

Indicative PhD Projects in the Dept of Materials Science University of Cambridge

The example PhD project list below is intended to provide an indication of the range of PhD projects available in the Department of Materials Science. You are encouraged to contact members of the academic staff working in your area(s) of research interest, for further information on the projects currently available (which may not include the specific examples listed here). Please note that funding has NOT been allocated to support these example PhD projects. Prospective applicants, in particular those from overseas, should refer to the Board of Graduate Studies' website at <http://www.graduate.study.cam.ac.uk/> for further information on the application process and the scholarship opportunities available through the University and Cambridge Trusts.

Department contact for informal enquiries:

Dr Rosie Ward
Department of Materials Science and Metallurgy
University of Cambridge
27 Charles Babbage Road
Cambridge CB3 0FS

Tel: +44 1223 331955

Email: remw2@msm.cam.ac.uk

PhD Projects

Biomaterials	4
Projects in the field of medical materials	4
Composite Materials	5
Characterisation of the Adhesion of Single Cells to Ti-based Surfaces, using Forced Liquid Flow	5
High Strain Rate Superelastic Behaviour of NiTi Shape Memory Alloys	5
Microstructure, Hardness and Tribological Characteristics of PEO Coatings	5
Mechanical Stability and Biocompatibility of PEO Coatings on Titanium Substrates	6
Electrical Discharge Characteristics of Plasma Electrolytic Oxide (PEO) Coatings	7
Colloidal films for complex multilayer structures.....	7
Microstructural changes in thin film AlO_x sensors	7
Deformation and friction in layered oxides for solid lubricants.....	7
Novel zinc oxide varistors	8
Electrostatic bonding	8
High temperature brazing of engineering ceramics.....	8
Device Materials	9
Mechanocaloric effects	9
Polymer-based nano-piezoelectric generators for energy harvesting applications	9
Electrocaloric cooling using multilayer capacitors	9
Combinatorial thin film growth.....	9
Spin injection devices	10
Magnetic vortex cutting in superconductors	10
Electric field effects in oxide magnetic materials	10
Spin torque devices	10
Superconducting Spintronics	10
The development of vapour deposition techniques, and the fabrication of novel nano-composite structures.....	11
Superconducting Single Photon Detectors.....	11
GdN thin films	11
Electrocaloric effects	11
Magnetoelectrics	11
New oxide interface electronics	12
Oxide memristors for next generation non-volatile memory in computing	12
New Electronic Devices Formed At The Interfaces Of Thin Films	12
Nanostructured superconductors for emerging applications.....	12
Oxides for Photovoltaics	12
Bioinspired Nanocomposite Thin Films For Revolutionary Electronic Devices	12
Next generation Magnetoelectric Materials	13
Electron microscopy.....	14
The crystal structure of pharmaceutical crystals	14
3D structure of semiconductor devices	14
3D electrostatic potentials.....	14
High Resolution Electron Energy Loss Spectroscopy	14
3-Dimensional Atomic Resolution	15
3-Dimensional Mesoscale Imaging and Analysis in the Dual Beam Microscope	15
Scanning Transmission Electron Microscopy in a Scanning Electron Microscope	15
Materials Chemistry	16
Cost-Effective Approach to Mineral Carbonation	16
Sustainable Lead Batteries.....	16
Light Weight Lead Batteries?.....	16
Next generation of Lithium batteries based on sulphur – carbon nanotube electrodes.....	16
Harnessing Sunlight for Redox Reactions.....	17
Minimizing Impedance in Intermediate Temperature Solid Oxide Fuel Cells.....	17

Measurement and interpretation of pyrometallurgical processes involving precious metal-bearing materials.....	17
Novel electroless coating for producing Metal Coated Particles (MCPs).....	18
Electrodics in Gas sensors	18
Materials Modelling	19
Constitutive Modelling of Deformation Mechanisms in Single Crystal Superalloys.....	19
Physical Metallurgy	20
Lifing of Electron Beam Physical Vapor Deposition (EBPVD) Thermal Barrier Coatings (TBCs).....	20
Rejuvenation of Ni-Base Single Crystal Superalloy Components.....	20
Electronic Metallization for Extreme Environments	20
Reactions at contacts in electronic devices for service in extreme conditions	20
Chalcogenide Alloys for Data Recording	20
Low-k dielectric materials	20
Solidification and Microstructure in Al Alloys.....	20
Macromolecular Materials Laboratory	21
Weblink to MML PhD vacancies	21
http://www.mml.msm.cam.ac.uk/opportunities	21
Rolls-Royce University Technology Centre.....	21
Weblink to RR UTC PhD vacancies.....	21

Biomaterials

Projects in the field of medical materials

A range of PhD projects will be available within the Cambridge Centre for Medical Materials. Information about current research is available at the group website www.ccmm.msm.cam.ac.uk. Research fields include ice templated biomacromolecular scaffolds, peptide control of cellular response, bioactive ceramics, resorbable polymers and composites, biocompatible metallic glasses, pharmaceuticals and drug delivery. Fields of application include orthopaedic and dental surgery, cardiac repair, breast cancer research and the treatment of blood disorders.

For further information contact Prof. Serena Best (smb51@cam.ac.uk) and Prof. Ruth Cameron (rec11@cam.ac.uk).

Composite Materials

Characterisation of the Adhesion of Single Cells to Ti-based Surfaces, using Forced Liquid Flow

This study will be carried out using bovine chondrocyte (cartilage) cells and human bone cells from an established osteoblast cell line. These cells will be distributed onto pure titanium and Ti-6Al-4V substrates, after they have been subjected to several different surface treatments. The cells will be left for a short period in a nutrient solution, to allow cell attachment to occur. Flow of liquid over the surface will then be stimulated, and observations made about the relationship between the flow conditions (velocity profile) and the cell detachment behaviour. Analytical and numerical modelling of the flow pattern will be carried out, taking account of cell shape, so that the detachment characteristics can be translated into mechanical adhesion parameters. Correlations will be sought with results from an ongoing project in which the force necessary to detach single cells is being measured directly. For further information contact Prof TW Clyne (twc10@cam.ac.uk).

High Strain Rate Superelastic Behaviour of NiTi Shape Memory Alloys

There is interest in the mechanical behaviour of shape memory (NiTi) alloys under high imposed strain rates [1, 2]. An attractive tool for study of the superelastic deformation of such alloys is the nanoindenter. There have been several recent studies [3, 4] of the nanoindentation response of NiTi, and it has been shown [4] that nanoindentation data can be used to establish whether deformation is occurring via superelasticity. Multiple impact indentation modes, transiently generating high local strain rates, will be used to explore high strain rate superelasticity in this way. Some exploratory work has been done [5], but more systematic studies are now needed, covering effects, such as adiabatic heating, which have not previously been considered. Comprehensive FEM modelling of the strain field during indentation will be undertaken, building on previous work [4-6]. NiTi specimens will be subjected to static and multiple impact nanoindentation, over a range of effective strain rates. Further experiments will be carried out using a simple coiled spring specimen geometry, with loading via a servo-hydraulic testing machine, over a range of frequency. Monitoring of whether purely superelastic deformation has occurred will be by checking whether there is any residual plastic strain on unloading, for various imposed strain amplitudes. This testing geometry has the advantage that the strain field is much simpler than that during nanoindentation. For further information contact Prof TW Clyne (twc10@cam.ac.uk).

1. Millett, JCF, Bourne, NK and Gray, G, *Behaviour of the Shape Memory Alloy NiTi during One Dimensional Shock Loading*, J. Appl. Phys., vol. **92** (2002) p.3107-3110.

2. Meziere, Y, Millett, J and Bourne, N, *Equation of State and Mechanical Response of NiTi during One-dimensional Shock Loading*, J. Appl. Phys., vol. **100** (2006) p.Art. 033513.

3. Shaw, GA, Stone, DS, Johnson, AD, Ellis, AB and Crone, WC, *Shape Memory Effect in Nanoindentation of Nickel-Titanium Thin Films*, Appl. Phys. Letts., vol. **83** (2003) p.257-259.

4. Muir Wood, AJ and Clyne, TW, *Measurement and Modelling of the Nanoindentation Response of Shape Memory Alloys*, Acta Materialia, vol. **54** (2006) p.5607-5615.

5. Ma, X-G and Komvopoulos, K, *Pseudoelasticity of Shape Memory Titanium-Nickel Films subjected to Dynamic Nanoindentation*, Appl. Phys. Letts., vol. **84** (2004) p.4274-4276.

6. Zhang, Y, Cheng, Y and Grummon, D, *Finite element modeling of indentation-induced superelastic effect using a three-dimensional constitutive model for shape memory materials with plasticity*, J. Appl. Phys., vol. **101** (2007) Art. 053507.

Microstructure, Hardness and Tribological Characteristics of PEO Coatings

Plasma electrolytic oxidation (PEO) is a novel surface engineering technology, allowing thick oxide coatings to be formed on metal components. It is based on electrolysis within an aqueous electrolyte, with dielectric breakdown of the growing oxide film occurring via a series of local discharge events, allowing production of films as thick as 100 μm or more. The discharge events have a profound effect on coating microstructure, and hence on the physical and mechanical properties of the coating. The process is particularly effective on aluminium and magnesium. Empirical process optimisation has led to coatings

with good tribological characteristics [1-3]. There is now a pressing need for improved understanding of the fundamentals, particularly relationships between electrolyte and alloy composition, coating microstructure/composition, hardness and wear resistance. Some of the work will build on recent progress [4-6] on correlations between production conditions, microstructural features and thermo-physical properties. Coatings will be produced in Cambridge. Initial work will focus on 1000, 2000, 5000 and 6000 series Al alloys. Porosity characteristics will be investigated by precision densitometry, mercury porosimetry, BET analysis and He pycnometry. Both global and local responses to indentation will be examined, over a range of temperature. The macroscopic hardness will be used as a general guide to the mechanical strength of the coatings, while a nanoindenter will be used to explore local variations in hardness and also to study the multiple impact response. Preliminary indications have already been obtained that the coating hardness varies with alloy composition and such variations will be systematically explored. Both pin-on-disk and erosive wear experiments will be carried out, and results will be correlated with both static hardness and dynamic nanoindentation results. For further information contact Prof TW Clyne (twc10@cam.ac.uk).

1. Nie, X, Meletis, EI, Jiang, JC, Leyland, A, Yerokhin, AL and Matthews, A, *Abrasive Wear/corrosion Properties and TEM Analysis of Al₂O₃ Coatings Fabricated using Plasma Electrolysis*, Surf. & Coat. Techn., vol. **149** (2002) p.245-251.
2. Rama-Krishna, L, Somaraju, KRC and Sundararajan, G, *The Tribological Performance of Ultra-hard Ceramic Composite Coatings obtained through Microarc Oxidation*, Surf. Coat. Techn., vol. **163-164** (2003) p.484-490.
3. Wei, T, Yan, F and Tian, J, *Characterization and Wear- and Corrosion-resistance of Microarc Oxidation Ceramic Coatings on Aluminum Alloy*, J. Alloys and Compounds, vol. **389** (2004) p.169-176.
4. Curran, JA and Clyne, TW, *Thermo-physical Properties of Plasma Electrolytic Oxide Coatings on Aluminium*, Surf. & Coat. Techn., vol. **199** (2005) p.168-176.
5. Curran, JA and Clyne, TW, *The Thermal Conductivity of Plasma Electrolytic Oxide Coatings on Aluminium and Magnesium*, Surf. & Coat. Techn., vol. **199** (2005) p.177-183.
6. Curran, JA and Clyne, TW, *Porosity in Plasma Electrolytic Oxide Coatings*, Acta Mater., vol. **54** (2006) p.1985-1993.

Mechanical Stability and Biocompatibility of PEO Coatings on Titanium Substrates

Plasma electrolytic oxidation (PEO) is a novel surface engineering technology, allowing thick oxide coatings to be formed on metal components. It is based on electrolysis within an aqueous electrolyte, with dielectric breakdown of the growing oxide film occurring via a series of local discharge events, allowing production of films as thick as 100 µm or more. Recent work in the Gordon Laboratory [2, 3] has led to improved understanding of the relationships between production conditions, microstructural features and thermo-physical properties. There is also growing interest in the potential for their use in various biomedical applications, since it has already become clear that high biocompatibility and bioactivity levels can be generated [4, 5]. PEO coatings will be produced on Ti-6Al-4V substrates, using a range of conditions designed to generate HA, or closely similar compounds, within the microstructure. These will be characterised in terms of density, pore structure, phase constitution and mechanical properties. Their biocompatibility will be assessed in the Cell Culture facility within the Gordon Laboratory, using bovine chondrocyte and human osteoblast cells. For further information contact Prof TW Clyne (twc10@cam.ac.uk).

1. Curran, JA and Clyne, TW, *Thermo-physical Properties of Plasma Electrolytic Oxide Coatings on Aluminium*, Surf. & Coat. Techn., vol.199 (2005) p.168-176.
2. Curran, JA and Clyne, TW, *The Thermal Conductivity of Plasma Electrolytic Oxide Coatings on Aluminium and Magnesium*, Surf. & Coat. Techn., vol.199 (2005) p.177-183.
3. Han, Y, Hong, SH and Xu, KW, *Structure and In Vitro Bioactivity of Titania-based Films by Micro-arc Oxidation*, Surf. Coat. Techn., vol.168 (2003) p.249-258.
4. Huang, P, Xu, KW and Han, Y, *Preparation and apatite layer formation of plasma electrolytic oxidation film on titanium for biomedical application*, Materials Letters, vol.59 (2005) p.185-189.

Electrical Discharge Characteristics of Plasma Electrolytic Oxide (PEO) Coatings

Substantial advances have been made recently in understanding of the process-microstructure-property relationships in PEO coatings [1-4]. These coatings, which can be relatively thick (~100 µm), are formed in aqueous electrolytes by repeated local dielectric breakdown events, with charge transfer and chemical changes occurring within the associated plasma channels. Microstructural features include a very fine grain size, the presence of an amorphous phase and relatively high levels of ultra-fine, inter-connected porosity. There is considerable interest in the dielectric properties of these coatings, over a range of frequencies and under both wet and dry conditions. This partly arises from possible use of these coatings for electrical insulation purposes, but these characteristics are also expected to give valuable insights into the way that the coatings are formed. Electrical characteristics of PEO coatings on aluminium alloys, particularly the voltage and current profiles during each cycle, will be studied over a range of conditions and correlations will be established with microstructural features. For further information contact Prof TW Clyne (twc10@cam.ac.uk).

1. Curran, JA and Clyne, TW, *Thermo-physical Properties of Plasma Electrolytic Oxide Coatings on Aluminium*, Surf. & Coat. Techn., vol. **199** (2005) p.168-176.

2. Curran, JA and Clyne, TW, *The Thermal Conductivity of Plasma Electrolytic Oxide Coatings on Aluminium and Magnesium*, Surf. & Coat. Techn., vol. **199** (2005) p.177-183.

3. Curran, JA and Clyne, TW, *Porosity in Plasma Electrolytic Oxide Coatings*, Acta Materialia, vol. **54** (2006) p.1985-1993.

4. Curran, JA, Kalkancl, H, Magurova, Y and Clyne, TW, *Mullite-rich Plasma Electrolytic Oxide Coatings for Thermal Barrier Applications*, Surf. Coat. Technol., vol. **201** (2007) p.8683-8687.

Colloidal films for complex multilayer structures

A major problem in the development of complex multilayer microsystems is the cracking during the drying of the colloidal layers. Such cracking also occurs in many other processes, both industrial and natural, such as the patterns that form in the polar regions of the earth and Mars, in photonic crystals, even cosmetics. Surprisingly the forces that drive this cracking and even the resistance to it are not understood, so that attempts to control cracking are all very empirical, although some variables. Such cracks often grow in a stable manner with a well-defined crack spacing. The project will involve studying the cracking in-situ using existing equipment to enable measurements of crack velocity, crack spacing and the distances between the various fronts associated with the overall process. Shape changes and crack opening will also be measured using profilometry and SEM to understand how the stresses and strains build up, the nature of this type of cracking and the underlying processes that drive it. The project forms part of a collaborative project funded by the EU at the level of fees for an EU student. For further information contact Dr Bill Clegg (wjc1000@cam.ac.uk).

Microstructural changes in thin film AlO_x sensors

Measurement of water vapour is important in sophisticated manufacturing processes, such as silicon chip fabrication, where moisture levels of parts-per-trillion are important, in energy efficient buildings and, as water vapour is one of the main greenhouse gases, in helping to develop accurate models for climate change (see Bell et al, *Int. J. Thermophysics*, 2008.) The principal problem with existing sensors is the long-term drift that occurs during use and which, at present, requires continued recalibration of the sensor. Most humidity sensors are based on porous alumina membranes, typically 1 µm thick made by anodising aluminium. Our initial work with one of the leading manufacturers of these sensors has suggested that that the drift is caused by changes in the porous structure of the film by a process analogous to liquid-phase sintering. The aim of the project is to investigate, in collaboration with the company involved, whether such structural changes do occur and how they might be minimised, perhaps by limiting the solubility of alumina in water. Tests will be carried out on alumina films aged in controlled environments and cycles to study how the properties change with time. The properties and structure will be studied using a variety of techniques such as impedance and capacitance measurements, ellipsometry, nanoindentation and a range of electron optical techniques to investigate how these mechanisms are influenced by the structure of the film and how the structure changes in service. For further information contact Dr Bill Clegg (wjc1000@cam.ac.uk).

Deformation and friction in layered oxides for solid lubricants

Rotating components operating at high temperatures or in vacuum, where the usual liquid lubricants would decompose or vaporise, require solid lubricants. There are a surprising number of layered structures, such as vanadium oxides that might be suitable for low friction uses, due to the very weak bonding across the plates and although they are used their properties and the structural features that control them are not well understood. Dislocations and plastic flow are known to be important in other layered structures, but it is not known how the bonding might be manipulated to produce materials with low friction coefficients for use as solid lubricants. The aim of this project is to investigate the deformation, friction and wear behaviour of the vanadium oxides (and the related titanium sub-oxides) and other chalcogenides. The project is a collaboration with the University of Aachen and will use suitably oriented micropillars and nanoindentation as a function of temperature to characterise the deformation behaviour, as well as nanoscratch for wear and friction measurements, combined with transmission electron microscopy. For further information contact Dr Bill Clegg (wjc1000@cam.ac.uk).

Novel zinc oxide varistors

Varistors derive their non-linear current-voltage characteristics from the addition of low levels of transition and heavy metal oxides. It is usual for commercial compositions to have five or six oxide additions. However, recent work here at Cambridge has shown that ZnO with additions of MnO₂ and V₂O₅ alone exhibits varistor behaviour rivaling that of commercial material. This Ph.D. project will establish microstructure-electrical property relationships in this ternary system by examining a range of ZnO-rich pellets by X-ray diffraction and transmission electron microscopy. An area of particular interest will be mapping of the electrical barriers at zinc oxide grain boundaries using electron holography and Fresnel fringe analyses. For further information contact Dr Kevin Knowles (kmk10@cam.ac.uk).

Electrostatic bonding

Electrostatic bonding is a common process in microelectromechanical systems (MEMS). For example, it is used to manufacture pressure sensors. The two materials, such as silicon and pyrex, are bonded together by applying a high d.c. voltage across the bond at a temperature of ~ 400 °C. In this example, pyrex, the poorer electrical conductor, is cathodic with respect to silicon. A requirement of electrostatic bonding is that the ceramic material used in the process is a sufficiently good electrical conductor at the temperature used to make the bond. In this PhD project the principle of electrostatic bonding will be applied to the bonding of metals (e.g., Nb, Cu, Ni and Al) to other ceramics and glasses, such as beta-alumina, soda-lime-silica glass and zirconia. The aims of the project will be to specify the range of temperature and d.c. voltage conditions within which good bonds can be formed between the metals and the beta-alumina and to characterise these bonds using a range of transmission electron microscopy techniques. For further information contact Dr Kevin Knowles (kmk10@cam.ac.uk).

High temperature brazing of engineering ceramics

The aim of this PhD project is to examine by X-ray diffraction, scanning electron microscopy and transmission electron microscopy, the microstructure of novel particle-reinforced brazes for joining engineering ceramics such as alumina, silicon carbide and silicon nitride to metallic materials such as nickel, so that the joints can be used at service temperatures of >500 °C. Experience at Cambridge with brazes for bonding SiC has shown that the introduction of small SiC particulates to high temperature braze compositions is beneficial for joining SiC to itself, producing mechanically sound joints. It is proposed to extend this methodology to other systems of engineering significance. For further information contact Dr Kevin Knowles (kmk10@cam.ac.uk).

Device Materials

Mechanocaloric effects

Mechanocaloric effects are thermal changes that arise in mechanically responsive materials due to changes of applied stress, and could be used for energy-efficient environment-friendly solid-state cooling applications [1-3]. The aim of this project is to develop mechanocaloric materials and devices. For further information contact Dr Xavier Moya (xm212@cam.ac.uk).

[1] Moya *et al.*, *Nature Materials* **13**, 439 (2014).

[2] Moya *et al.*, *Nature Physics* **11**, 202 (2015).

[3] Lloveras *et al.*, *Nature Communications* **6**, 8801 (2015).

Polymer-based nano-piezoelectric generators for energy harvesting applications

Energy harvesting for small power applications is a hot research topic due to its potential applications in powering portable electronics, wireless sensors and medical implants, to name a few. Powering devices from scavenged ambient energy from the environment is an attractive avenue for replacing or extending the lifetime of traditional power sources. Piezoelectric energy harvesting devices constitute the simplest means of scavenging power directly from ambient vibrations through the conversion of mechanical energy into electrical energy. The aim of the PhD project is to design and fabricate a nano-piezoelectric generator based on ferroelectric polymer. While there have been recent reports of nano-piezoelectric generators based on semiconductors and ceramic ferroelectric oxides, it is interesting to study polymer-based nano-piezoelectric generators with a view to enhance output power and reduce cost of fabrication. The project will thus involve growth of polymer nanowires, rigorous characterisation by X-ray diffraction (XRD), scanning electron microscopy (SEM) and piezo-force microscopy (PFM), and fabrication and testing of prototype nano-piezoelectric energy harvesting devices. The project will also explore the possibility of “all-organic” flexible nano-piezoelectric generators. For further information contact Dr Sohini Kar-Narayan, sk568@cam.ac.uk.

Electrocaloric cooling using multilayer capacitors

Refrigeration and air-conditioning account for 20% of the UK’s energy consumption. Cooling is typically achieved using vapour-compression cycles, but the efficiency is low (~40%) and the fluids are harmful to the environment. An efficient and clean alternative lies in the development of a solid-state cooling technology using ferroelectric materials that display a giant electrocaloric (EC) effect, i.e. a reversible change in temperature due to an applied electric field. The PhD project is aimed at the development of new EC materials, the understanding and design of optimized EC devices and the implementation of these devices in cooling applications. In particular, cooling using multilayer capacitors based on giant EC materials will be investigated. The project will involve thin-film and multilayer growth techniques, structural characterization by X-ray diffraction (XRD), electrical characterization of ferroelectric materials, thermal characterization by scanning thermal microscopy (SThM) and thermal modeling/simulation using finite-element analysis. For further information contact Dr Sohini Kar-Narayan, sk568@cam.ac.uk.

Combinatorial thin film growth

Many new materials targeted for specific applications have multiple components or critical doping levels within a complicated phase diagram. Combinatorial materials synthesis, in which a continuous composition spread is deposited on a single substrate, coupled with high throughput analysis can lead to discovery and optimisation of a desired materials property in the shortest possible time. We have developed pulsed laser deposition combinatorial techniques to produce a variation of properties on a single substrate. The aim of this project is to extend combinatorial studies to other parameter spaces through the development of artificial substrates whose lattice parameter varies as a function of position; this will enable us to investigate continuous variation of lattice mismatch-induced strain in films grown on these substrates. We will develop this technique through the study of perovskite systems in which it is already clear that strain considerably modifies the electronic and magnetic behaviour of the film and sometimes can reveal properties which do not occur at ambient pressure in the bulk.

Spin injection devices

The ability to inject, manipulate and detect electron spin will enable the development of spintronics devices. In order to inject and detect spins from a ferromagnetic metal into a semiconductor, the resistivity mismatch problem has to be overcome. This can be achieved by inserting a tunnel or Schottky barrier to create a large resistance at the interface. Tunnelling through a thin barrier is more attractive than a Schottky contact because an artificial tunnel barrier also offers symmetric behaviour under forward and reverse bias; however, oxide tunnel barriers must be absolutely free of pin-holes and other defects and are known to be difficult to deposit on semiconductors. The aim of this project is to investigate the deposition of semiconductors onto preformed tunnel barriers on either superconductors or ferromagnets in order that the tunnel barrier properties can be optimised independently of the type of semiconductor used.

Magnetic vortex cutting in superconductors

The behaviour of quantised magnetic vortices in type II superconductors is of enormous practical significance for applications and is of fundamental interest because many of their interactions are still not properly understood. In particular, there is a great deal of interest in the behaviour of non-parallel vortices if they are forced towards each other. This specific question can be visualised as two pieces of elastic being pushed together at an angle to each other – do they entangle and stretch or is there a process by which they can pass through each other? The aim of this project is to study a new experimental geometry which will enable us to test directly the many theoretical models of this behaviour which have emerged in recent years.

Electric field effects in oxide magnetic materials

In semiconductor devices the field effect is used to change the carrier density in the channel linking the source and drain and hence control the conductivity of the device. There is considerable potential for modifying the properties of many oxide magnetic materials by changing the electric field across them because the number of carriers is rather low. Since the magnetism in many systems is linked to the carrier density it might be possible to control the Curie temperature of some of these oxides electronically which would give considerable scope for magnetoelectronic devices. The aim of this project is to develop field-effect devices which can be used to investigate such effects. For further information contact Prof MG Blamire (mb52@cam.ac.uk).

Spin torque devices

In ferromagnetic materials an electric current transports spin as well as charge. There are many ways in which this effect can be used including so-called spin transistors and light emitting diodes which emit polarised light. In the last few years it has been shown that the spin carried by an electric current can be used to rotate the moment of a thin ferromagnetic layer; this “spin torque” effect can in principle be used as a means of storing data and performing logic operations. However the current densities required in the current devices are far too high, indeed they are close to the currents at which devices melt. The aim of this project is to investigate novel device geometries which might significantly reduce the current densities required. For further information contact Prof MG Blamire (mb52@cam.ac.uk).

Superconducting Spintronics

There are well-defined physical limits to the scaling of semiconductor transistor logic including power dissipation and current leakage. Superconducting spintronics has the potential to overcome these problems and has emerged from a series of recent discoveries that combine superconductivity and spintronics (Nature Physics 11, 307 (2015)). The Cooper pairs of electrons, which carry charge in conventional superconductors, consist of electrons with antiparallel spins and so a standard supercurrent has no net spin component. However, it is now established that these "singlet" pairs can be transformed by a suitable magnetic interface into "triplet" pairs in which the spins are parallel. Consequently, supercurrents can be created that carry spin in addition to charge. By drawing on insights from the field of spintronics such as spin injection, detection and spin-relaxation, and the field of superconductivity such as quantum coherence and the proximity effect, this project involves investigating devices in which charge and spin are controlled in the superconducting state. The projects longer term vision involves create devices in which superconducting spin currents are used for energy efficient logic and memory

operation. In addition to exploring the effects observed in conventional spintronics, we expect new phenomena to emerge in the superconducting state. For further information contact Dr Jason Robinson (jjr33@cam.ac.uk) & Prof. Mark Blamire (mb52@cam.ac.uk).

The development of vapour deposition techniques, and the fabrication of novel nano-composite structures

Much research within the Device Materials Group is based upon thin film fabrication using vapour deposition techniques, and we are further developing our deposition technology. For example, an additional rf plasma between a vapour source and a substrate leads to ionisation of the depositing flux, and allows increased control during film growth. We have demonstrated the potential for fabrication of very novel film structures: for example, nickel – carbon thin films which consist of nickel nano-particles surrounded by carbon “nano-onion” shells; and extremely porous, vertically oriented, nano-pillar arrays.

There are several different aspects that could be followed within a PhD project: control and optimisation of the film growth itself (including plasma analysis techniques for characterisation of the deposition environment); micro-structural and physical characterisation of the deposited film structures (requiring the highest resolution methods); and/or the fabrication of different metal – carbon (and other) composites and film materials, in order to investigate further novel structures and properties. For further information contact Dr ZH Barber (zb10@cam.ac.uk).

Superconducting Single Photon Detectors

These require the fabrication of extremely thin (< 10 nm), very stable, films, with very high quality superconducting properties. We are collaborating with other groups, providing them with film material and patterned detectors for several photon-detecting applications. Further optimisation of film material (including the potential for the use of different superconducting systems), deposition parameters, substrate materials, and fabrication issues, would enhance device capabilities and lead to significant progress in the development of these detectors. For further information contact Dr ZH Barber (zb10@cam.ac.uk).

GdN thin films

GdN is an intriguing compound, showing a range of electronic transport properties (semi-metallic, semiconducting and insulating), combined with ferromagnetism at low temperatures. Much research is required to fully understand its properties, and to be able to exploit them. We are able to fabricate polycrystalline GdN thin films by reactive sputter deposition, and would like to study the control of film microstructure, and its influence upon properties, as well as the potential for preparation of single crystal, or oriented films grown epitaxially. For further information contact Dr ZH Barber (zb10@cam.ac.uk).

Electrocaloric effects

Electrically driven thermal changes are known as electrocaloric effects. Electrocaloric materials have been proposed for use in energy efficient heat pumps, for cooling applications such as refrigeration and air-conditioning which account for perhaps 20% of electricity usage. The discovery of large electrocaloric effects in ferroelectric materials near the Curie temperature [1-2] has stimulated worldwide research activity. The aim of this project is to develop electrocaloric materials and devices. For further information contact Professor ND Mathur (ndm12@cam.ac.uk).

[1] A.S. Mischenko *et al.*, *Science* **311** (2006) 1270

[2] B. Neese *et al.*, *Science* **321** (2008) 821

Magnetoelectrics

Strong magnetoelectric coupling, between the magnetization of a ferromagnet and the electrical polarization of a ferroelectric, permits magnetic and electrical signals to be interconverted [1-3]. The aim of this project is to design devices for electrical control of magnetism. This could be attractive for data storage, as an electric-write magnetic-read process would combine the best of FeRAM and MRAM, where FeRAM is ferroelectric random access memory used in Sony Playstation II, and MRAM is magnetic random access memory used in Airbus aeroplanes. For further information contact Professor ND Mathur (ndm12@cam.ac.uk).

[1] M. Fiebig, *J. Phys. D* **38** (2005) R123

[2] W. Eerenstein, N.D. Mathur and J.F. Scott, *Nature* **442** (2006) 759

[3] C. W. Nan, M. I. Bichurin, S. Dong, D. Viehland and G. Srinivasan, *J. Appl. Phys.* **103** (2008) 031101

New oxide interface electronics

In the last few years, there have been very exciting reports about the new functional properties which can be achieved at the interface between oxide films, e.g. there is the possibility to achieve new kinds of fast, energy efficient semiconductor processors and even possibly room temperature superconductors. This project involves exploring such phenomena. It will involve growth of ultrathin, single crystal thin films using a world leading, state-of-the-art advanced pulsed laser deposition system with in-situ diagnostic tools (XPS, UPS), followed by their measurement using a variety of means including electrical measurements, synchrotron studies, and atomic force microscopy (scanning probe) techniques. For further information contact Prof J Driscoll (jld35@cam.ac.uk).

Oxide memristors for next generation non-volatile memory in computing

Non-volatile memory (NVM) is critical for all aspects of modern computing, as well in future generation digital technologies like the Internet of Things (IoT) and neuromorphic computing—technologies that will penetrate into many realms of society. Among NVM technologies, resistive random access memory (RRAM) based on metal oxide (MO) films as the resistive switching (RS) layers has the potential of high-speed, low operation voltage, low power consumption, and good endurance that enables the highest performance at the lowest cost possible. There are a number of challenges which need to be addressed with these materials, relating to their nanostructuring and composition. We have solved these problems in a model system and now wish to take this forward to more simple systems. This project will develop such systems. We will collaborate with a number of groups on testing and implementation of industry prototypes. For further information contact Prof J Driscoll (jld35@cam.ac.uk).

New Electronic Devices Formed At The Interfaces Of Thin Films

In the last few years, there have been very exciting reports about the new functional properties which can be achieved at the interface between oxide films, e.g. there is the possibility to achieve new kinds of fast, energy efficient semiconductor processors and even possibly room temperature superconductors. This project involves growth of ultrathin, perfect oxide films using a brand new, state-of-the-art advanced pulsed laser deposition system with in-situ diagnostic tools (XPS, UPS), and their measurement by a variety of means including electrical measurements and atomic force microscopy (scanning probe) techniques. For further information contact Prof JL Driscoll (jld35@cam.ac.uk).

Nanostructured superconductors for emerging applications

We are working with companies in Europe, the US and Asia, to create state-of-the-art, superconducting conductors using our past, present and future inventions in nanostructuring and novel processing routes. The work is being used for make new applications in the areas of high field magnets and fault current limiters. This project will involve nanostructural materials design, conductor fabrication using pulsed laser deposition. For further information contact Prof JL Driscoll (jld35@cam.ac.uk).

Oxides for Photovoltaics

Achieving stable, efficient, cost-effective photovoltaics are urgently needed for the widespread application. This project is involved with scalable, high-throughput processing techniques to make (at low temperatures) low-cost oxide materials for photovoltaic (PV) devices. As well as using oxides as active semiconductors, we are also interested in them as charge blocking layers for improving hybrid solar cell performance. Indeed, we study both all-oxide inorganic cells as well as inorganic-organic hybrid cells. For further information contact Prof JL Driscoll (jld35@cam.ac.uk).

Bioinspired Nanocomposite Thin Films For Revolutionary Electronic Devices

Achieving self-assembling/self-organizing systems are the holy grails of nanotechnology. Spontaneous organisation is not unique to the physical sciences since nature has been producing such systems for millions of years. In biological systems global patterns emerge from numerous interactions among lower-level components of the system. The same is true for physical systems. In this project, self assembled

vertical heteroepitaxial nanocomposite (VHN) films will be made which copy natural structures This project will explore the novel very fast ionic channels which can be designed into such VHN films, from the basic science through to demonstrating their huge potential in solid oxide fuel cells. For further information contact Prof JL Driscoll (jld35@cam.ac.uk).

Next generation Magnetoelectric Materials

There exists no single phase material with a sizeable magnetoelectric coefficient at room temperature. However, by new materials nanodesign paradigms developed in our group, novel 3D strained composite thin films can be grown which have near room temperature magnetoelectric properties. The holy grail of room temperature devices is now within reach, but outstanding issues of unwanted electronic conduction and ease of nanoscale self-assembly now need to be explore further. This project will directly address those challenges. For further information contact Prof JL Driscoll (jld35@cam.ac.uk).

Electron microscopy

The crystal structure of pharmaceutical crystals

The vast majority of pharmaceutical crystal structures remain unknown. Potentially useful and important drugs may never come to market because their crystal structure cannot be solved using conventional x-ray diffraction. The reason is often that the pharmaceutical is produced in multi-phase or polymorphic form and the lack of spatial resolution in most x-ray diffraction experiments means that it is difficult, if not impossible, to deconvolve the crystal structure of interest from other crystals in the sample. Electron microscopy offers very high spatial resolution with the ability to form diffraction patterns from very small (nanometre-sized) regions of the sample. Recent developments in new methods of electron diffraction (e.g. electron precession) and new algorithms for structure solution (e.g. charge flipping) may lead to new insights into the structures of pharmaceutical crystals. This project would concentrate on acquiring high quality electron diffraction patterns from a number of unknown crystal structures and, in conjunction with a small team in the EM Group, develop and apply new structure solution algorithms suited especially to electron diffraction. For further information contact Prof PA Midgley (pam33@cam.ac.uk).

3D structure of semiconductor devices

As individual components within modern integrated circuits become ever smaller, the fine scale composition and structure of the device becomes increasingly critical. For many years transmission electron microscopy (TEM) has been used to investigate the fidelity of semiconductor structures and to determine the precision of the manufactured device. A conventional 'slice' through the device for TEM examination may be 100nm thick and a single micrograph is a projection through that slice. Any variation through that thickness would be difficult to visualise in the image of the slice. This has led the microelectronics industry to consider electron tomography as a means to investigate the 3D structure of devices without possible mis-interpretation from projecting fine scale detail. This project would be to develop techniques to investigate semiconductor devices, taken in the form of a 'core sample' from wafers. Relatively thick samples would be imaged using new TEM imaging modes (such as incoherent BF imaging) to understand large-scale 3D structures, with higher resolution tomography (using HAADF imaging) used following further dual beam ion thinning. For further information contact Prof PA Midgley (pam33@cam.ac.uk).

3D electrostatic potentials

Off-axis electron holography is a TEM technique that allows the projected electrostatic potential of a sample to be reconstructed quantitatively. For example, holography can be used to measure the spatial variation in the potential across a semiconductor junction and hence determine the electric field across that junction and the related space charge regions. Many devices are becoming 3-dimensional in design and one of the major barriers to designing successful 3D devices is the current inability to map potentials (and dopants) in 3D with high spatial resolution (~5nm). Combining electron holography with electron tomography offers a means to reconstruct electrostatic potentials in 3D with very high spatial resolution. The student would work together with Dr Alison Harrison of the EM Group to further develop this holography technique and to establish it as a reliable and quantitative tool for the microelectronics industry. For further information contact Prof PA Midgley (pam33@cam.ac.uk).

High Resolution Electron Energy Loss Spectroscopy

The Department will shortly take delivery of a new generation transmission electron microscope which has aberration correction on the probe forming lens to enable sub Angstrom spatial resolution and an electron monochromator to allow energy loss spectra to be acquired with better than 0.25 eV resolution. The combination of high spatial and high spectral resolution enables new experiments to be undertaken on a variety of important materials, especially modern semiconductor heterostructure devices. By choosing ternary and quaternary alloys, semiconductor bandgaps can be engineered to high precision. A technique is needed to map the band gaps of such heterostructures and high resolution EELS is the primary candidate. Further, the details of the low loss spectrum beyond the band edge can reveal a remarkable array of other electron transitions, such as band to band transitions, Cerernkov radiation and surface and waveguide modes that are potentially of great importance in device communication in optical computers. These modes can be 'hidden' within the overall plasmon loss using conventional energy loss spectroscopy but implementing the monochromator, coupled with the ability to disperse the spectrum in

momentum (or k -) space, can reveal spectral detail, and hence information about the electronic structure, not normally seen. For further information contact Prof PA Midgley (pam33@cam.ac.uk).

3-Dimensional Atomic Resolution

Electron tomography has now established itself firmly as a key technique in materials science for the study of structures in 3D at nanometre resolution. The 'holy grail' however is to push the resolution still further to achieve true atomic resolution in 3 dimensions. To reach this goal, a combination of two techniques is probably needed. Firstly to use a conventional tilt series approach, to investigate the atomic structure from different viewpoints and secondly to use a confocal method whereby an optical section of the sample is recorded by minimising the depth of field, analogous to confocal optical microscopy. In order to sample the whole structure a through-focal series is recorded. However the sampling resolution is far from isotropic, with perhaps sub-Angstrom resolution in the lateral plane but with nanometre resolution in the perpendicular plane. Methods need to be developed to combine the two approaches such that atomic resolution may be achieved in all 3 dimensions. The project will involve the use of a state-of-the-art aberration-corrected TEM, to be delivered to Cambridge in the near future, and computer simulations to optimise the methods and understand the results. For further information contact Prof PA Midgley (pam33@cam.ac.uk).

3-Dimensional Mesoscale Imaging and Analysis in the Dual Beam Microscope

The dual beam microscope is essentially a scanning electron microscope (SEM) with an additional ion column that allows ion beam thinning (and imaging) to be combined with simultaneous SEM studies. In the summer of 2007 the Department will take delivery of a new dual beam microscope that will allow a so-called 'slice-and-view' method to achieve a 3D reconstruction slice by slice. More than that, each freshly exposed face can be studied using electron backscattered diffraction and energy-dispersive X-ray analysis. At each image pixel, a diffraction pattern and an x-ray spectrum can be recorded such that the orientation (strain), composition and microstructure can be mapped in 3 dimensions with <100nm resolution over cubic microns of sample. Using key materials structures, especially deformed polycrystalline metal alloys, this project will focus on acquisition technology, methods to best interpret and analyse such a large data set, and to develop new image processing and data mining tools. This project will likely involve close collaboration with the instrument manufacturer. For further information contact Prof PA Midgley (pam33@cam.ac.uk).

Scanning Transmission Electron Microscopy in a Scanning Electron Microscope

The Department will shortly have installed a dual beam microscope based on a high resolution field emission scanning electron microscope. Importantly the microscope has post-specimen detectors which enables forward scattered electrons to be recorded. By scanning the electron beam, BF and DF STEM images can be recorded with beam voltages at 30kV and below. For materials composed of low atomic number species (e.g. carbon nanotubes), low voltage operation minimises knock-on beam damage. This project will develop low voltage STEM imaging in the dual beam microscope, optimising the performance of the SEM column to achieve sub nm resolution and understanding the contrast seen in the images at low voltage operation. This project will likely involve close collaboration with the instrument manufacturer. For further information contact Prof PA Midgley (pam33@cam.ac.uk).

Materials Chemistry

Cost-Effective Approach to Mineral Carbonation

Mineral carbonation involves the permanent sequestration of CO₂ by exothermic reaction with suitable natural or waste metal oxides to form geologically stable solid carbonates. Suitable oxides may be derived from widely available natural silicate minerals or from industrial waste feedstocks such as metallurgical slags. Processing of those feedstocks can result in the separation of by-product amorphous silica and trace metals. Added value may be derived, for example, where the energy or products of carbonation can be utilised, where valuable metals can be recovered, where hazardous wastes can be remediated and where CO₂ emissions are priced.

Of the various approaches to mineral carbonation that have been investigated, indirect aqueous-phase carbonation processes are considered the most promising. The focus for the first objective of the program is the development of pre-processing methods for the feedstock materials to separate pure calcium/magnesium oxides or hydroxides from silica and potentially valuable trace metal salts. The focus of research for the second object of the project is the exploration and optimisation of process materials chemistry for the fast and complete carbonation of magnesium and calcium (hydro) oxides. The role of NaOH, KOH and other additives will be investigated as potential carbonation catalysts, including quantification of regeneration. Industrial collaboration with Cambridge Carbon Capture Ltd, will be available in this project. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Sustainable Lead Batteries

Lead Acid batteries represent a recycling success story; in that 90% are already recycled and over 50% of new batteries are produced using recycled lead. However, the processes used to recover lead are in themselves environmentally unfriendly. The most common method involves smelting the battery at a high temperature (> 1000°C) to decompose the PbSO₄ in the spent battery and releasing large quantities of sulphur dioxide and Pb fumes along with CO₂ into the atmosphere. Other new solutions being trialed involve dissolving the battery with highly toxic and corrosive chemicals, and recovering the lead using capital and electrically intensive processes. Due to the environmental costs of the processes, batteries are increasingly shipped across continents for processing in countries with less stringent environmental regulations, a step which simply moves the environmental damage and which may also be restricted in the near future by EU legislation on the transport of toxic materials. A new patented process is being developed in this Department, which chemically leaches and crystallizes the battery contents into a form that can, by a simple combustion-calcination, be used directly in the manufacture of new batteries. The reactants arise from biological sources, making the process nearly C-neutral. This method was designed with the dual goals of being environmentally sound and being cost-effective to operate either locally on a small scale or on larger industrial scales. Industrial collaboration will be available for this project. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Light Weight Lead Batteries?

There is so much emphasis on producing Li base batteries for Electrical Vehicles that the most established automotive battery over 100 years has not been seriously considered for the next generation of EVs and HEVs. It is surprising given the cost advantages are by a factor of 10. Of course Pb is heavy and Li is light. In reality the active component is not lead but oxides. The heavy lead grid in the battery only serves to hold the paste and conduct electricity and can be replaced by a light modern advanced material. The active lead oxide can be made super-efficient by using nano-particles in the paste. In this project, foundations will be laid for the next generation of low-cost, light weight and high energy density lead based batteries. Collaboration with universities in China and Turkey will be available for this project. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Next generation of Lithium batteries based on sulphur – carbon nanotube electrodes

The lithium-sulphur (Li-S) battery has a very high theoretical capacity and a very high specific energy density in comparison with the well-established Li-ion batteries. A modest 50% S utilization in a Li-S battery would give an approximate specific energy density of 588 Wh/Kg of cell weight, twice that of the best Li-ion battery.

The paramount development goal in a Li-S battery is for achieving increasing sulphur utilization at large numbers of discharging – charging cycles (> 3000 at 80 % depth of discharge). The nanoscale control of cell chemistry, ion movement and electrolyte access offered by the appropriate use of conductive nanomaterials such as carbon nanotubes (and graphene) offers new opportunities to achieve this development goal.

In this project, nanostructured carbon will be incorporated within the electrode in order to achieve a high active surface area and the mesoporous morphology of the electrode material will be optimized to improve electrolyte accessibility and ion intercalation dynamics. The effect of such a structure on the reduction (during discharge) and oxidation (during charge) of the sulphur species will be investigated over a number of cycles such that chemically active sulphur is retained in the cathode without either significantly shuttling away or passivating the carbon surfaces. Conductivity within the cathode will be enhanced by optimising the conductive pathways through the electrode material via control of the shape, arrangement and distribution of the nanostructured carbon within the electrode material. Spatial arrangements between the scaffold and the current collector are another area of investigation in order to achieve significant weight reduction. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Harnessing Sunlight for Redox Reactions

Solar driven photocatalytic redox reactions on metal-oxide composite structures can be harnessed for a number of environmentally friendly processes such as disinfection of water or formation of hydrogen from water. It is crucial to understand the redox mechanism in order to improve photocatalytic efficiency, before solar energy based redox processes can lead to competitive technologies. In this project photocatalytic metal oxides nanocrystals will be hybridized with metallic elements and/or doped with non-metallic elements and redox properties investigated with respect to selected reduction and oxidation reactions. Opportunities for designing and fabricating laboratory-based solar reactors for carrying out selected redox reactions will be a crucial aspect of the project. Industrial collaboration with CAMSES Ltd will be available for this project. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Minimizing Impedance in Intermediate Temperature Solid Oxide Fuel Cells

We are currently developing IT- SOFC based on InkJet printing of the active layers. In order to decrease the operating temperature towards 550°C, it is important to optimize the overall structure of the active layers and the morphology of the anode and the cathode layers. It is expected that cathode will offer serious impedance problem as temperature is decreased. In this project, it is aimed to activate the cathode electrocatalytic performance by doping with metallic particles and nano structuring the composite cathode. The effect of incorporating nano-metallic catalysts and superoxidic metallic ion states will be investigated. Simple half cells and full fuel cells will be constructed and electrically characterized. Collaboration with Non-Ferrous Technology Centre, Hyderabad, India will be available for this project. For further information contact Dr RV Kumar (rvk10@cam.ac.uk) or Prof BA Glowacki (bag10@cam.ac.uk).

Measurement and interpretation of pyrometallurgical processes involving precious metal-bearing materials

This research project aims to improve the measurement and interpretation of our primary smelting processes, in which we smelt a range of precious metal containing spent catalysts, secondary materials, and primary materials from global mining operations. The project will involve the research, development and testing of a range of techniques to measure key aspects of the smelting processes and products. This will allow us to enhance our fundamental understanding of the smelting processes and thereby improve our product quality and first pass yield. The project will utilise analytical facilities at both the University of Cambridge and Johnson Matthey Technology Centre, which include high resolution electron optics and diffraction techniques such as EPMA, SEM/EDX and XRD, to facilitate the characterisation of products and by-products from the smelting processes. Studying for or having completed at least a 2:1 degree (or equivalent) at Master's level in Metallurgy, Materials Science or a related discipline, the successful candidate should be of outstanding calibre and keen to gain experience of industry led R&D. Candidates should be proficient experimentalists and be able to demonstrate an innovative approach to problem solving. Good project planning, interpersonal and communication skills are needed. Experience of advanced measurement and characterisation techniques for molten materials

would be an advantage. Applicants should have been ordinarily resident in the UK for 3 years prior to the start of the project so that they pay home rate fees, although students from EU countries other than the UK will also be considered. The studentship is for three and a half years, with a starting date of October 2013. (CASE Studentship in collaboration with Johnson Matthey plc). For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Novel electroless coating for producing Metal Coated Particles (MCPs)

Metal Matrix Composites (MMC) have found application of many areas of daily life. There are numerous ways of producing MMC such as powder metallurgy, foil diffusion, physical vapour deposition, etc. Using metal coated particles (MCPs) have recently been of interest. When using MCP products to form MMCs, the bonding process is only between the metal coatings. Therefore, during consolidation of the MMCs, the metal coated particles behave more like pure metal powder than many existing metal powder consolidation processes and can be utilised to fabricate new forms and types of high quality MMCs with superior properties.

Some of the advantages of the MCPs are as follows:

- Wide range of substrate materials and particle sizes.
- Superior bonding and ductility.
- Near zero scrap rates.
- Coatings can be engineered down to micron size.
- Acts as an excellent thermal spray material.
- Increase wettability.

The main aim of this project is to develop new means of producing MCPs. The novel process(s) should comprise:

- 1- *Low cost*
- 2- *Ability to be mass produced*
- 3- *Uniform particle coverage*
- 4- *Ability to apply thick or thin coatings*
- 5- *Short production cycles*

This PhD studentship is partially funded by Welding alloys Ltd (www.welding-alloys.com) and will be carried out in collaboration with Welding Alloys. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Electrodics in Gas sensors

Reactions at the electrodes must be controlled in order to develop gas sensors that can provide meaningful information. We have developed suitable catalysts in the electrode system that can provide selectivity in gaseous measurements. A number of approaches are available such as the use of auxiliary phases that can transduce partial pressure information into chemical activities and electrical signals within an electrochemical cell; or utilise differential rates of catalysis of competing reactions to harness mixed potentials; or utilise photochemically induced catalysis for changing electrical properties. In the laboratory we have successfully developed several types of sensors and many of these are licensed and industrially manufactured. In the next generation of sensing development, our aim is to expand the range of applications by focussing on the catalytic activities at the interfaces and harness the processes for obtaining smart sensing response. Our sensors platforms vary from bulk and mini-solid state electrochemical cells to metal-oxide thin films and CMOS micro-hotplates. For further information contact Dr RV Kumar (rvk10@cam.ac.uk). (Co-supervisor: Florin Udea)

Materials Modelling

Constitutive Modelling of Deformation Mechanisms in Single Crystal Superalloys

In recent years many detailed models of the deformation of single crystal superalloys have been developed based upon a number of deformation mechanisms identified in these alloys. Each mechanism gives rise to distinctive mechanical responses. However the stress and temperature ranges over which these mechanisms operate, the effect of micro-structural instabilities such as anisotropic γ' growth (rafting) and TCP precipitation and how they combine with prior damage are not well understood. Detailed observations in the TEM and SEM of the dislocation mechanisms operating in a small number of representative alloys will provide the basis for constitutive models of deformation over a range of conditions of stress and temperature critical to engine components. Central to this is an understanding of the 'deformation mechanism maps' of an alloy. This describes the temperature, stress and strain rate range over which various mechanisms operate. These include: diffusion controlled climb/glide by FCC dislocations in the γ matrix, shear of the γ and γ' by combinations of partials and stacking faults, micro-structural instabilities such as rafting and the processes leading to fracture such as raft cutting and porosity at topologically close packed (TCP) phases. Moreover, the boundaries between the different mechanisms are a sensitive function of the alloy parameters such as γ' size and volume fraction, misfit, solid solution hardening and stacking fault energy in both γ and γ' . For further information contact Prof CA Rae (cr18@cam.ac.uk).

Physical Metallurgy

Lifing of Electron Beam Physical Vapor Deposition (EBPVD) Thermal Barrier Coatings (TBCs)

Modern aeroengine turbines operate under extremely high temperatures and pressures. Traditionally, single crystal Ni-base superalloys were typically used under these severe environments. However, demands for higher efficiency and power output resulted in large temperature increases in the hot gases entering the turbine. With current gas temperatures exceeding the melting point of the single crystal alloy, ceramic coatings are necessary to minimize metal temperatures and prevent failure. The ceramic coatings are applied onto the turbine blades in a complex series of processes. With spallation of the coatings leading to the premature failure of the blade, developing a mechanistic understanding of the failure modes is critical in blade design and extending the useful lifetime of the components.

Rejuvenation of Ni-Base Single Crystal Superalloy Components

Large costs are associated with the manufacture of turbine engines and components for both power generation and aerospace applications. Consequently, service and repair of used components is a growing worldwide business. Due to the extreme operating conditions of the turbine engine environment, plastic deformation and microstructural changes often occur in components that have seen service. Careful thermal-mechanical treatments have shown great promise in restoring both the mechanical properties and the original microstructure of the component. When dealing with single crystal components, great care has to be taken to prevent recrystallization during these thermal treatments. This project will focus on investigating both the micro and macrostructural changes that occur in these complex Ni-base systems during service and the subsequent rejuvenation treatment.

Electronic Metallization for Extreme Environments

Reactions at contacts in electronic devices for service in extreme conditions

This project is part of a "Faraday" consortium involving several universities and companies. It is concerned with developing the metallic interconnects, wires and contacts for electronic devices to be embedded in aeroengines, oil-drill bits, etc. The main part of the work will be microscopy and analysis of metal contacts, looking at the influence of various factors (including electromigration) on the interdiffusion and reactions at the contacts. For further information contact Prof AL Greer (alg13@hermes.cam.ac.uk).

Chalcogenide Alloys for Data Recording

This is intended to be a CASE award with a local company Plasmon Data Systems (based in Melbourn Cambs and in California) to work on various issues associated with the phase-change material in CD-RWs and DVDs. This might include looking at the possibilities for exploiting this technology other than in discs. The project will involve electron microscopy and analysis of phase-change kinetics. For further information contact Prof AL Greer (alg13@hermes.cam.ac.uk).

Low-k dielectric materials

This is intended to be a CASE award with Trikon Technologies in Newport, Gwent. The speed of modern integrated circuits is limited by the RC time delays. The resistance R of the interconnect lines is reduced by having Cu lines rather than Al. The capacitance C can be reduced by having an insulator of lower dielectric constant than the silica which is used at present. These low-k materials are porous on a nm scale, and the aim of the project is to characterize their structure and properties. For further information contact Prof AL Greer (alg13@hermes.cam.ac.uk).

Solidification and Microstructure in Al Alloys

This project (CASE award under negotiation) is on the control of microstructure in Al alloys, involving microstructural characterization and modelling, with a strong emphasis on developing predictive models. For further information contact Prof AL Greer (alg13@hermes.cam.ac.uk).

Macromolecular Materials Laboratory

Weblink to MML PhD vacancies

<http://www.mml.msm.cam.ac.uk/opportunities>

Rolls-Royce University Technology Centre

Weblink to RR UTC PhD vacancies

<http://www.rputc.msm.cam.ac.uk/vacancies>

The University of Cambridge and the Department of Materials Science & Metallurgy value diversity and are committed to equality of opportunity.