The University Of Sheffield.

Materials & Manufacturing Research at The University of Sheffield

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Materials and Manufacturing research at The University of Sheffield spans a diverse range of disciplines with core activity in the Faculties of Engineering, Science and the Advanced Manufacturing Research Centre.

Within the Faculty of Engineering, materials and manufacturing research and development is conducted across a number of departments, notably Materials Science & Engineering, Mechanical Engineering, Chemical & Biological Engineering and Electrical & Electronic Engineering. The broad and interdisciplinary nature of our materials and manufacturing research is enriched by collaborations with science departments such as Chemistry and Physics & Astronomy delivering the highest quality fundamental research, whilst development at higher technology readiness levels includes the participation of the Advanced Manufacturing Research Centre with Boeing and the Nuclear Advanced Manufacturing Research Centre. Further translational research is underpinned by close collaborations between the Schools of Medicine and Dentistry and the more traditional engineering disciplines, allowing our researchers to exploit their understanding of underlying physical phenomena for the public good.

Long term investment and support by our sponsors, both private (e.g. Rolls-Royce, Boeing, GKN, Seagate, Tata Steel, Johnson Matthey) and public (RCUK, Technology Strategy Board, EU), is in excess of £20M/annum, which we devote to creating a better understanding of the fundamentals of material science and to resolve challenges in a number of domains, especially the aerospace, automotive, healthcare, information technology and energy sectors. This has led to the Faculty of Engineering in the University of Sheffield being ranked 2nd in the UK with overall research income over £50 million per annum and 1st in the UK for Technology Strategy Board and Knowledge Transfer Partnerships.

In the Faculty of Science, The Department of Chemistry is one of the largest departments in the University, whose international reputation for research was demonstrated by the last Research Assessment Exercise which rated 70% of its research output as “internationally excellent” or “world leading.” The Department of Physics & Astronomy is one of the UK’s top 10 physics and astronomy departments. In the most recent Research Assessment Exercise, 90% of research in this department was considered to be of international quality.

A global exemplar for translational research and delivery to industry, the Advanced Manufacturing Research Centre has grown from an initial collaboration with Boeing and now boasts over 70 industrial members who benefit from the manufacturing and engineering know-how that has been developed over the past decade, expertise that can now be accessed via the High Value Manufacturing Catapult.

Light weight titanium undercarriage

The Department of Materials Science and Engineering is working with industry on the use of duplex environmentally-friendly plasma-based treatments to improve performance in terms of reduced wear, friction and corrosion, and to also reduce aircraft weight.

Cambridge-based advanced coatings company Tecvac worked with Leonardo Centre academics, bearing manufacturer NMB-Minebea and Airbus UK to develop a tough and hard nanocomposite coating on diffusion-treated titanium bearings that will significantly reduce the weight of new Airbus aircraft, reducing fuel consumption and therefore, CO_2 emissions.

The aim was to replace steel/bronze pintle (and other) bearings on A350/A380 aircraft with a surface-engineered titanium-on-titanium alternative. There are typically over 2,500 steel bearings on each Airbus aircraft, so replacing the existing bearing materials with Ti-6Al-4V halves the weight and reduces CO_2 emissions. The tribological performance of the titanium alloy was drastically improved using the 'duplex' plasma diffusion and coating treatment.

The market for this new technology is potentially very large. Manufacturers around the world are eager to reduce the weight of aeroplanes in order to increase fuel efficiency and conform to impending emissions standards. Airbus has already placed a £19m order for one type of wing structure bearing attaching the main landing gear for the new Airbus A350.

A smarter hip joint (SMART-HIP)

Leonardo Centre academics have been working on developing new enhanced wear resistant coating to increase implant longevity in Metal on Metal (MoM) hip prostheses and future applications on trunnions and tapers to prevent fretting and corrosion.

The University of Sheffield worked together with other universities, Cambridge based coating specialist, Tecvac Ltd and leading UK hip prosthesis manufacturer, Corin Ltd, on a project known as 'SMART-HIP'. New PVD silver bearing coatings were developed to protect against post-operative infection and provide a barrier to minimise metal ion release. Optimised coatings reduced the release of cobalt metal ions, implicated in chronic tissue inflammation by 99%. The inherent wear resistant, anti-leaching and anti-microbial benefits have the potential to substantially reduce the life time cost of hip replacement implants to the NHS and health organisations worldwide, while providing a much improved patient experience.

Overall the SMART-HIP project demonstrated the potential of the new family of coatings to reduce initial post-operative implant wear by a factor of 4 and eventually to double implant service life. The new coatings, which contain both chromium nitride and silver in the outer layer of the coatings provided the planned and self-sustaining release of beneficial silver anti-microbial particles. This gives both self-lubrication of the bearing surfaces and short and long term protection against post-operative infections.

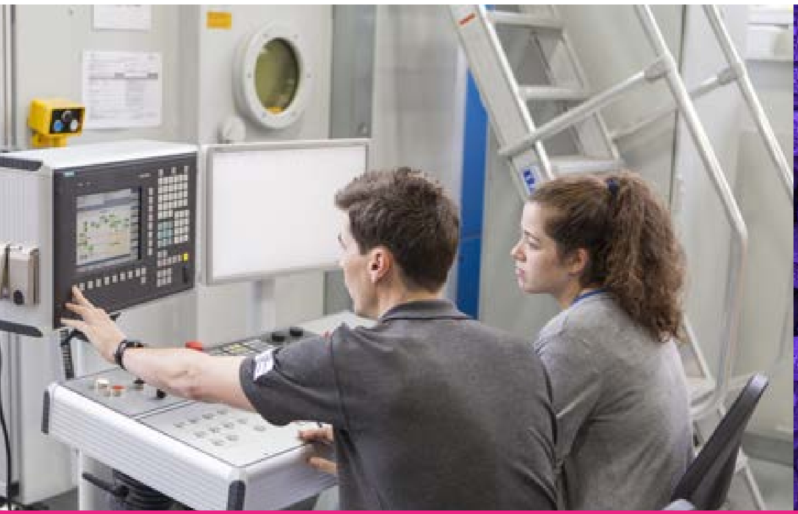
The Mercury Centre

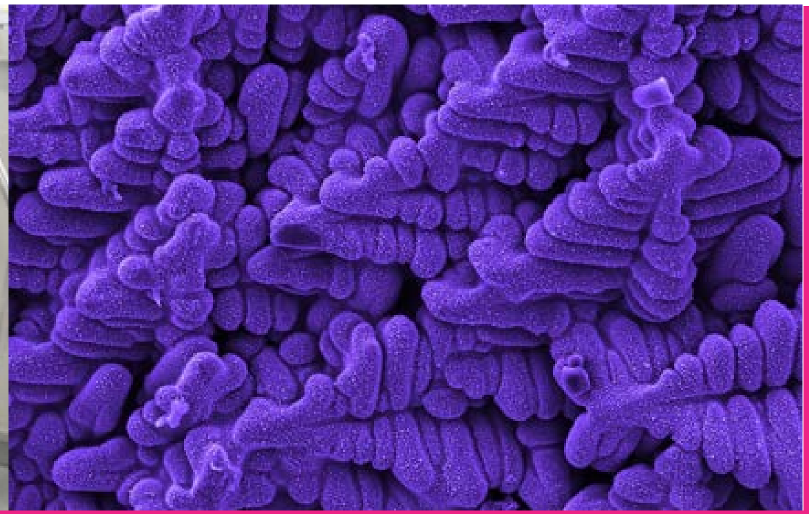
The Mercury Centre for innovative materials and manufacturing is a £12m research centre, part financed by the European Regional Development Fund, which is boosting the manufacturing industry by providing a hub of expertise in materials development and additive manufacturing.

We provide industry with access to our cutting edge manufacturing facilities and work with manufacturers to encourage the adoption of this advanced manufacturing technology into the supply chain for the development of innovative products and manufacturing processes.

Our facilities offer sophisticated development and testing solutions which bring together advanced design, manufacturing and analysis services:

- Computer modelling of products, materials and manufacturing processes to optimise performance prior to production
- Rapid manufacture of components using the latest additive manufacturing technologies
- Materials development and characterisation to improve process and product performance





METALLURGY

3D printing automotive parts in titanium

Metalysis is a high value metal powder business based in Rotherham, which owns the global rights to a transformational platform technology capable of producing a wide range of innovative metals and alloys. Metalysis' process can produce metals at a lower cost and with a smaller environmental footprint than traditional processes.

The Mercury Centre has worked with Metalysis on a number of materials based projects in the past and they came to us when they wanted to test their new product. They have developed a new way of producing lower-cost titanium powder, which is radically cheaper and environmentally benign compared with existing methods. They wanted to assess the feasibility of using this powder for additive manufacturing and worked with the Mercury Centre to produce parts including turbocharger impellers and aerofoil section.

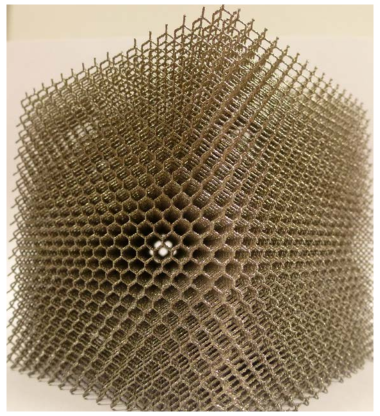
The combination of the new, lower cost titanium powder with the cost benefits brought by additive manufacturing through reducing waste associated with machining components from solid billets brings the exciting possibility of greater use of titanium in components across the automotive, aerospace and defence industries. Titanium makes an attractive alternative to standard automotive materials due to its strength-to-weight ratios and corrosion resistance.

Novel manufacturing of metal parts

Within the Department of Materials Science and Engineering at the University of Sheffield there is a range of activity on novel and disruptive metal manufacturing processes.

Continuous extrusion forming
A recent development has led to a novel disruptive technology capable of manufacturing continuously rolled or extruded titanium parts. Using low cost titanium powder provided by Metalysis. researchers have managed to roll sheet (left) and extrude wire and, via diffusion bonding of the particles, to produce parts in three steps whose properties compete with forged components that have been thermo-mechanically processed in excess of 30 times.

Metal Foams
These are materials with a random porous structure, like a foam or a sponge. They can still have many different structures. These materials find uses in a number of areas, from protection (they absorb a significant amount of energy on crushing) to functional applications, such as heat exchangers, where the conductivity of the metal and the high surface area offer advantages. At Sheffield we are examining a new generation of these materials where the porous structure is controlled to be non-uniform in shape or to change with location in the sample, to maximise the heat exchanger performance.



Metal Lattices
With advanced manufacturing techniques it is now possible to produce these materials with finer size in a more cost-effective way. The vast control over the structure means that highly mechanically efficient structures can be made, or ones precisely tailored for certain purposes; we have looked at improving impact and blast resistance. The exact selection of shape and properties also makes these materials interesting for implants into the body, and we have been testing the response of cells to the material, and how this can be improved.

Feasibility of vitrification of simulant intermediate level nuclear waste

The UK has been engaged in the development of civil nuclear power for more than 50 years and has a commitment to dispose of the historic legacy of waste generated over this time. Plutonium Contaminated Material (PCM) is a special type of intermediate level waste, associated with plutonium production, and includes filters, used personal protective equipment and decommissioning waste such as metals and masonry. It is a significant fraction of the UK's radioactive waste inventory and requires immobilisation prior to disposal.

The current treatment method for non-compactable plutonium contaminated wastes involves cement encapsulation, a process which typically increases the overall volume. The team from the Immobilisation Science Laboratory firstly demonstrated the feasibility of the vitrification approach – turning the waste material into glass – by producing a suite of prototype demonstration materials. Of the prototype materials identified, blast furnace slag, a commonly available by-product from steel production, was preferred as it performed well against the agreed criteria such as the presence of residual waste material.

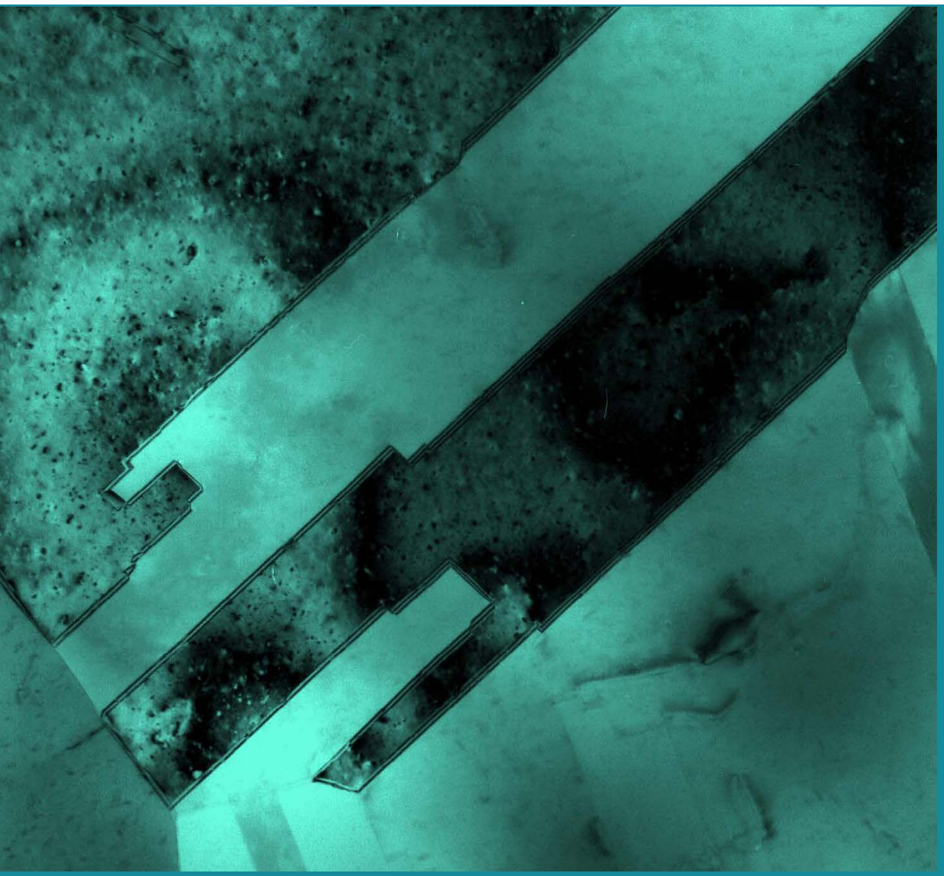
This project has successfully demonstrated the feasibility of immobilising simulant PCMs within a passively safe material – blast furnace slag – by a high temperature process prior to interim storage and disposal. This innovative use of blast furnace slag could potentially save storage space and costs due to the achieved volume reductions of between 65-95%.

CERAMICS

Functional ceramics for GPS antennae

Ceramics have always been a major part of the Department of Materials Science and Engineering's research portfolio, with a particular emphasis on adding functionality to existing or novel materials. An example of this work is seen in the development of prototype multilayer, multiband antenna for global positioning systems.

This antenna is the outcome of a Knowledge Transfer Partnership between Materials Science & Engineering with Sarantel Ltd (now part of Maruwa) who manufacture high precision ultra small GPS antennas. The KTP resulted in the patenting of a new multilayer version of Sarantel's GeoHelix® antenna fabricated by deposition using electrophoresis of an intermediate polymer layer between two Cu helical metal strips mounted on the surface of a cylindrical ceramic puck. The new design gives an increase in antenna efficiency and also creates a multiband response which could be engineered to access any/all of the orbiting satellite positioning networks. The invention opens up the possibility of the development of a single antenna that could work on all satellite networks with extreme accuracy even with dense, high-rise urban environments.



"a multiband response which could be engineered to access any/all of the orbiting satellite positioning networks"

Li-ion batteries

Electric vehicles (EVs) and hybrid electric vehicles (HEVs) have the potential to reduce CO_2 arising from transport by using more renewable energy derived electricity. To achieve this, energy storage devices with high energy density, charge/discharge rates and service life are necessary, along with a high degree of safety. Next-generation lithium-ion batteries could be used not only to power 3C portable products but also contribute to meeting global demands for advanced energy storage systems in terms of grid stabilisation, renewable energy source integration (solar and wind power), transportation, and military applications.

The key research targets for electrode materials for lithium-ion batteries focus on the increase of energy and power density as well as achieving a low-cost manufacture process. University of Sheffield researchers are creating a platform for lithium-ion battery R&D including new potential materials synthesis (cathode and anode) such as the 3.5 V $Li_2FeP_2O_7$ cathode material below, advanced characterisation techniques, cell device development, and module system analysis in EV for battery applications.

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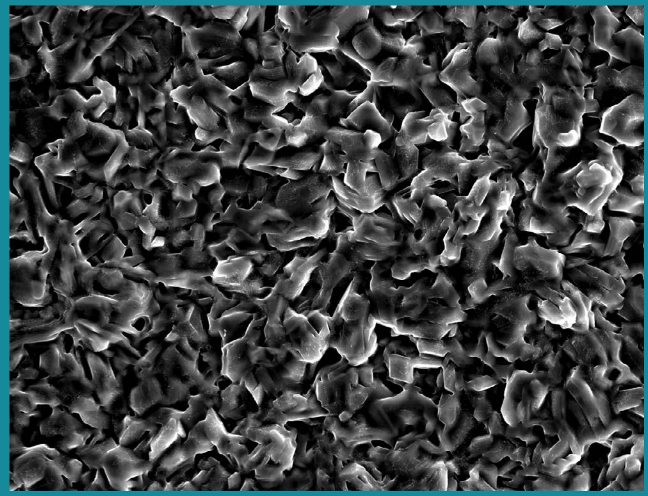
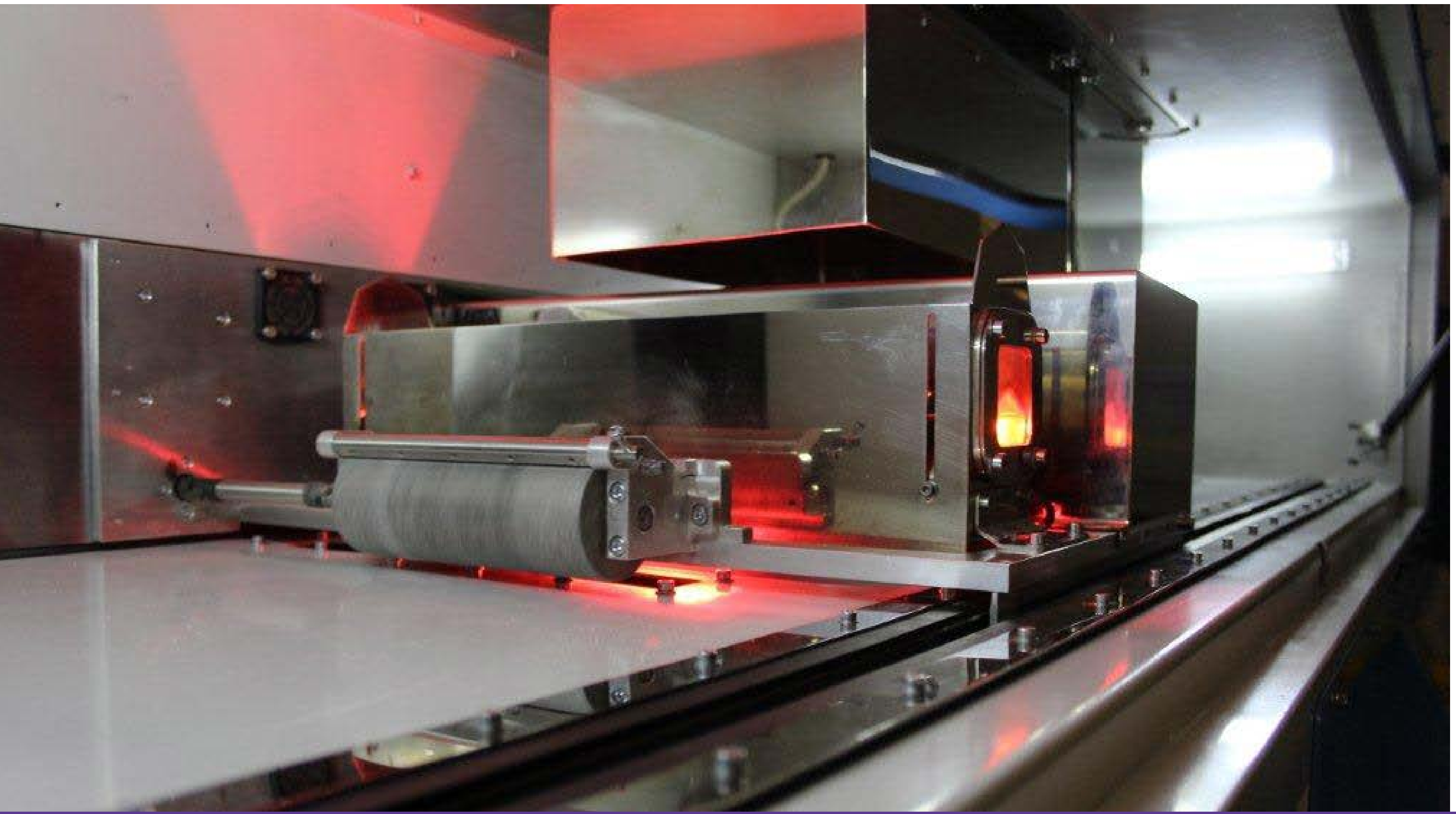


Industrial implementation of additive manufacturing through advanced polymer sintering (I AM APS)

A three year, £1.5M project funded by The Technology Strategy board and industry is developing supply chain and full scale production capabilities for novel additive manufacturing technologies based on laser sintering (LS) and high speed sintering (HSS) for application in three major industrial sectors within the UK economy. These include Fast Moving Consumer Goods (Unilever), Aerospace (BAE Systems) and Space (Cobham Technical Services). The project is further supported by product design speciality (Sebastian Conran Associates) and inkjet solution providers (Xaar).

University of Sheffield spin-out company Farapack Polymers is working with the industry partners and with Loughborough University, who own the high speed sintering patents, to develop and exploit the manufacturing process. The project will deliver a validated supply chain with suitable demonstrator products in multiple industry sectors and an appropriate exploitation plan for effective commercialisation of LS and HSS.

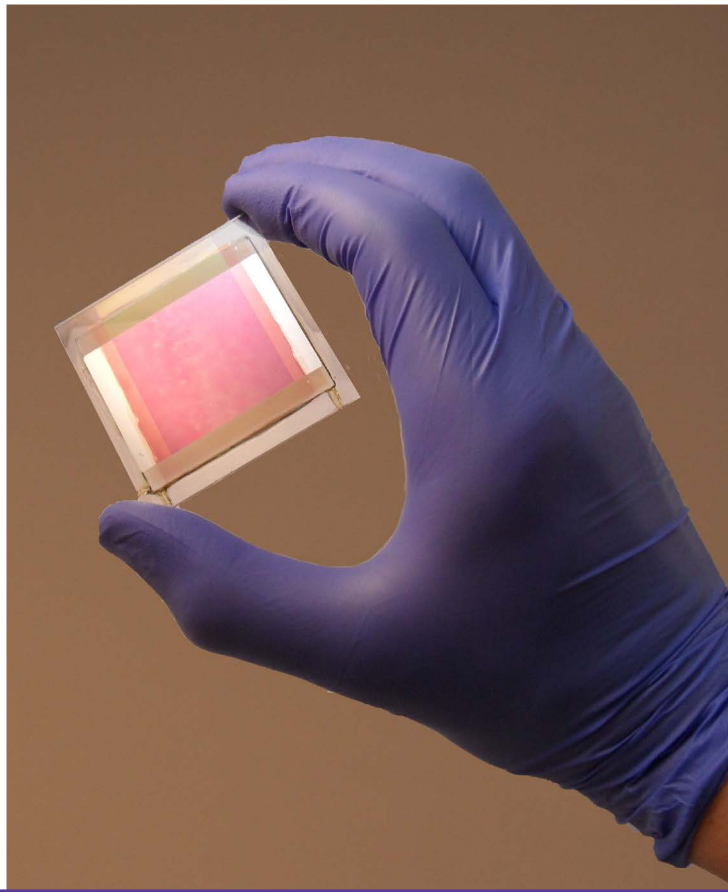


Spray coated PV

Experts from the University of Sheffield's Department of Physics and Astronomy and the University of Cambridge have created a method of spray-coating a photovoltaic active layer by an air based process – similar to spraying regular paint from a can – to develop a cheaper technique which can be mass produced. Most solar cells are manufactured using special energy intensive tools and using materials like silicon that themselves contain large amounts of embodied energy. Plastic, by comparison, requires much less energy to make. By spray-coating a plastic layer in air the team hope the overall energy used to make a solar cell can be significantly reduced. Encouragingly, spray-coated solar cells operate as efficiently as solar cells fabricated by non-scalable deposition techniques.

Professor David Lidzey from the University of Sheffield said "Spray coating is currently used to apply paint to cars and in graphic printing. We have shown that it can also be used to make solar cells using specially designed plastic semiconductors. Maybe in the future surfaces on buildings and even car roofs will routinely generate electricity with these materials. The goal is to reduce the amount of energy and money required to make a solar cell. This means that we need solar cell materials that have low embodied energy, but we also need manufacturing processes that are efficient, reliable and consume less energy."

> *"Maybe in the future surfaces on buildings and even car roofs will routinely generate electricity with these materials"*



Composite materials

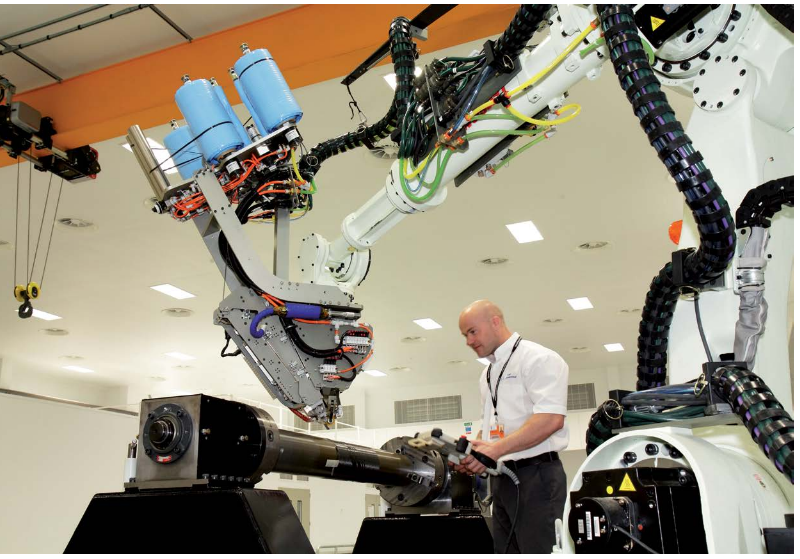
Composites at Sheffield fuses the academic rigour of the Composite Systems Innovation Centre with the manufacturing and industrial expertise of the AMRC with Boeing. It brings together more than 60 researchers, engineers and academic staff developing composite materials and systems for advanced structures, multifunctional technologies and environmentally friendly products and systems.

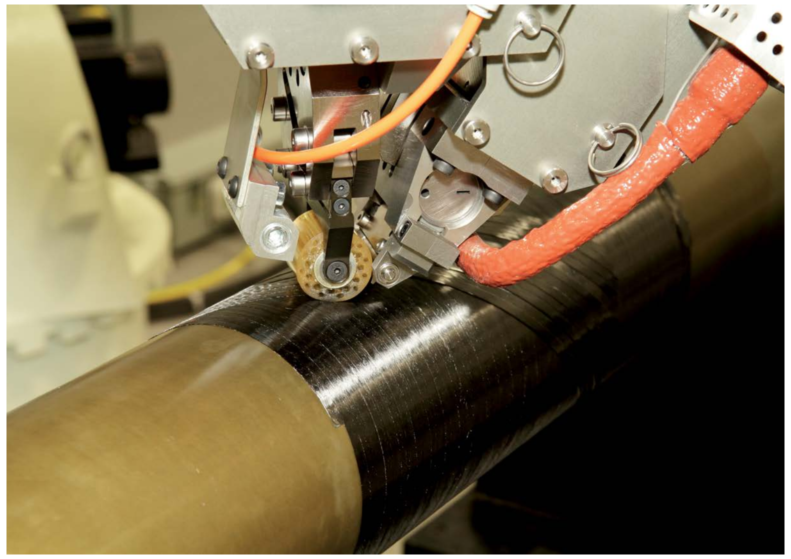
Examples of projects include:

Multi-functional printed composites: automated multi-layered systems are being developed which incorporate printed self-sensing and self-ameliorating structures. These structures can provide significant improvements in function and performance, while comprising only 0.02% of material and preserving structural integrity.

Multi-scale modelling: We specialise in modelling the behaviour of composite structures from the molecular level up to full structures and systems subjected to complex loading conditions such as blast, ballistic impact and fatigue. This allows us to design materials that are stronger and safer without needing large investment.

Automated manufacturing & machining: We are investigating the use of automated manufacturing cells to increase throughput and reduce errors by minimising human involvement in the production process. We are also developing new cutting tools and machining fluids for cutting composite materials, as well as developing innovative techniques for drilling, trimming, surface machining and stack machining.





Unravelling the secrets of silk

Materials are a cornerstone of our society, global economy and a major challenge facing us in the 21st century. Materials manufacture and processing results in over 20% of the world's carbon emissions, with many structural materials sourced from non-sustainable supplies. Here nature can contribute much to the discussion, as its materials tend to be supremely energy efficient as well as recyclable.

Biopolymers, specifically silks, offer inspiration and solutions to challenges facing the synthetic polymer industry; provided we understand how to process them correctly. The Natural Materials Group is currently investigating how silks are spun into fibres that possess properties as yet unmatched by their industrial counterparts. Taking lessons from the spider and silkworm, this group is developing a range of biomimetic spinning devices capable of processing naturally sourced feedstocks into products with predictable properties. This industrially new, yet evolutionarily ancient, way of manufacturing materials in a sustainable and environmentally benign manner has the potential to change the way in which we process our own materials. It is most likely to find applications ranging from high performance fibres to biomedical implants, sensors and optical devices.

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Geopolymer cement

University of Sheffield researchers are leading the world in the development of new types of cement, to reduce the environmental damage which is currently caused by the construction industry. Cement production is currently responsible for as much as 8% of global human-derived CO_2 emissions, and so Sheffield researchers are analysing and optimising several types of alternative cement which could reduce this emissions footprint.

The most promising option in this area is 'geopolymer' cement, which is obtained by the reaction between a solid aluminosilicate material (including industrial by-products such as blast furnace slag or coal fly ash) and a source of alkalis. These materials can reduce CO_2 emissions by around 80% compared to a standard Portland cement, while offering excellent performance and durability.

Sheffield is working in partnership with UK and international companies to accelerate the use of geopolymer technology on a large scale in construction and infrastructure, and using cutting edge science to provide reliable predictions of the long-term durability of these new materials.

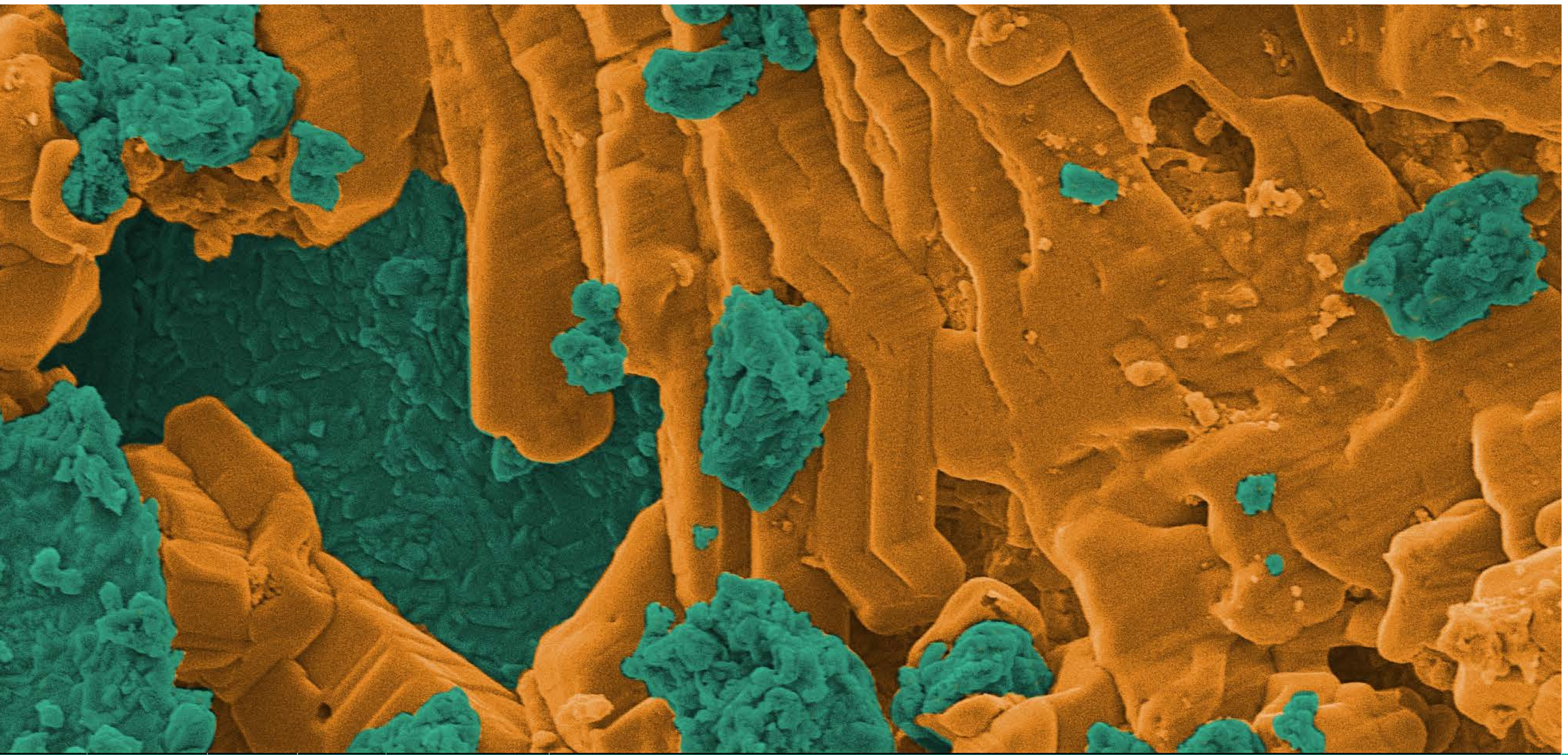
CEMENTS

Glass-ionomer bone cements

Glass-ionomer cements (GICs) have been used in dentistry for over 30 years and set by an acid-base reaction between an acid-degradable glass and a polymeric acid such as poly(acrylic acid). While relatively successful, its clinical application has been limited by fears regarding biocompatibility. Research into its biocompatibility conducted at the University of Sheffield led directly to the start-up of a UK company Corinthian Surgical Ltd., creating jobs in the supply chain and wealth via international sales, and making available a new, safe and clinically effective medical device that has maintained or restored hearing to improve the quality of life of over 10,000 patients world-wide.

The cement is now used in a large number of clinical procedures in middle ear surgery including repair of the ossicular chain, occlusion of bony defects, and fixation of other medical devices such as the cochlear implant.

More recently, Sheffield academics have improved the formulation of the cement to make it potentially useful in a wider range of surgical procedures including in orthopaedics, spinal surgery, and facial reconstruction. This work resulted in a new patent application and the University is working with industrial partners to take this to the medical market.



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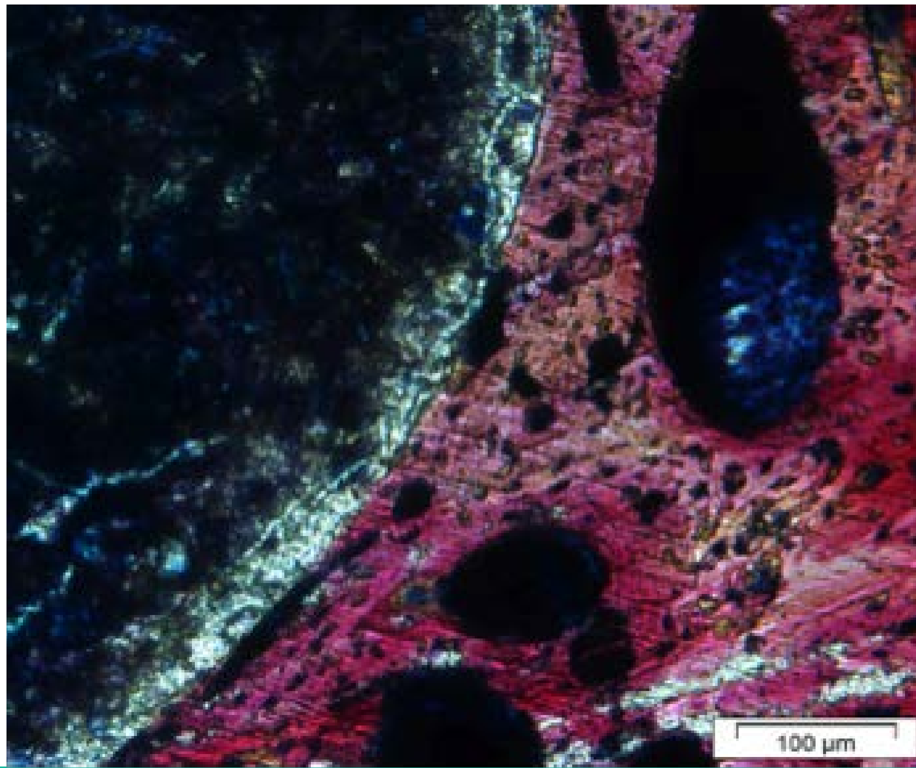
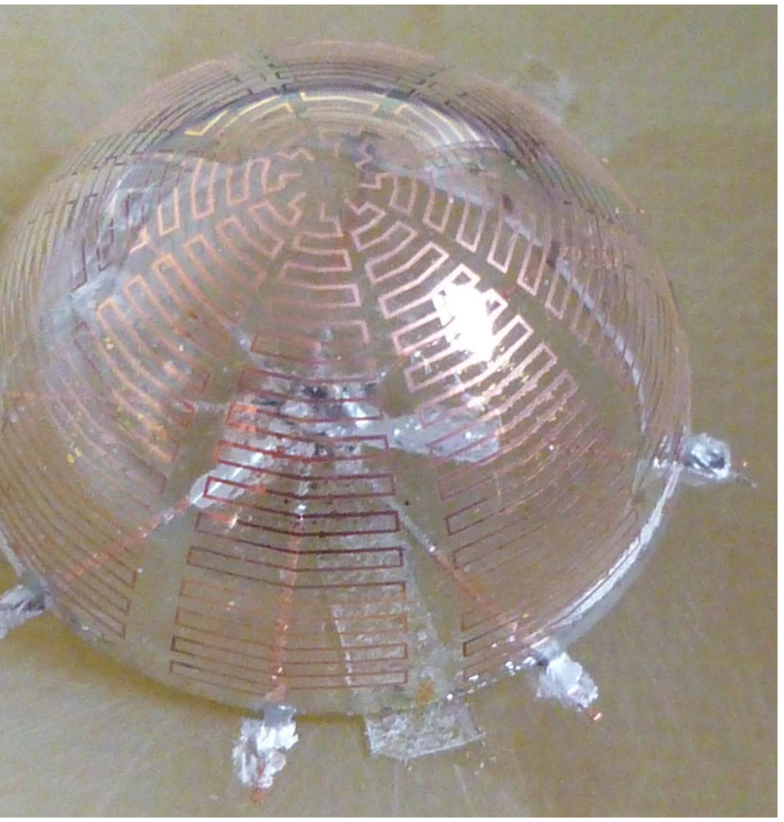


3D photolithography

Photolithography is a vital technique for the semiconductor fabrication industry, where it is used to pattern billions of tiny features onto silicon chips. These chips are inherently flat, which makes the pattern transfer tractable. Researchers in Sheffield are developing the necessary techniques to enable photolithography to be extended to the patterning of grossly non-planar surfaces. This enables rapid patterning of otherwise challenging surface topographies. Examples include hemispherical antennae (below); inkjet print heads; micro-fluidic channels and vertical interconnections between silicon chips. The technique relies on the computation of special holographic masks that, when illuminated with sufficiently coherent light, produce the required 3D light distribution. The light distribution is used to expose the substrate, which is pre-coated with a light-sensitive resin (photoresist) and thus transfer the pattern to the substrate. The standard processes for selective material removal, deposition or modification can then be applied.

3D photolithography is a new micro-fabrication method that has the potential to displace existing sequential direct-write techniques and also enable new product designs. The work has been undertaken in collaboration with industrial suppliers and end users, with extensive funding from EPSRC.



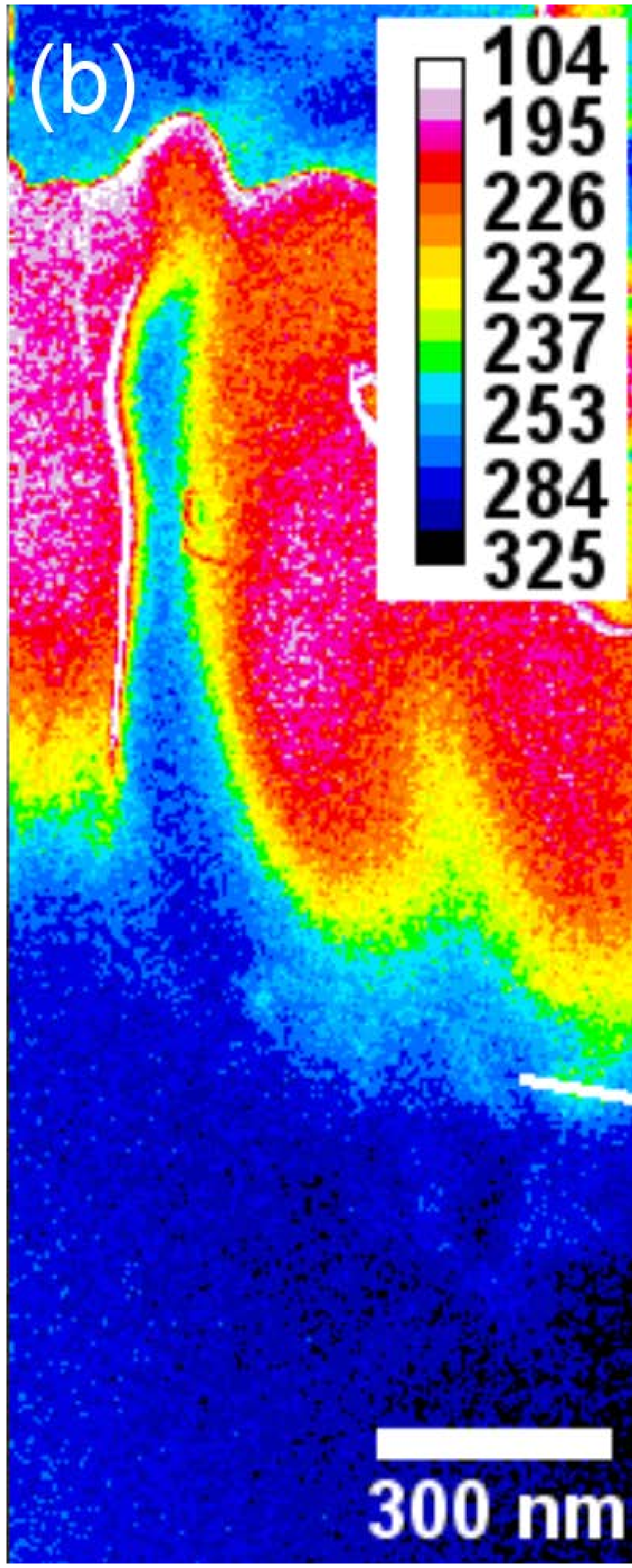
“3D photolithography has the potential to displace existing sequential direct-write techniques and enable new product designs.”

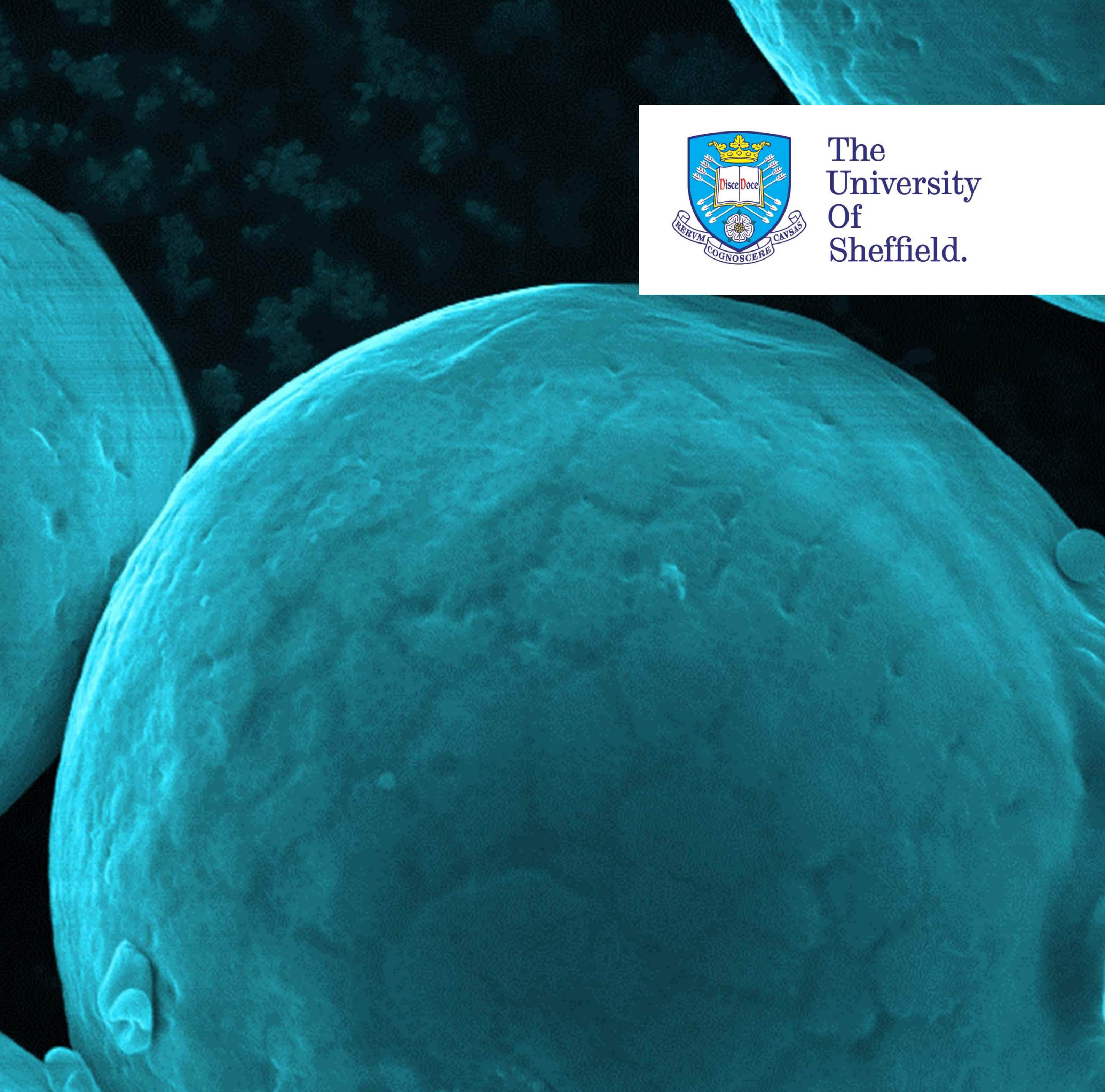
Microstructural characterisation

Researchers at the University of Sheffield work with leading microscopy companies to enable efficient engineering of materials through revealing high contrast images of nanostructures invisible with conventional technology using a combination of some unique equipment at the Sorby Centre for Electron Microscopy and latest state of the art equipment at collaborating companies such as FEI company and Carl Zeiss Microscopy GmbH.

The Sorby Centre has a comprehensive series of electron microscopes, ranging from basic machines for training and routine use to high performance instruments for high level research. In particular, the Sorby centre houses ‘state of the art’ electron microscopes, a FEI Tecnai 20 transmission electron microscope (TEM), a JEOL JSM 3010 300kV TEM which is dedicated to high resolution electron microscopy with a `point to point´ resolution of 0.17nm and a FEI Sirion Field Emission Gun Scanning Electron Microscope (FEGSEM) with Electron Back Scattered Diffraction system (EBSD).

Examples of microstructural characterisation include acceptor-donor phase mapping in organic electronics with energy filtered scanning electron microscopy, or the determination of wall thicknesses and nanoscal-topography in polymer foams obtained from high internal phase emulsions (HIPEs) using Helium Ion Microscopy as result of a collaboration with Carl Zeiss.





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