturing is the UK core of research activity on multifunctional Additive Manufacturing (AM) technology. The fundamental and translational research carried out within this world-class research hub will help shape the future national and international AM research agenda. Through deeply rooted technological expertise and research professionalism, the EPSRC Centre's activities will enable UK companies to achieve and maintain leadership in the commercial realisation of the next generation of AM technology.

Ink-jetted multi-material polyacrylate component with integrated flow channels.

The emergence of multifunctional Additive Manufacturing

Additive Manufacturing (AM) is the direct fabrication of end-use products and components employing additive layer manufacturing technologies. It enables the manufacture of geometrically complex, low to medium volume production components in a range of materials, with little, if any, fixed tooling or manual intervention beyond the initial product design.

As a manufacturing technology, AM enables a number of value chain configurations, such as personalised component part manufacture but also economic low volume production within high cost base economies. This innovative approach to manufacturing is now being embraced globally across industry sectors from high value aerospace and automotive manufacture to the creative and digital industries.

In the past, AM research has focused upon the production of single material, homogeneous structures (in polymers, metals and ceramics). In these applications AM is now adopted in many industries and considered an established manufacturing process.

The idea underpinning the formation of this EPSRC Centre is that the global research agenda will increasingly concentrate on next generation, multi-material active additive manufacturing processes, materials and design systems. These will allow applications that exhibit increased levels of functionality and radically new designs.

By contemporaneously depositing dissimilar materials, multifunctional AM will enable the production of novel, high-value, multi-material products demanded by the user community. Multifunctional AM platforms will effectively deliver entire working systems in a single process step. By allowing the embedding of functionalised structures, such as electrical circuitry, power sources, sensors and displays, the benefits inherent to the additive approach can be multiplied.

> "The additive approach could be extended to include conductive, optical or even biological circuitry. This would have the potential to unify printed functionality with Additive Manufacturing."
>
> Richard Hague
> EPSRC Centre Director

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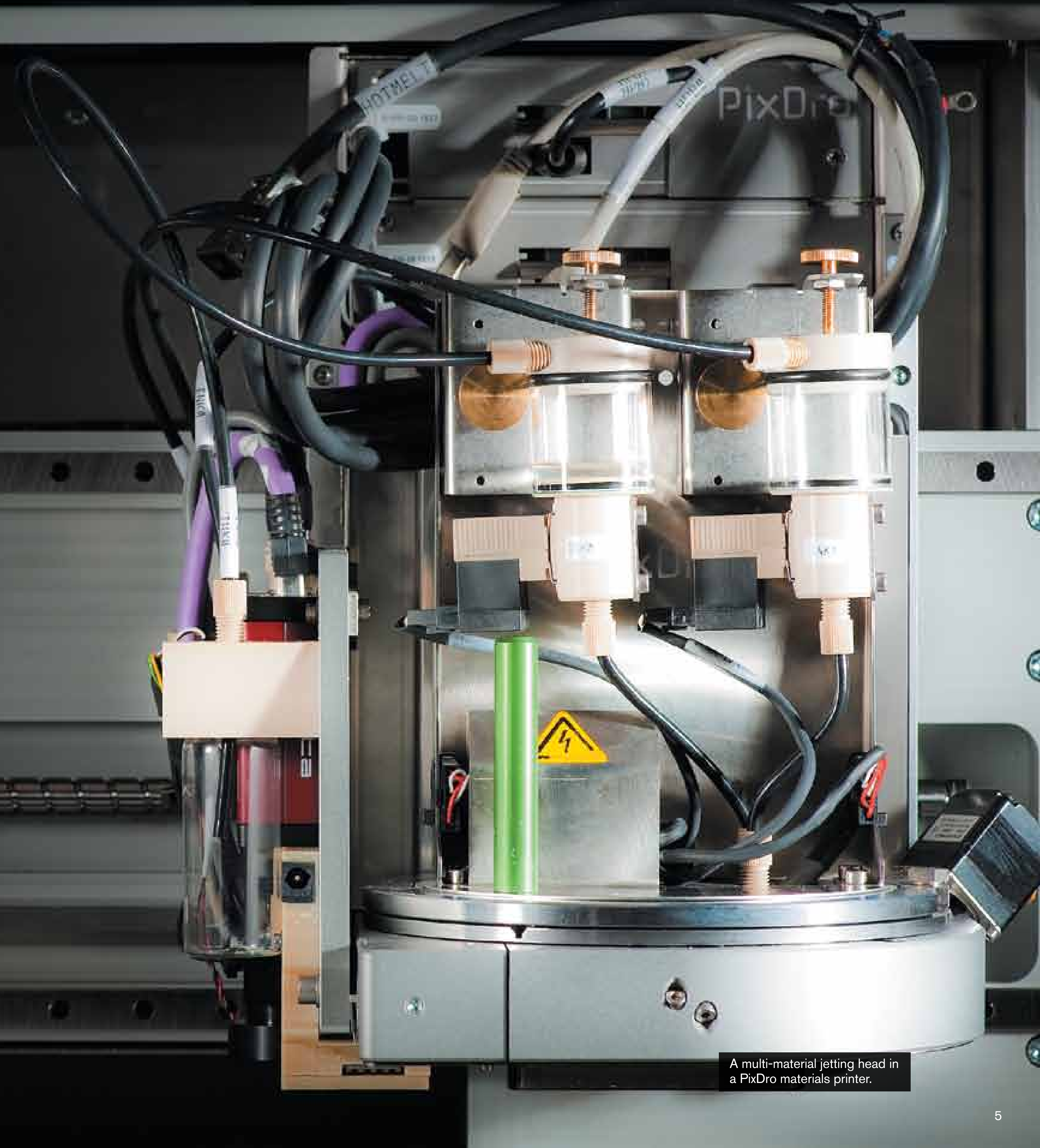
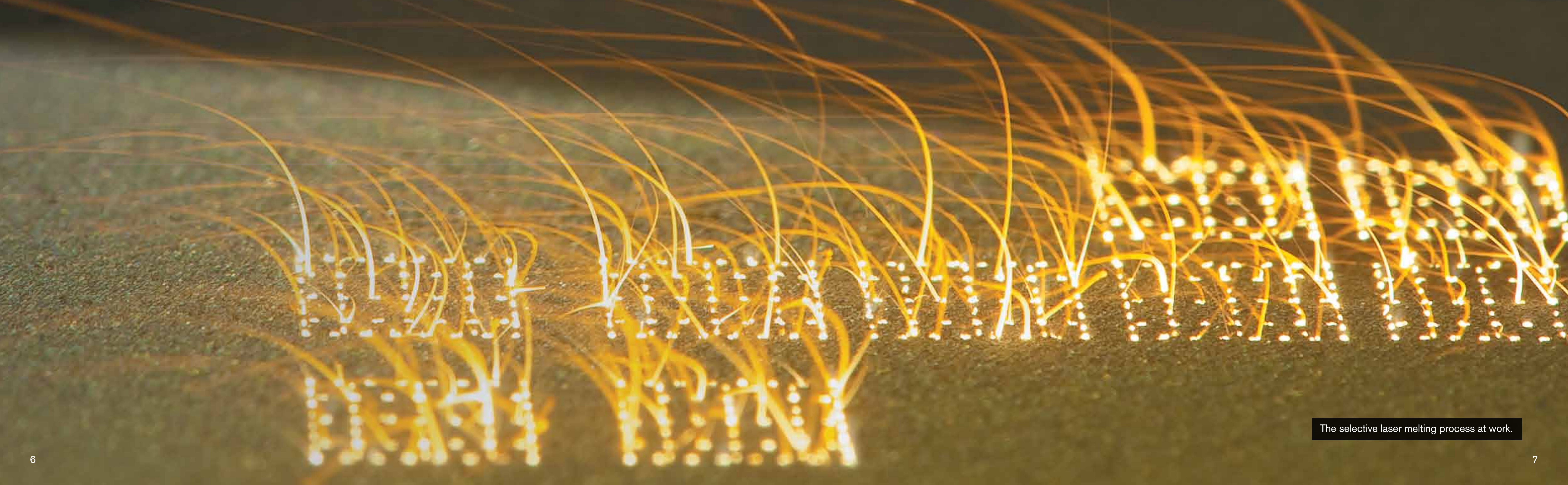


A multi-material jetting head in a PixDro materials printer.

Last year's highlights at a glance

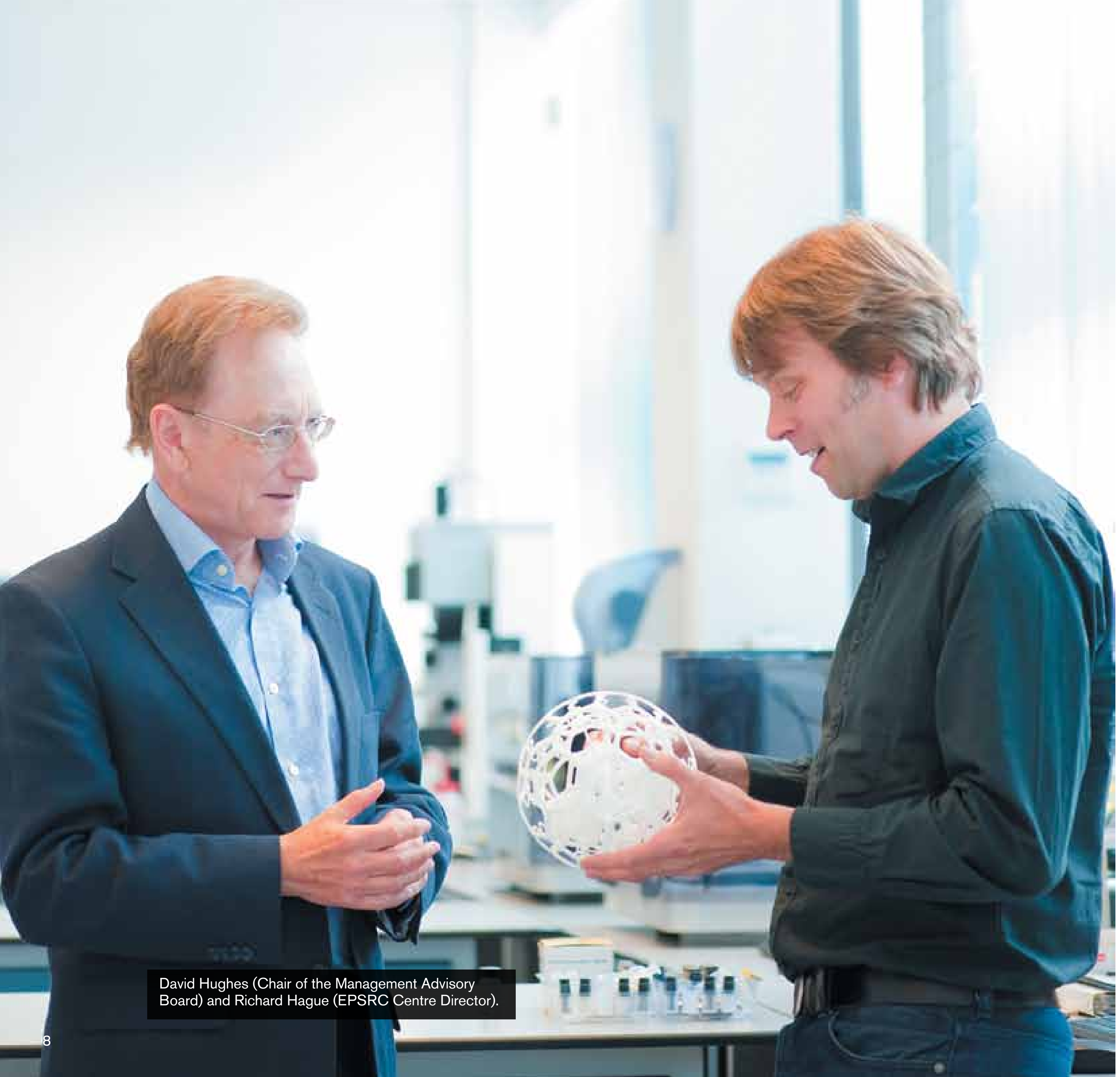
- Recruited eight new members of staff at the researcher level and four new PhD students.
- £3.48 million of additional grant funding awarded.
- £2.5 million laboratory facilities opened by Sir Andrew Witty, Chief Executive Officer of GlaxoSmithKline and Chancellor of The University of Nottingham in March 2013.
- Successful completion of our first cohort of summer interns from mixed disciplines.
- Organised the International Conference on Additive Manufacturing and 3D Printing in July 2013, attended by over 240 delegates from 20 countries.
- Funded two external research projects at the University of Birmingham and the University of Newcastle.
- Launch of the EPSRC Centre's outreach initiative in May 2013 under the ADD3D brand, available at www.add3d.co.uk
- Facilitation of a Multifunctional 3D Printing User Day in January 2013, attended by sixteen international industrialists.
- Prof Phill Dickens joined the team contributing to the EPSRC Centre at The University of Nottingham.
- Partnered with the London Science Museum in a high profile exhibition starting in October 2013.



The selective laser melting process at work.

Executive summary 2012–2013

Completing its second year of operation, this Annual Report provides an overview of progress within the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing. Continuing in a two-node configuration, this EPSRC Centre for Innovative Manufacturing is led from The University of Nottingham with Loughborough University as a partner.



David Hughes (Chair of the Management Advisory Board) and Richard Hague (EPSRC Centre Director).

We are delighted to present the Annual Report for 2012-2013, which covers a year of intense activity in our core research areas of multifunctional Additive Manufacturing (AM) processes, materials and design systems, and the down sizing of multifunctional AM. Further significant progress was achieved in the external research funded by our EPSRC Centre and through the National Centre for AM research, which has now received its brand identity as “ADD3D”.

The theme running through the second year of our EPSRC Centre’s operation is one of ‘growing new roots’: following the reconfiguration of the EPSRC Centre to a two-node structure in our first year, the majority of the EPSRC Centre’s team, including the leadership group, is now firmly established within The University of Nottingham. On an organisational level, the EPSRC Centre is now robustly rooted within the newly formed Additive Manufacturing and 3D Printing Research Group (3DPRG). Key physical facilities of the EPSRC Centre have become fully operational and embedded within the research group’s new laboratory at the Faculty of Engineering at The University of Nottingham.

The EPSRC Centre’s activities continue to be overseen by an experienced Management Advisory Board, which has convened three times over the second year of operation. To further integrate the activities of the Executive Board and the Investigator Group, a format of joint meetings was adopted and proved successful in ensuring Centre cohesion between the nodes. Our second year of operation has clearly demonstrated the commitment of the EPSRC Centre members to our ambitious research programme and our shared vision.

The strategic purpose of the EPSRC Centre’s initial flagship projects is to provide a bedrock of fundamental research and development activity relating to multifunctional AM. As the second year of progress in this research has shown, the key to achieving the required complementarity is close collaboration between all involved researchers and investigators. Developing the deposition processes, novel materials, process models and design capabilities for multifunctional AM in parallel is an inherently multidisciplinary undertaking and requires a high degree of refinement, considerable technological expertise and often also a certain appetite for risk.

Alongside the flagship projects, the EPSRC Centre is continuing to fund complementary external academic research. In the second year of operation, one external project has been completed – “Generation of Compound Microdrops” at the University of Birmingham. Moreover, the EPSRC Centre maintains industrial engagement through several projects hosted by the 3DPRG.

Two examples for such projects that give the EPSRC Centre significant industrial exposure are the Technology Strategy Board (TSB) funded ALSAM project investigating innovative additively deposited aluminium structures and the EU funded Diginova Project which explores the convergence between 2D digital printing technology and Additive Manufacturing.

The members of the EPSRC Centre have also been rather successful in securing additional research funding, being awarded grants worth in excess of £3.48 million over the course of the year. Notably, this includes a £2.7 million new equipment grant under the EPSRC’s Capital for Great Technologies programme and two grants under the Highly Innovative Technology Enablers in Aerospace 2 programme from the TSB, with a combined worth of £400k.

Illustrating The University of Nottingham’s commitment to our activity, we are also happy to report that the purpose built £2.5 million AM laboratory, into which the EPSRC Centre’s physical facilities are embedded, was formally opened by the University’s new Chancellor Sir Andrew Witty on his installation day. This ceremony was attended by numerous dignitaries and was a highlight of the academic year for all EPSRC Centre members and research group staff. We are also pleased to report that a number of new staff on the researcher levels have been recruited at Nottingham and Loughborough, and that our Centre has attracted a number of promising PhD students through a recruitment campaign running throughout the year. We are also delighted to announce that that Phill Dickens has decided to join us in Nottingham; he will maintain his role within the EPSRC Centre’s investigator team.

The National Centre for AM research has also had a busy year, establishing itself under its new brand identity ADD3D. The second year of operation started off with a presence at the impactful 3D Print Show in London in November 2012, leading to significant exposure to industry and media circles and the wider public. Beyond this, ADD3D has taken part in numerous outreach activities, including participation in the ISO standards committee, a fact finding mission to Taiwan and hosting a stand at the Cheltenham Science Festival 2013. As in its first year, the EPSRC Centre has organised the highly relevant International Conference on Additive Manufacturing with over 240 delegates in July 2013.

The rapid pace of technological development and the current high levels of public awareness continue to make our work towards novel AM processes and ground-breaking products exciting. Now that our initial programme of flagship research projects has progressed considerably, it is time to place our attention on realising the impact of this work. Therefore, we anticipate that the theme running through the coming year will be one of ‘making impact’.

We wish to use this opportunity to extend our gratitude to all those who are driving forward this EPSRC Centre with dedication, hard work and vision. We thank all researchers, our industrial collaborators and the members of the Management Advisory Board. Moreover, we thank EPSRC for their continued support and sponsorship.

Richard Hague, EPSRC Centre Director

EPSRC Centre management

Formed in October 2011, the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing has brought together excellence in scientific and engineering research with a strong connection and relevance to industrial reality. The research group that hosts the EPSRC Centre at The University of Nottingham, along with colleagues at Loughborough University, has a strong heritage in Additive Manufacturing research and is recognised as internationally leading this exciting area.

The EPSRC Centre's management passionately believes that to bring the disruptive technology of multifunctional AM to fruition will necessitate both substantial research and understanding at the fundamental level, and also the manipulation and refinement required to ensure successful deployment by industry.

David Hughes
Chair, Advisory Board

David is a Fellow of the Royal Academy of Engineering and a Chartered Director. He currently runs a management consultancy advising CEOs on innovation strategy. He is also a Director of the Quantum Innovation Centre in London and visiting Professor of Engineering Management at City University, London. In 2006, David completed a four year term with DTI as lead Government official developing and implementing Government policy on innovation and was responsible for the creation of the Technology Strategy Board. Prior to this appointment, David has had fifteen years senior level technology management experience within three major global businesses – Ford, Lucas and GEC-Marconi including management of multi-national project teams at Ford, Head of Engineering at Lucas and Technology Planning Director at GEC. David has a record of achieving successful exploitation of key corporate competencies to achieve commercial benefits.

Prof Richard Hague
Director

Richard is a Professor of Innovative Manufacturing in the Department of Mechanical, Materials and Manufacturing Engineering at The University of Nottingham, Head of the Additive Manufacturing and 3D-Printing Research Group (3DPRG) and Director of the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing. He has been working in the AM field for 20 years and has a background of leading and managing large multi-disciplinary, multi-partner research projects. Richard's research interests are focused on AM specific processes, materials and design systems across a wide spectrum of industrial sectors with a particular interest in design and design systems; current research programmes are focused on the design and production of multifunctional additively manufactured devices. Richard is also Chair of the International Conference on Additive Manufacturing & 3D Printing and active within the ASTM F42 AM Standards initiative.

Dr Chris Tuck
Deputy Director

Chris is an Associate Professor in The University of Nottingham's Faculty of Engineering. At the EPSRC Centre of Innovative Manufacturing in Additive Manufacturing Chris currently runs a number of projects based around the manufacture of multi-material and multifunctional inkjet printing, nano-scale Additive Manufacturing systems, and the development of metallic AM systems for use in industry. Chris joined the Additive Manufacturing (AM) Research Group at Loughborough University in 2003 as a Research Associate principally working on the supply and business effects of Additive Manufacturing on a number of DTI, EU FP6 and EPSRC funded projects. Chris is also an Executive Member of the ASTM F42 AM standards committee and a participant in the BSi initiative of AM standards development. Chris is a regular presenter at numerous international conferences, a panel member for EPSRC and a reviewer for international funding agencies.

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Prof Ian Ashcroft
The University of Nottingham

Ian Ashcroft is a Professor of Mechanics and Solids at The University of Nottingham. After being awarded D.Phil from Oxford University in 1991, Ian held various postdoctoral positions in UK and Australia and worked at DERA Farnborough until 2000. His research interests and activities include: design and analysis of composite joints for aerospace applications, modelling environmental degradation in bonded joints, lifetime prediction for joints subjected to variable amplitude fatigue, in-service monitoring of bonded joints, indentation of viscoelastic materials, and hybrid joining techniques.

Prof Phill Dickens
The University of Nottingham

Phill is a Professor of Manufacturing Technology at The University of Nottingham. Phill founded the Rapid Manufacturing Research Group in the early 1990's leading various research projects, supervising many successful PhD students. Phill has led international government missions, published widely, given a number of international keynote speeches and acts as a consultant to this industry. His research work has evolved through Rapid Prototyping and Rapid Tooling and is now concentrating on Additive Manufacturing processes.

Prof Russ Harris
Loughborough University

Russ is a Professor of Medical Engineering and Advanced Manufacturing at Loughborough University. He specialises in materials and manufacturing process research, conducted through research council and industrially sponsored projects. His research achievements have been recognised by a multitude of prize awards, peer reviewed publications, press features, and invited presentations. He has received grant funding awards as Principal Investigator from EPSRC, EC Framework Programme, and Department of Health. He has presented his research, by invitation, at the Royal Society and provided keynotes at many international conferences.

Prof Paul Conway
Loughborough University

Paul is a Professor of Manufacturing Processes at Loughborough University. Educated at the University of Ulster, Jordanstown and Loughborough University. He is interested in joining and assembly processes in micro-scale systems, packaging of intelligent sensor and electronics data processing into new environments, materials processing for electronics and photonics intensive products, micro materials analysis and modelling, Design for manufacture of electronics systems, and Healthcare production engineering.

Dr Ruth Goodridge
The University of Nottingham

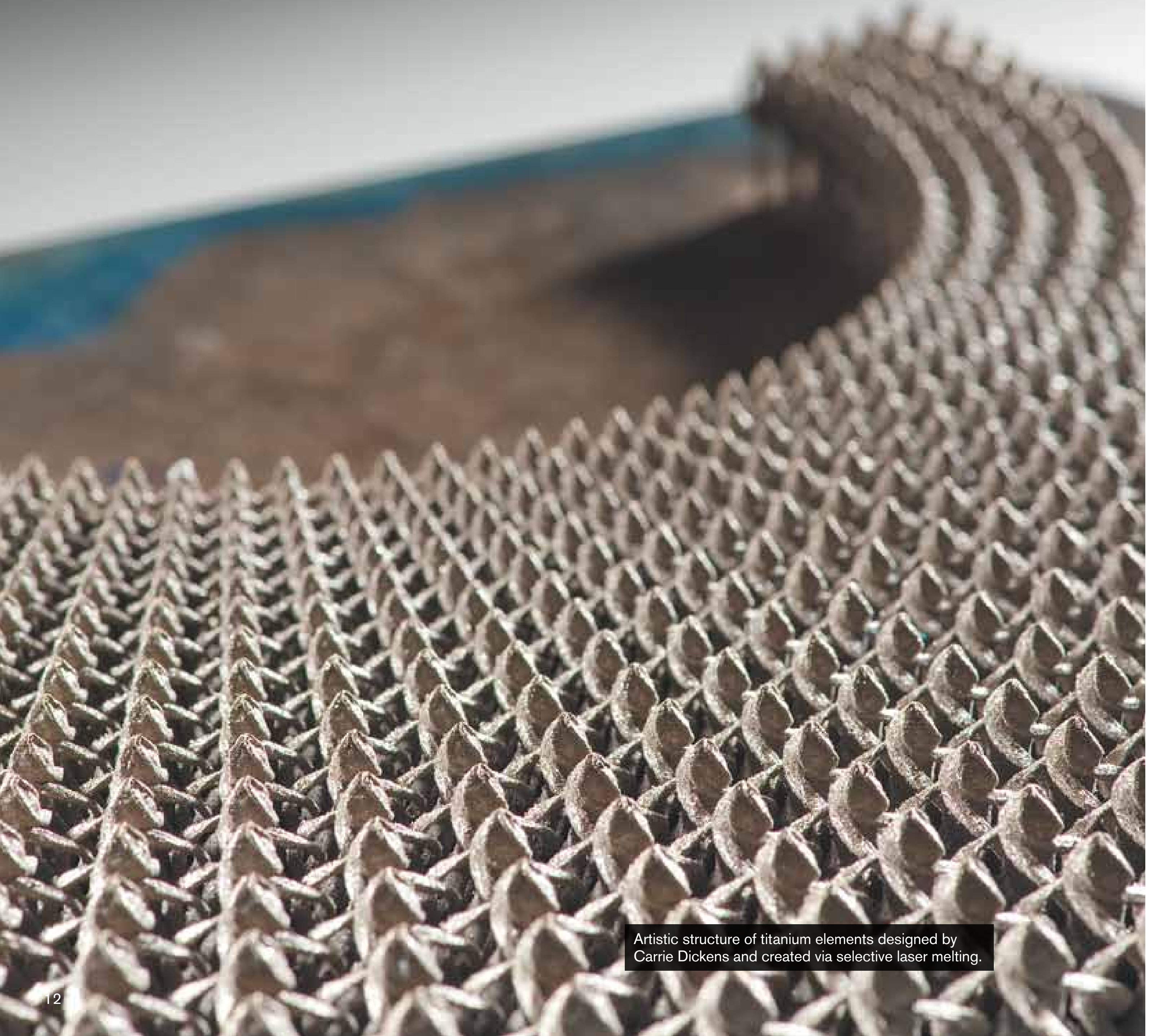
Ruth is a Lecturer in Additive Manufacturing & 3D Printing at The University of Nottingham. Upon completion of her PhD in 2004, Ruth was awarded a JSPS Fellowship to investigate new materials for laser sintering at NAIST, Japan. She joined the Additive Manufacturing Research Group at Loughborough University in 2006, where she continued her research into new materials for Additive Manufacturing/3D-Printing. In April 2012, she moved to The University of Nottingham as part of the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing.

Prof Ricky Wildman
The University of Nottingham

Ricky is a Professor of Multiphase Flow and Mechanics at the Faculty of Engineering, University of Nottingham. He has a background in Physics and Chemical Engineering, and is contributing his expertise in the areas of multiphase flow and mechanical modelling, stress analysis, transport phenomena and biomedical engineering. His main areas of interest are in the rheological characterisation and modelling of ink jetting materials and in the development of reactive jetting processes for 3D printing. Currently he is leading the connections to biological applications, working with colleagues in Pharmacy and Biology on the development of 3D printing for pharmaceutical delivery and the manufacture of drug delivery devices.

Key individuals

A broad range of expertise is flowing into the EPSRC Centre's flagship research in the areas of multifunctional additive processes, materials and design systems, and the scaling down of these processes to the micro/meso scale. These research activities and the EPSRC Centre's day-to-day operation are conducted in collaboration between the two partner institutions, The University of Nottingham and Loughborough University.



Artistic structure of titanium elements designed by Carrie Dickens and created via selective laser melting.

Dr Adedeji Aremu
Research Fellow
The University of Nottingham

Mrs Mirela Axinte
EPSRC Centre Administrator
The University of Nottingham

Dr Martin Baumers
EPSRC Centre Research Coordinator
The University of Nottingham

Dr David Brackett
Research Fellow
The University of Nottingham

Dr James Brennan-Craddock
Research Fellow
The University of Nottingham

Dr Xuesheng Chen
Research Fellow
The University of Nottingham

Mark East
Head Technician
The University of Nottingham

Dr Ross Friel
Lecturer
Loughborough University

Dr Ruth Goodridge
Lecturer
The University of Nottingham

Mark Hardy
Additive Manufacturing Technician
The University of Nottingham

Dr Qin Hu
Research Fellow
The University of Nottingham

Sophie Jones
ADD3D Website Coordinator
Econolyst Ltd.

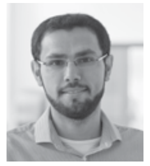
Dr Ji Li
Research Associate
Loughborough University

Bochuan Liu
Research Fellow
The University of Nottingham

Ian Maskery
Research Fellow
The University of Nottingham

Dr Ajit Panesar
Research Fellow
The University of Nottingham

Dr Phil Reeves
ADD3D Outreach Coordinator
Econolyst Ltd.



Dr Ehab Saleh
Research Fellow
The University of Nottingham

Dr Saeid Vafaei
Research Fellow
The University of Nottingham

Dr Hongyi Yang
Research Fellow
The University of Nottingham

PhD Students contributing to the EPSRC Centre
Meisam Abdi, Aziz Alghamdi, Meisam Askari, Amir Badiee, Sarah Everton (with MTC), Yinfeng He, Muhammad Farhan Khan, Adam Naas, Marco Simonelli, Craig Sturgess, Jayasheelan Vaithilingam, Stefan Ziegelmeier

A multimaterial component created with a photopolymer 3D printing process.

Projects in core theme 1:

Multifunctional additive processes, materials and design systems

To investigate delivery platforms & design systems for multifunctional additive manufacturing

Design Systems Development for Multifunctional Additive Manufacturing

The key to unlocking the user benefits of multifunctional AM lies in the design freedoms that the additive approach engenders; it is this immense design flexibility that gives the potential of multifunctional AM components and structures. Here, the major challenge is to produce a combinatorial design methodology that enables the design of devices / structures that are potentially topologically optimised with integral lattices (for light-weighting) and opto-electrical pathways (for embedded functionality). This combinatorial approach to design presents a radical advance in product design where weight, performance, functionality and aesthetics are combined in one part and manufactured as a single item.

This project is now in its first quarter of the second year, and progress is being made in several areas of the planned work, specifically in the placement and routing techniques, the efficient meshing techniques and the lattice generation approaches. With regards to placement and routing, a formal framework has been defined and the capability has been extended to 3D, which has subsequently been evaluated with some test cases.

Underpinning efficient meshing techniques for finite element analysis, the effect of the parameters of the quadtree decomposition technique for topology optimization has been investigated to understand the efficiency gain limits achievable. A journal paper is in preparation detailing these results. The remeshing capability has also been extended to 3D and coupled with a topology optimization algorithm to allow the tackling of practical problems and to allow integration with the 3D placement and routing techniques developed in parallel.

With regards to the lattice generation, progress has been made on two strands of the work. Firstly, the functionally graded generation approach based on dithering techniques has been investigated in more detail using different cell designs and a journal paper has been submitted for publication. Secondly, an alternative ‘net’ skin technique has been developed for the voxel tesselation approach to connect up hanging members. This has some advantages compared to previous ‘net’ skin techniques, and is in the process of being compared to identify which method suits which applications best. A journal paper detailing this method and the results is in preparation.

Project Team: Prof Richard Hague, Prof Ian Ashcroft, Prof Ricky Wildman, Dr David Brackett, Dr Ajit Panesar, Dr James Brennan-Craddock, Dr Adedeji Aremu

Additive Manufacture of Novel Multifunctional Metal Matrix Composites by Ultrasonic Consolidation

The aim of this project is to realise new multifunctional components by the freeform integration of electrical circuitry within dense metal components processed in the solid-state. This will allow the fabrication of novel engineered components that have been previously unobtainable as a result of the solid state nature of the Ultrasonic Consolidation (UC) process that will allow the integration of a wide variety of components due to the absence of elevated bulk temperatures. The printing of dielectric and conductive mediums, singularly and in unison, onto inter-laminar UC foil surfaces and their related surface geometry, and the effect on these by UC processing, is being investigated. Elements of the work have been conducted in collaboration with our EPSRC Centre partner, PEL.

Since the last reporting period we have been able to feed into and incorporate the new relevant jetting facilities as they became established at The University of Nottingham, conducted via our link into the JET project. Earlier work demonstrated the fundamental viability of electrical circuitry printing (comprising of dielectric/conductive/dielectric) onto UC surfaces. This has now been extended to incorporate the investigation of undertaking this by freeform methods. Other manufacturing methods for generating electrical pathways have been incorporated for comparison and benchmarking. Experimental results and discoveries are now informing the design of appropriate constructs to obtain electrical functionality of the circuitry. Surface geometry has been identified as a key consideration factor and is undergoing extensive analysis of the varying production stages.

An invited CIRP keynote on UC was presented by Prof Harris in April 2013 which included some of this project work. Dr Ross Friel has successfully obtained a lectureship in the Additive Manufacturing Group at Loughborough. He has been replaced by a new post-doctoral research associate from RWTH Aachen.

Project Team: Prof Russ Harris, Prof Phill Dickens, Prof Ian Ashcroft, Dr Ross Friel, Dr Chris Tuck, Dr Ji Li

Reactive Jetting of Engineering Materials

Creating new materials is vital for widening the applicability of 3D printing for end-use part production. A promising technique is reactive jetting, whereby instead of depositing polymers in the form of a solution, the monomer and a catalyst are deposited separately to induce the polymerisation in situ, usually post-deposition. Early work in this area investigated the production of nylon using a reactive jetting approach.

Current work is focussing on the deposition of a number of polymeric materials through reactive inkjet printing. This list includes polymethyl methacrylate (PMMA), polyimides, polyurethane and polysiloxanes which have significant engineering usage. Full characterisation of multi-layered deposition is required, since the degree of cure and therefore mechanical properties will be age dependent. In order to discover the degree of cure throughout manufactured samples, nano-indentation coupled with state of the art inverse analysis techniques has uncovered the temporospatial nature of the long term behaviour of ink-jetted materials.

In order to broaden the types of materials that are capable of 3D reactive jetting, new deposition methods have been employed to achieve an increase in the viscosity range of the materials that can be processed. Specifically, the use of Nordsen EFD Picodot deposition heads has resulted in a significant increase in the range of viscosities possible. This ranges from around 20 centipoise (cp) with conventional inkjet technologies to a maximum of 250,000 cp with the Picodot system. These deposition heads have been coupled with three dimensional translation stages to effectively develop a bespoke high-viscosity 3D printer. Work is on-going in order to identify techniques that will allow the deposition of a range of chemistries and viscosities, which will open up the vista of ink jet based 3D printing even further.

Project Team: Prof Ricky Wildman, Prof Phill Dickens, Prof Ian Ashcroft, Dr Chris Tuck, Dr Hongyi Yang

Area Sintering for Multifunctional Additive Manufacturing

Whilst flexible and providing significant design freedom, AM is dominated by technologies that are inherently slow; this has in many ways been the burden of AM since its transformation from Rapid Prototyping. The current market is predicated by point-by-point consolidation mechanisms, notably in the powder bed sector, dominated by technologies such as laser sintering and selective laser melting. The move to multifunctionality is not only a challenge to the printing of ‘active’ elements within an additive component but also to have systems that can consolidate the structural elements of a component with increased speed, resolution and repeatability. This project attempts to explore these criteria through the use of novel masking systems for full layer sintering of polymers.

Over the second year of the EPSRC Centre, significant progress has been made in the design, manufacture and installation of an Area Sintering test rig. Following a feasibility study, which detailed the possible avenues of research, a second study has been undertaken by a team of undergraduate students in the form of a summer internship. In the course of this work, suitable materials and additives were selected and tested for area sintering suitability. Novel polymers produced in collaboration with Prof Steve Howdle of The University of Nottingham’s Chemistry Department were included in the investigation. In addition to material characterisation, a prototype area sintering rig has been developed.

Project Team: Prof Richard Hague, Dr Chris Tuck, Dr Ruth Goodridge, Dr Helen Thomas, Jiaming Bai, Mark East, Hena Bagha, Jannik Lam, Nicholas Southon

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Developing Models that can Accurately Simulate the Jetting Process and the Post-Deposition Behaviour of Materials

Jetting is one of the integral AM techniques for the manufacture of the multifunctional devices that are the core deliverable of the EPSRC Centre. In order to understand, develop and optimise the jetting process it is essential to develop models of the process that can accurately simulate the delivery, deposition and post-deposition behaviour of materials. This requires the development of a suite of multiphysics modelling tools.

The modelling techniques required can be divided into two parts. Firstly, those required to model the material deposition process itself, which involve computational fluid dynamics and fluid-solid interactions. Secondly, those required to model the post deposition behaviour of the manufactured devices, which involve multiphysics finite element analysis and multi-scale mechanical modelling. This project is divided into two stages. The first stage involved state of the art reviews and pilot studies to identify future research directions. This led to combined modelling-experimental investigations into nano-fluid drop formation and the accurate finite element representation of jet printed dielectric and biodegradable polymers, which are ongoing. In the second stage, PhD projects in the two parts introduced above will be used to further develop the models and techniques required to model the deposition of materials via the jetting process and the post deposition behaviour of the manufactured parts. This work underpins and informs work carried out at the EPSRC Centre in the areas of jetting of conductive and dielectric elements and the jetting of biodegradable materials.

Project Team: Prof Ian Ashcroft, Prof Ricky Wildman, Dr Chris Tuck, Dr Xuesheng Chen, Dr Saeid Vafaei

Jetting of Conductive and Dielectric Elements in Additive Systems

The move to multifunctionality in AM is littered with technical challenges, from the accurate and reliable deposition of different materials together and their interaction, to the design of these components and how best to integrate different materials for a given function. What is also clear is that current AM technologies such as laser sintering or fused deposition modelling, whilst having some advantages have some clear drawbacks for the production of multi-material parts. These are namely, in their accuracy, resolution and the processing environment required during manufacture. In the first year of this project a strategic review of the available manufacturing routes open to multifunctional AM has been carried out, with significant promise being shown by drop-on-demand inkjet techniques for processing conductive, dielectric and other materials.

On this basis, new experimental material deposition test beds have been procured and adapted along with the necessary characterisation equipment to ensure material applicability to the jetting processes. In total three jetting systems have been commissioned, one based on the FujiFilm Dimatix DMP2831, and two based on the PixDro LP50 architecture. All these systems are capable of depositing particulate based inks (such as those filled with silver nanoparticles) and a host of other materials with various viscosities and surface tension.

The project is now concentrated on multi-material printing in 3D (especially in the vertical direction), as well as the integration of printing on to existing additively manufactured substrates, such as those produced by ultrasonic consolidation, or materials developed in the sister project, Reactive Jetting of Engineering Materials. Benchmarking of the printing systems, printing process and materials is a key milestone in the development of the project and a clear Design of Experiments has been formulated to ascertain best practice and the gap between capability and key performance indicators in industry.

Project Team: Dr Chris Tuck, Prof Ricky Wildman, Prof Ian Ashcroft, Prof Russ Harris, Prof Phill Dickens, Prof Richard Hague, Dr Bochuan Liu, Dr Ehab Saleh

Research Fellow Bochuan Liu.

Project in core theme 2:

Scaling down of additive processes

To investigate the methodologies for micro/nano scale multifunctional Additive Manufacturing

Nano-functionalised Optical Sensors (NANOS)

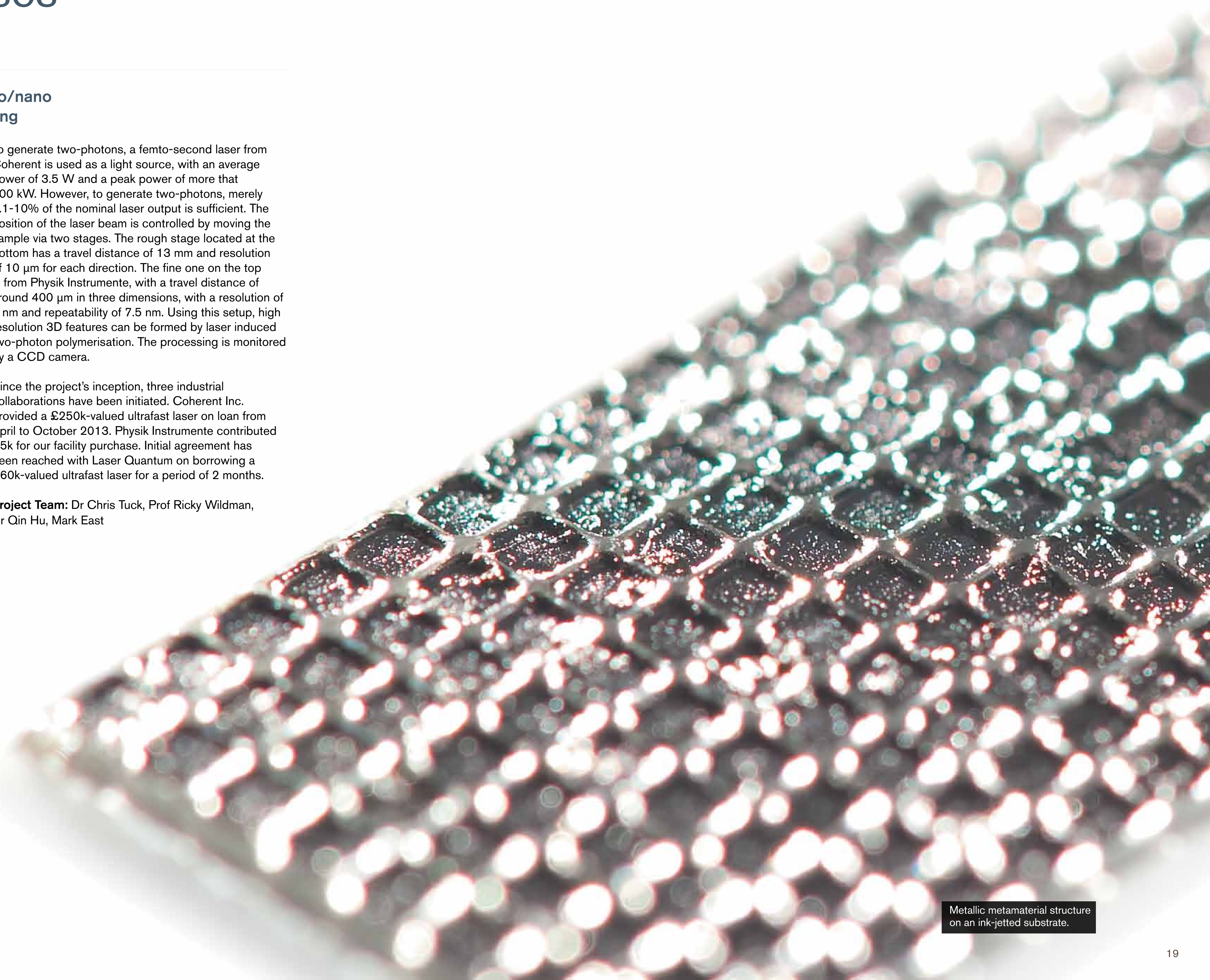
The requirements for future AM systems to produce complex multi-material and multifunctional components and products are reliant on two aspects, increased material capability and increased resolution. NANOS specifically targets these two aspects through the research and development of nano-resolution manufacturing systems, principally 2-photon lithography, that are capable of producing structures in the order of 100nm in materials that have relevance to the sensing applications. In addition, NANOS intends to utilise developments in optical tweezer technology to functionalise the structures made using 2-photon lithography. NANOS will enable the production of nanoscale structures in new materials that promote the development of new sensor systems.

Since the project's inception a number of strategic changes have been made to ensure the relevance of the project to industrial needs and to use the enhanced technical capability that is now available to the project team at The University of Nottingham. These changes in effect allow the project to focus on the manufacturing system and materials development, whilst utilising specific expertise in optical tweezer technology based in The University of Nottingham's School of Pharmacy.

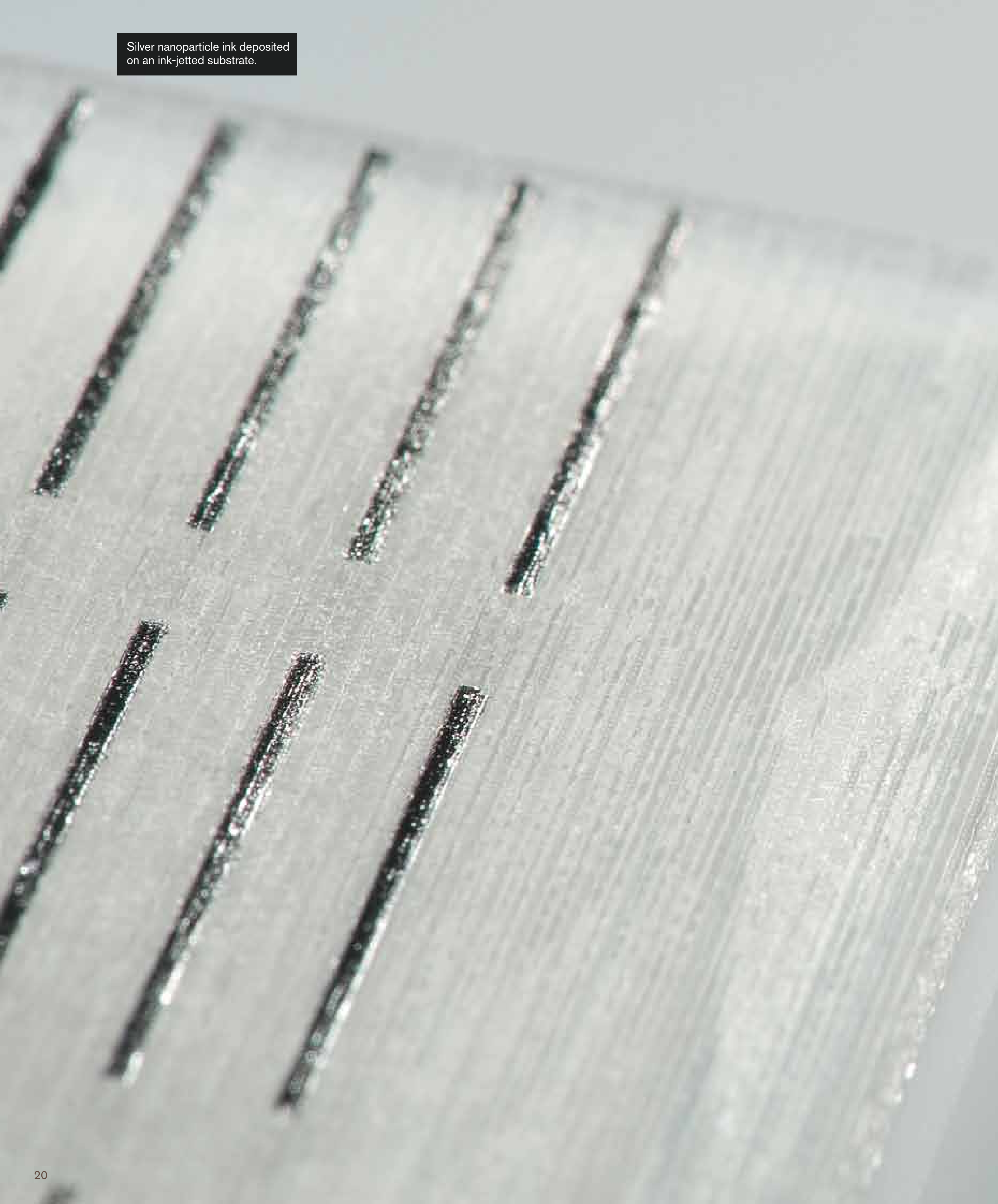
To generate two-photons, a femto-second laser from Coherent is used as a light source, with an average power of 3.5 W and a peak power of more that 300 kW. However, to generate two-photons, merely 0.1-10% of the nominal laser output is sufficient. The position of the laser beam is controlled by moving the sample via two stages. The rough stage located at the bottom has a travel distance of 13 mm and resolution of 10 µm for each direction. The fine one on the top is from Physik Instrumente, with a travel distance of around 400 µm in three dimensions, with a resolution of 1 nm and repeatability of 7.5 nm. Using this setup, high resolution 3D features can be formed by laser induced two-photon polymerisation. The processing is monitored by a CCD camera.

Since the project's inception, three industrial collaborations have been initiated. Coherent Inc. provided a £250k-valued ultrafast laser on loan from April to October 2013. Physik Instrumente contributed £5k for our facility purchase. Initial agreement has been reached with Laser Quantum on borrowing a £60k-valued ultrafast laser for a period of 2 months.

Project Team: Dr Chris Tuck, Prof Ricky Wildman, Dr Qin Hu, Mark East



Metallic metamaterial structure on an ink-jetted substrate.



Silver nanoparticle ink deposited on an ink-jetted substrate.

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External research funded by the EPSRC Centre

Generation of Compound Microdrops (University of Birmingham and University of Oxford)

This project forms part of a feasibility study for a full-scale cross-disciplinary research proposal to be submitted to the EPSRC jointly by the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing and the School of Mathematics at the University of Birmingham.

The goal is to develop an additive-manufacturing-based method of creating a new class of composite materials whose internal structure and physical properties are tailored to the specification of the user. This special functionality can be achieved by literally ‘building’ the material using, as building blocks, compound microdroplets which consist of core droplets of one material coated in another material. Successive deposition of such microdroplets simultaneously with the controlled solidification of the body they form creates a material with predetermined geometry and high concentration of the dispersed phase whose physical properties differ from the continuous matrix. This will allow the creation of composites with unique properties, for example, geometrically structured non-conducting and highly magnetic materials, which cannot be produced using any other method.

The study is aimed at the key element of the process: to determine the feasibility of forming compound microdrops with different materials for the core and the carrier drops. The project team developed a computational modelling tool that, based on the finite element method, is able to capture the initial stages in the formation of both a single and a compound microdrop. In the former case, validation against both previous numerical work as well as experimental analysis has confirmed that the current scheme is accurate and has a degree of flexibility exceeding previous codes. In contrast, for compound microdrop formation, the developed software is producing the very first predictions of the dynamics of this process.

Future grant-funded research will enable both the modelling and the computational techniques, whose power has been demonstrated in the feasibility study, to be extended to allow the topological change (the actual ‘break-up’ of the liquid thread) to be captured. By mapping the (8-dimensional) parameter space for compound microdrop formation in a fast, flexible and economic manner, the resulting software will be unique in its ability to guide the EPSRC Centre at Nottingham in the development of the next generation of complex additively manufactured products.

Project Team: Prof Yulii Shikhmurzaev, Jonathan Simmons (University of Birmingham) and Dr James Sprittles (University of Oxford). The project is overseen by Prof Ricky Wildman.

3D Printing of Biologically and Mechanically Functional Tissue Engineering Structures (University of Newcastle)

The overall aim of this project is to evaluate approaches to 3D printing of biologically functional structures allowing for a structural biopolymer to be generated in the same processing step. The process is expected to consist of at least three stages: firstly printing a layer of polymer or monomer, secondly crosslinking the polymer or monomer to create a polymer structure, and thirdly printing the cells, proteins and/or pharmacological agents (either together or separately) into the polymer structure, before repeating the steps to create the next layer of the 3D structure. The challenge is that the fabrication of the structural biopolymer should not at any stage expose the biological materials to environmental conditions which will inhibit or destroy their properties. This project explores a number of potential avenues to creating the mechanical structure and to protecting the cells and proteins from damage.

One way of addressing both the potential for damage within the printing process and limiting exposure to a damaging environment is to temporarily encapsulate growth factors and/or cells in a protective shell. The project will examine the use of polyelectrolyte layers and microbubble encapsulation to protect cells and proteins throughout the printing and material consolidation steps of the process.

Further, two approaches to creating a biopolymer structure will be investigated by the project: (i) printing monomers and then polymerising, and (ii) printing linear polymers and then subsequently cross-linking them to create a solid structure. In both cases there is a need to ensure that at neither the printing nor the polymerisation/cross-linking stages is there any loss of function for the biological elements of the structure.

Commencing in September 2013, the project will take forward the most promising material system and will optimise the printing of hard biopolymer structures in that material system, with basic mechanical property testing undertaken. When a consistent processing regime has been established, co-processing of the polymer structure with cells and growth factors will be undertaken to create a mechanically and biologically functionally gradient structure. This will be followed by an investigation of the viability of the processed cells.

Project Team: Prof Kenny Dalgarno, Dr Mark Birch, Dr David Fulton, Dr Matt German, Dr Matt Benning, and Dr Sarah Upson (University of Newcastle). The project is overseen by Prof Ricky Wildman and Dr Chris Tuck.

Advanced functional geometry created via polymeric laser sintering.

Complementary Additive Manufacturing research projects

The research groups contributing to the EPSRC Centre at The University of Nottingham and Loughborough University are also participating in a number of projects in close collaboration with industry, other funding agencies and partner institutions.

TSB Project – ALSAM

ALSAM (Aluminium Lattice Structures via Additive Manufacturing) is an on-going TSB project dedicated to creating strong, lightweight components from aluminium alloys. The utilisation of lattice structures in place of previously solid material, in addition to the well-known capabilities and design freedoms of additive manufacture, has led to an estimated minimum weight saving of 40 % per component.

Work on the ALSAM project is already underway and has begun to demonstrate how lattice structures can achieve the ultimate aims of weight saving and efficient design. Novel design tools are in development that will allow full computational analysis and optimisation of complex lattice structures – an invaluable part of the continuing work and relevant in all sectors of additive manufacture, not just selective laser melting (SLM). From the materials and processing standpoint, the chief aim is the successful production of high quality parts from industrially relevant aluminium alloys. Work in this area is progressing, with large parts of SLM parameter space being explored to find the optimum build parameters. Throughout the whole materials and process development process, and indeed throughout the whole project, close collaboration between the academic and industrial partners will be key to meeting ALSAM's goals.

Project Team: Dr Chris Tuck, Prof Richard Hague, Prof Ian Ashcroft, Prof Ricky Wildman, Prof Colin Garner (Loughborough University), Dr Yau Yau Tse (Loughborough University), Dr Adedeji Aremu, Ian Maskery

This project is funded by the Technology Strategy Board.

EU FP7 Project - Diginova

The emergence of major societal trends and consumer needs such as customisation, personalisation and on-demand fulfilment will impact the established manufacturing structure. Successful innovation in the digital age requires networked, flexible and open approaches. To an extent, the advent of 'digital fabrication' will enable innovations that bypass the established manufacturing structure. Diginova builds on the vision that consumers will be able to order, define or even (co)create and locally manufacture their own products in materials of their choice. They will no longer be bound by the mass-produced selection found in the stores today.

Diginova is helping to catalyse the new digital industrial revolution by providing a forum for relevant actors to define and promote advances in innovation for digital fabrication and its use with new materials. As a Seventh Framework funded Coordinated Support Action project, initiated by Océ Technologies, Diginova will broker collaboration between materials research and industrial representatives in helping to create what could be called "Industry 2.0".

The EPSRC Centre for Innovative Manufacturing at The University of Nottingham has been leading a work package in the Diginova project, successfully completing the project's mid-term review in May 2013. The subject of the performed work is an analysis of the technological and business drivers and the key technology challenges associated with Digital Fabrication. The work package deliverables are being achieved through an on-going series of workshops, seminars and reports.

Project Team: The Diginova project team is composed of a large number of industrial and academic partners. At The University of Nottingham, the project team includes Prof Richard Hague, Dr Chris Tuck and Dr Martin Baumers

This project is funded by the European Union.

3D Printed Vehicles

The objective of the 3D Printed Vehicles (3DPV) project is to contribute to the realisation of an additively manufactured remotely piloted or autonomously controlled rotorcraft. The motivation for this DSTL funded project lies in the opportunity to provide extra functionality and/or new supply chain thinking to this application.

Being carried out in the context of the EPSRC Centre, 3DPV explores how multi-material AM techniques can be employed to effectively 3D print such vehicles onsite, for example, in the theatre of operation, requiring minimal or no other parts and assembly.

Besides making use of a state-of-the art Additive Manufacturing research laboratory, the research activities have drawn on the EPSRC Centre's expertise in the area of structural optimisation, materials, and manufacturing processes.

Completed in June 2013, the project developed novel chassis designs incorporating embedded electronic pathways, proposed materials, energy storage devices and testing specifications, and produced various technology demonstrators.

Further, the project contained an element of research into the applications and future potential of such innovative unmanned rotorcraft.

Project Team: Dr Chris Tuck, Prof Richard Hague, Dr Helen Thomas, Dr Ajit Panesar, Dr Ehab Saleh, Dr Martin Baumers, Dr David Brackett

This project is funded by the DSTL Centre for Defence Enterprise.

Additive Manufacturing of Tailored Electromagnetic Materials

The Additive Manufacturing of Tailored Electromagentic Materials project proposes a novel electromagnetic (EM) application of Additive Manufacturing (AM). The dielectric properties of additively manufactured composites can be tailored to condition (i.e. reflect, deflect, transmit, focus, and absorb) electromagnetic waves.

AM composites offer better controlled properties than conventional random composites. When applied to material components, 3D printing of inks into sub-wavelength lattices at µm to mm scales will allow tailored control of composite dielectric properties. This can be achieved by varying the proportions of high and low loss materials deposited in the lattice.

Applications include advanced Low Observable (LO) materials, graded refractive index lens materials, decoys and tissue equivalent materials for health and safety checking.

Project Team: Dr Chris Tuck and Prof Richard Hague

This project is funded by the DSTL Centre for Defence Enterprise.

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EU FP7 Project - ArtiVasc 3D

ArtiVasc 3D is a collaborative European research project in the subject of Artificial Vascularised Scaffolds for 3D-tissue-regeneration.

The goal of the project is to develop fully vascularised bioartificial tissue that enables entire nutrition and metabolism based on new micro- and nano-scale manufacturing and functionalisation technologies. It is planned that this new bioartificial vascularised skin could be used in tissue replacement, as a transplant in trauma treatment, and as an innovative in-vitro skin equivalent for pharmaceutical, cosmetics or chemical substance testing, thereby possibly reducing or eliminating the need for relevant animal testing.

The research comprises of the study and modelling of vascular function, and the translation of this into biologically driven scaffold design. The production of these scaffolds, and their differing tiers of scale and complexity, are to be achieved by a hybrid additive manufacturing process of multi-photon polymerisation, jetting, and electro-spinning. Multiple levels of biological assessment and evaluation are being performed.

Loughborough University leads a work package in the project which concerns scaffold design and manufacturing process integration. Modelling and design of blood flow, oxygen delivery, and nutrient permeation are used to inform the efficient computer-aided-design of highly complex vascular branched scaffold structures. This is underpinned by Loughborough's prior work in Automated-Biological-Design-Integration (ABDI). Our manufacturing process research concerns the translation of resultant scaffold data and integrating with the hybrid additive manufacturing process.

To date the work has successfully demonstrated new parametrically driven design algorithms that provide high computational efficiency by avoiding Boolean operations. Multiple vascular design arrangements have now been generated by these construction algorithms which have been prototyped in optically transparent materials to allow flow analysis and particle tracing.

Project Team: The ArtiVasc 3D project team is composed of a large number of industrial and academic partners with a budget of €11 million. The project team at Loughborough University is led by Prof Russell Harris.

This project is funded by the European Union.

The multi-material 3D printing process at work.

National Centre outreach activities

After the start of the EPSRC Centre in 2011, funds were awarded to act as a National Centre for AM research. These funds are targeted at supporting the UK Additive Manufacturing research community in project initiation and to foster joint working. Funds are available to external organisations to support travel for research set-up meetings and also to allow the use of the EPSRC Centre's facilities to UK researchers. A budget has also been allocated to develop public facing initiatives such as a comprehensive website, branded as the ADD3D initiative (see www.add3d.co.uk), to promote UK research at trade shows and conferences, and also for the facilitation of regular networking and focus groups.

The specialist AM consultants at Econolyst continue to support the delivery of much of the National Centre agenda, including the setting up and management of a national AM research web portal, the development and provision of a presence at trade shows and a rolling program of events. Over the course of 2012-2013, a number of targeted outreach events and activities have been organised, engaging with the AM community, industry, the wider public, and influencing policy towards AM.

Engaging with the AM Community

International Conference

In July 2013 the EPSRC Centre once again hosted the International Conference on Additive Manufacturing and 3D Printing. The four day event was attended by over 240 delegates from 20 countries, including the UK, USA, Japan, South Africa and mainland Europe. 17 speakers were invited to attend the conference by the Centre Director and National Centre Coordinator, from organisations including IBM, Xaar, MIT, Stanmore Implants and the Cambridge Innovation & Knowledge Centre.

ASTM F42 and ISO Standards Committee

Directly following the International Conference, the EPSRC Centre played host to the American Standard's for Testing Materials (ASTM) F42 committee meeting, which was attended by almost fifty international delegates. The ASTM F42 is a global committee of industrialists and academics which meets twice per year to develop and ratify standards relating to Additive Manufacturing & 3D Printing. The ASTM meeting was then followed by a meeting of the ISO Additive Manufacturing standards group, for the first time allowing for joint ASTM & ISO interaction in the field of AM standards development.

ADD3D

In May 2013 we launched ADD3D, the new brand identity and web portal for the National Centre at www.add3d.co.uk. ADD3D includes a number of features aimed at promoting the UK additive manufacturing research community, including a searchable database of research capability and capacity at UK institutions focused on AM related research. ADD3D also includes case studies, an industry event diary, a jobs and recruitment section and a section dedicated to helping companies and academics identify research funding opportunities.

Engaging with Industry

Multifunctional 3DP user day

In January 2013 we hosted the first of our AM technology user days, which was focused on the subject of multifunctional 3D printing. This day long facilitated workshop based on the Meta-planning process was attended by sixteen international industrialists and five EPSRC Centre academics. Following an evening networking reception, a full day was then spent identifying potential commercial applications for multifunctional 3D printed products. From this a number of product concepts were developed in detail leading to a series of roadmaps, which were then used to validate the direction of research activity within both the EPSRC Centre and other research organisations within the UK.

Ingenia article

In June 2013, the EPSRC Centre Director, Prof Richard Hague and National Centre Coordinator, Dr Phil Reeves, wrote a detailed article published in the Royal Academy of Engineers Ingenia magazine. The article was focused on 'myth busting' and redressing the hype surrounding consumer and commercial 3D printing. The article considered the current state of the art in AM/3DP but also considered the direction of university research and the potential future impact that this may have on industry and society.

Direct company engagement

During 2012 and 2013 the National Centre for AM research and EPSRC Centre staff engaged with a wide range of new industrial contacts looking to understand and implement AM/3DP within their value chains. Contacts included companies such as HP, Samsung, Sharp, Boots, DSM and IBM. In some cases engagement included simply facilitating visits to University laboratories and meetings with academics and researchers. However, in other cases, companies engaged in more in-depth AM/3DP ideation sessions, workshops and training sessions delivered by National Centre staff.

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Engaging with the Wider Public

3D Print Show

In November 2012 the National Centre for AM research was delighted to exhibit at the world's first consumer and industry 3D Printshow in London. The 3D Printshow was attended by over 4,000 people, including industrialists, consumers, investors, students and journalists. The University of Nottingham and the National Centre were the only university invited to participate in this important event. The National Centre 'pavilion' was focused on a 3D printed interactive map of the UK, highlighting each of the UK universities engaged in AM/3DP research.

The London Science Museum support

During 2012 and 2013, the Centre Director and National Centre Coordinator have been assisting the London Science Museum in the detailed planning of a year-long exhibition, which will open on the 8th October 2013 dedicated to 3D Printing technologies and their impact on society. Through the Centre's extensive network, we have been helping the Science Museum to identify and secure funders from both industry and government. We have then worked alongside the Science Museum to develop content themes, identify cutting edge exhibits and helped to ensure that information panels and text are both informative and factually correct.

V&A panel session

On the 17th September 2013, the EPSRC Centre Director and the National Centre Coordinator participated in a panel session at the Victoria and Albert museum in London. The session was focused on 'the future of 3D printing' and how the technology could be applied to improve society, from the environment and healthcare to education and security.

Cheltenham Science Festival

In June 2013, the EPSRC Centre had the opportunity to exhibit in the Discovery Zone at the Cheltenham Science Festival. Dr Martin Baumers and Jayasheelan Vaithilingam introduced the opportunities that lie within AM to a very enthusiastic public audience and demonstrated the 3D printing process during the show using the EPSRC Centre's Makerbot Replicator 2 3D printer.

Influencing Strategy & Policy

Royal Academy of Engineering event

On the 17th May 2013 the EPSRC Centre Director and the National Centre Coordinator participated in a round table event at the Royal Academy of Engineering in London. The event was attended by the UK's leading industrial users of AM/3DP along with leading research group heads and funding bodies. The outcome from the event was a positioning paper which highlights the UK's current position, competences and future needs to maintain and grow the AM/3DP industry and science base.

Ningbo China fact finding mission

On the 7th June 2013, Prof Phill Dickens and the National Centre Coordinator, Dr Phil Reeves, participated in a conference and panel session at The University of Nottingham's Ningbo Campus in China. The conference was organised to develop linkages between the UK AM/3DP science base and companies and universities within China. The event also provided a platform to better understand recent Chinese government investment initiatives centred on AM/3DP, and to identify potential areas for future collaboration.

Community outreach at the opening ceremony for the new laboratory.

A state-of-the-art Additive Manufacturing laboratory

Demonstrating The University of Nottingham's commitment to the activity within our EPSRC Centre, we were honoured that the University's new Chancellor, Sir Andrew Witty, agreed to formally open our new purpose built £2 million AM laboratory on his installation day on 12th of March, 2013.

This ceremony was attended by numerous dignitaries and was a highlight of the academic year for all EPSRC Centre members and research group staff.

The EPSRC Centre's main research activities are taking place in this unique 320 square metre facility. It houses all equipment and additive machinery needed for the ambitious research in the EPSRC Centres flagship research projects in the fields of multifunctional additive processes, materials and design systems, and the scaling down of additive processes.

Specially laid out for our research activities, the laboratory incorporates three separate laboratory rooms with restricted access for confidential research, such as the work performed for Area Sintering for multifunctional Additive Manufacturing.

The range of equipment available for the research activities within the EPSRC Centre has expanded considerably over the last year. In terms of commercially deployed and experimental Additive Manufacturing, the new laboratory houses the following systems:

Renishaw
SLM250
Selective Laser Melting system

Stratasys
Objet 260 Connex
Multi-material 3D Printer

FujiFilm
Dimatix DMP2831
Materials printing system

EOS
EOSINT P 100 Formiga
Laser Sintering system (2x)

Realizer
SLM50
Selective Laser Melting system

PiXDRO
LP50
Research inkjet printer (2x)

Stratasys
FDM400mc
Fused Deposition Modelling system

BluePrinter
SHS 3D Printer
Selective Heat Sintering system

MakerBot
Replicator 2
Low-cost filament extrusion 3D printer (3x)

Ultimaker
3D Printer
Low-cost filament extrusion 3D printer

Velleman
K8200
Low-cost filament extrusion 3D printer

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The new laboratory also boasts an impressive array of analytic machinery and research equipment. This includes:

PerkinElmer
DSC8500
Differential Scanning Calorimeter

Malvern
Mastersizer 3000
Particle size analyser

Lenton
WN200
Natural convection oven (2x)

Krüss
DSA100
Drop shape analyser / contact angle analyser

Guyson International
Euroblast 4
Blast cleaning cabinet

Malvern
Kinexus pro
Research rheometer

Malvern
Bohlin Gemini 2
High temperature research rheometer

Coherent
Chameleon Ultra II
Femtosecond laser

PhD student Marco Simonelli operating a selective laser melting system.

Summer internships 2013

During the summer of 2013, a cohort of summer interns were supported by University funding to work within the EPSRC Centre at The University of Nottingham. Working in small teams and made up from a diverse range of undergraduates, the interns were tasked with developing and innovating in the field of novel additive processes and designs. The objective of the exercise was to highlight AM as a potential post graduate research topic to students, including those from non-engineering disciplines such as physics or chemistry.

Additive Manufacture of multimaterial energy supplies

3D printing of electronic elements is a key focus within the EPSRC Centre and consequently the ability to print energy supplies within the additive process would synergise progress within this field. Moreover, the dielectric properties of additively manufactured composites can be tailored to condition (i.e. reflect, deflect, transmit, focus, and absorb) electromagnetic waves in the radio frequency and microwave spectrums.

This summer project focused upon early stage research in the printing of multi-material energy supplies and meta-materials. This included a review of existing work in this field (including methods and materials), development of research strategy to investigate printing of energy supplies, practical lab based work, and testing and assessing selected materials.

Project internship team: John Campbell (Engineering), George Roberts (Physics), Chris Wiseall (Chemistry), Anthony Wood (Physics)

Progressing area sintering technology

The objective of the Area Sintering project which forms one of the EPSRC Centre's flagship research projects, is to explore a proof of concept for a novel sintering system based on a new masking principle (utilising IR as the radiant energy). To further progress and validate the original approach, it was decided to create a complementary project for summer interns. Work has concentrated on the investigation of the opportunities for future research and the exploitation of this technology.

It is thought that an area sintering system could provide a more cost efficient and productive alternative to existing systems of the powder bed fusion type, which normally incorporate a laser or electron beam for energy delivery. Building on previous research carried out in the EPSRC Centre, the project members developed and verified a new system design, including the manufacture of a test rig and the identification of a range of suitable materials.

Project internship team: Hena Bagha (Chemistry), Jannik Lam (Engineering), Nicholas Southon (Physics)

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Design of a multifunctional Additive Manufacturing showpiece

Many examples exist in the public domain that showcase the advantages of conventional AM parts. However, work within the EPSRC Centre is focussed upon developing multi-material/multifunctional parts. The Science Museum in London has provided the EPSRC Centre an opportunity to create a show piece for an exhibition (sponsored by the EPSRC Centre) giving an insight into the potential of multi-material Additive Manufacturing. This showpiece, depicted on the cover of this annual report, illustrated the EPSRC Centre's activities in terms of novel process development, optimisation based design systems and innovative materials.

To create this showpiece, the research project built on previous work performed on topology optimisation, latticing and routing. The researchers developed an impressive demonstrator for the capability of multi-material Additive Manufacturing.

Project internship team: Mary Amos (Engineering), Matthew Cardell-Williams (Engineering), Scott Wimhurst (Engineering)

3D Microstructures printing by hot melt ink

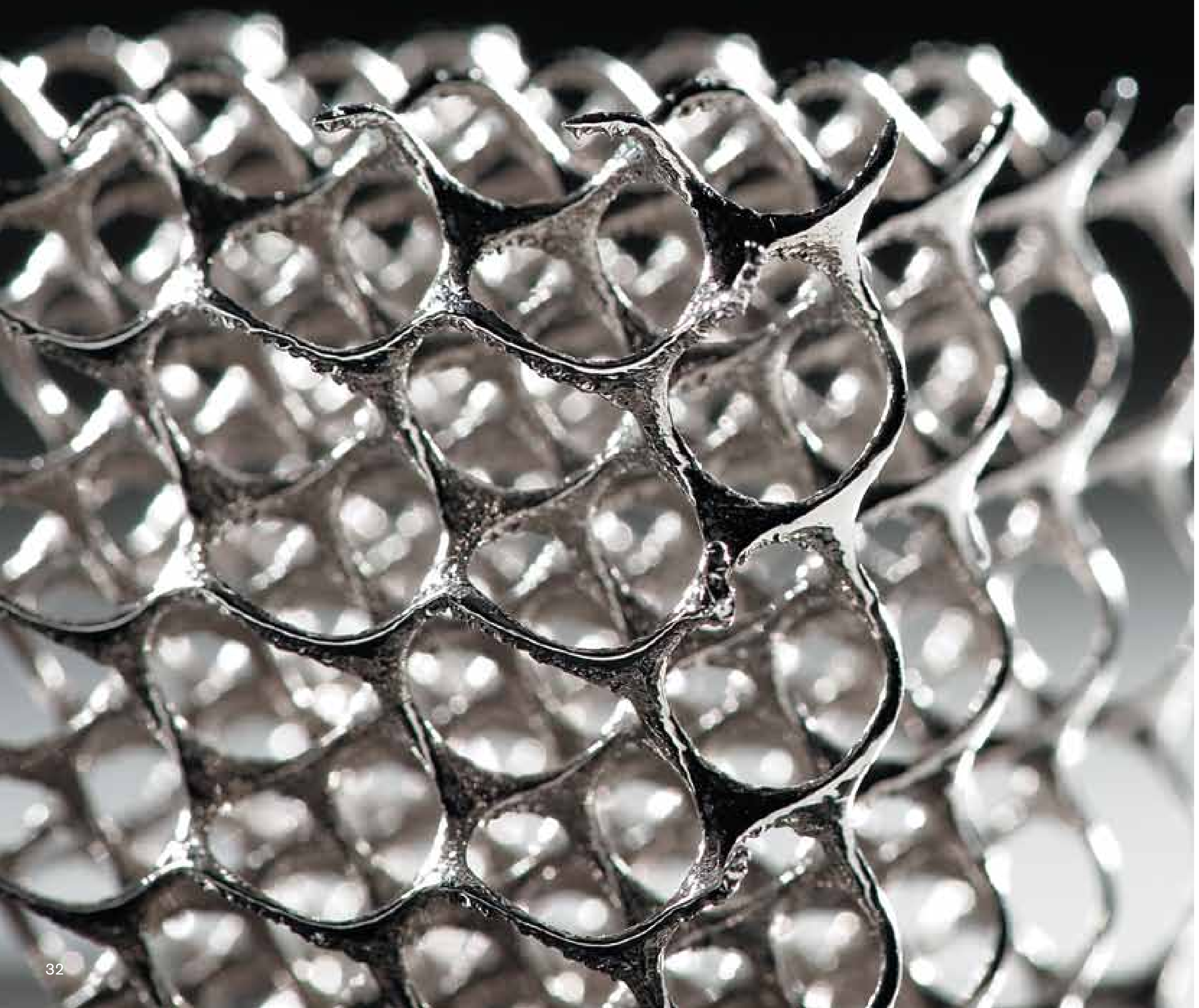
The 3D printing inkjet system in this project was based on digital printing technology and composed from the following components: a hot melt ink, a state-of-the-art print head and an LP50 desktop printer system.
Hot melt inkjet printing employs an ink which solidifies after impact on a substrate unlike water based inks which rely on evaporation of solvent for drying. Due to solidification during droplet spreading, it may be possible to control the final spread diameter and height of the droplet.

This project tested the feasibility of printing complex micro-scale geometries from the hot melt ink. In the context of the EPSRC Centre, this project contributed towards the design of a multi-head material jetting based system for use in manufacturing applications.

Project internship team: Hagit Gilon, supported by Dr James Brennan-Craddock

Silver tracks jetted onto a glass substrate.

Polished stainless steel lattice structure created via selective laser melting.



Further information

The EPSRC Centre Additive Manufacturing Collaborators

3TRPD
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BAE Systems
BMW
Boeing
Centi
Delcam
Delphi
DSTL
Econolyst
ENAS, Fraunhofer
EOS
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