

PhD Projects in the Dept of Materials Science University of Cambridge

The 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 available. Please note that funding has not been allocated to support these PhD projects. Prospective applicants, in particular those from overseas, should refer to the Board of Graduate Studies' website at <http://www.admin.cam.ac.uk/students/gradadmissions/prospec/index.shtml> for further information on the application process and the scholarship opportunities available through the University and Cambridge Trusts.

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Biomaterials

Optimisation of calcium phosphate bone cements for defect filling

The current, widely used methods of implant fixation and bone defect filling are still far from ideal and in response to this need for improvement the use of calcium phosphate bone cements (CPBCs) has developed. The materials consist of a powder phase which forms a plastic paste upon mixing with a liquid. The eventual phase which results from the reaction in the cement is hydroxyapatite (HA, $(\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2)$) which is one of a series of highly biocompatible calcium phosphates and closely resembles the mineral component of bone. Although these materials are extremely promising in terms of the in-vivo bioactivity, there still remains a great deal of room for improvement both biologically and in terms of mechanical stability with time. This project will involve the development of cements which provide reproducible and enhanced properties in terms of phase composition, crystallinity and biological and mechanical performance and, by incorporating or engineering the evolution of novel substituted apatites with compositions more closely matched to bone mineral than hydroxyapatite, a method of increasing bone integration may be developed. For further information contact Prof Serena Best (smb51@cam.ac.uk).

Mechanical characterisation and processing of substituted apatites

The benefits of "substituted apatites" (hydroxyapatite-based materials with physiologically relevant (bone-like) ionic lattice substitutions) have now been established. Although the materials are now on the verge of clinical application and technology transfer to industry, there is still a great deal more work which needs to be conducted to fully understand the structural and mechanical implications of the ionic substitutions. Detailed investigations are required to provide data on the static and dynamic mechanical behaviour and processing properties of the materials to take them forward from granules for defect filling towards a whole raft of different applications ranging from bioactive porous orbits to middle ear implants. For further information contact Prof Serena Best (smb51@cam.ac.uk).

Calcium phosphate Gels as injectable bone repair systems

Current figures show that only 8% of the bone graft market is comprised of synthetic materials and of these, the main commercially available source of hydroxyapatite (HA) is from coralline and bovine sources. There is a great deal of scope for improvement of materials developed for defect filling and augmentation. The development of highly bioactive, injectable calcium phosphate materials will be investigated using physical, chemical and biological analyses. The materials will be investigated as purely synthetic systems but also with a view to the incorporation of biological moieties. The systems developed will be studied in-vitro using the unique wet system capabilities provided by environmental scanning electron microscopy and confocal microscopy. For further information contact Prof Serena Best (smb51@cam.ac.uk).

Thin film substituted calcium phosphate coatings

In the search for bioactive implants for major load bearing applications, interest has been directed towards the use of calcium phosphate coatings on metallic substrates. The vast majority of research and development has been concentrated on plasma sprayed coatings and these are widely used in the orthopaedics industry. However, the disadvantage of plasma sprayed coatings is that they often contain microstructural defects and may have variable phase compositions and crystallinity. RF-Magnetron Sputtering offers the potential to apply thin coatings of controlled chemistry and phase composition to metallic and polymeric substrates. The project will involve the deposition and characterisation of hydroxyapatite and substituted apatite coatings using scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD) and FT-infrared spectroscopy and coating evaluation using biological testing techniques. For further information contact Prof Serena Best (smb51@cam.ac.uk).

Formulation and production of bioactive glass ceramics

There is an ever expanding range of possible applications for materials produced through the glass ceramics route. As a class of materials, ceramics alone allow the selection and optimisation of material composition to enhance bioactivity. This project will encompass the advantages of near net shape forming, the ability to produce fully dense ceramic components with controlled microstructures and

optimisation of chemical composition the development of bioactive glass ceramics. Through research into new formulations, a new family of strong, tough, bioactive materials with potential for application in major load bearing applications will be developed. For further information contact Prof Serena Best (smb51@cam.ac.uk).

Mechanical evaluation of ceramic articulating surfaces

The orthopaedics industry has highlighted as a priority the need for the improvement of the wear performance of the articulating surfaces in hips and knees. Current solutions include the use of ceramic femoral heads and knee surfaces, but there are still major problems in terms of implant lifetimes. There is a need for the development of improved materials and processes that must be economically viable in industry. Areas of investigation will include optimisation of the performance of ceramic / ceramic systems and investigation of the potential for functionally graded metal / ceramic components. The scope of the project will range from mechanical evaluation through to ultramicroscopic examination of structures using electron microscopy. For further information contact Prof Serena Best (smb51@cam.ac.uk).

3D structures from resorbable polymers

Poly(glycolic acid) is a biocompatible, biodegradable, semi-crystalline polymer which is approved for use in the body. It is used to make resorbable sutures and recent and ongoing research in this lab has focused on its development as a controlled drug delivery matrix. This project will centre on the production and properties of controlled foams of poly(glycolic) acid and other biocompatible resorbable polymers. The physical properties of the foams, their potential as a drug carrier and the relationships between microstructure and release will be examined. Sintering of foam particles will be explored with the aim of producing degradable foam structures for mechanical wound support or tissue engineering applications. A wide range of physical techniques will be applied. For further information contact Prof Ruth Cameron (rec11@cam.ac.uk).

Modelling of resorbable polymers: interplay of microstructure, reaction and diffusion

Newly developed hierarchical computer modelling procedures will be employed to model the behaviour and consequent drug release profiles in resorbable polymer systems. These procedures involve molecular dynamic regimes (atomic level), lattice mesoscale models with chain detail and fully macroscopic models (such as those used to model Case II diffusion). Our experimental results on poly(glycolic acid) have allowed us to develop a conceptual model of the interplay between diffusion, reaction and drug release profile. The model is in some senses similar to Case II diffusion. By changing the boundary conditions of the model, it should be possible to explore the behaviour of other resorbable polymers in the poly(glycolic acid) / poly(lactic acid) system. This will be a mainly computational project, but will involve close liaison with experimental groups. For further information contact Prof Ruth Cameron (rec11@cam.ac.uk).

Drug delivery from biocompatible coatings

Biocompatible coatings can enhance to performance of a range of medical devices by facilitating a functional interface between the implant and the body. This project takes the further step of considering the incorporation and release of drug molecules from such coatings, designed to give highly localised and controlled delivery of drugs around the device. Physical, chemical and biological information will be combined to gain the understanding required to design devices with appropriate tailored drug release profiles. For further information contact 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) or Dr AE Markaki (am253@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).

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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.

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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).

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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) or Dr AE Markaki (am253@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).

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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 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 rivalling 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

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).

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

In the electrocaloric effect, electrically insulating materials undergo changes of temperature/entropy due to changes in applied electric field, i.e. changes of voltage drive them hot and cold. Electrocaloric materials have therefore 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 Dr 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 Dr 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

Multiferroic thin film devices

Ferromagnets tend to be metallic, and ferroelectrics must be insulating or else they depolarise. Surprisingly, a few materials are both ferromagnetic and ferroelectric, i.e. "multiferroic". The aim of this project is to enhance the properties of thin film candidate materials, and fabricate devices in order to investigate the coupling of the ferromagnetic and ferroelectric order parameters, e.g. to switch the magnetic state by applying an electric field. Appropriate oxide films, grown by pulsed laser deposition, will be electrically and magnetically characterised using a range of techniques, including local probes in the form of piezoforce microscopy and magnetic force microscopy (both of these techniques use an appropriately configured atomic force microscope). For further information contact Dr ND Mathur (ndm12@cam.ac.uk).

Mesoscopic texture in manganites

Radically different phases can coexist over radically different lengthscales in the manganites [1,2]. This is because the magnetic, electronic and crystal structures of these exotic oxides of manganese interact strongly with one another. Surprising new phases [3] and surprises about the old phases [4] make this field exciting. The aim is to create patches of one phase within another at controlled locations in thin film devices. In this project, such patches will be examined using magnetometry and electrical transport measurements. For further information contact Dr ND Mathur (ndm12@cam.ac.uk).

[1] *Mesoscopic texture in manganites*, Neil Mathur and Peter Littlewood, *Physics Today* **56** (January 2003) 25-30

[2] *Nanotechnology: The Third Way*, Neil Mathur and Peter Littlewood, Nature Materials **3** (2004) 207-209

[3] *Charge-ordered ferromagnetic phase in La_{0.5}Ca_{0.5}MnO₃*, JC Loudon, ND Mathur and PA Midgley, Nature **420** (2002) 797-800

[4] *Weak charge-lattice coupling requires reinterpretation of stripes of charge order in (La,Ca)MnO₃*, JC Loudon, S Cox, AJ Williams, JP Attfield, PB Littlewood, PA Midgley and ND Mathur, available at <http://lanl.arxiv.org/abs/cond-mat/0308581>

Development of high magnetic field high critical current A-15 conductors for use in NMR and cryogen free magnets utilisation of the novel reduction of oxides process

The ternary alloyed Nb₃Al intermetallic is recognised by the superconductivity community as an excellent source for future superconducting multifilamentary conductors capable of operation at magnetic fields of much higher than 25 Tesla and under extreme mechanical and irradiation conditions such as will occur in the International Thermomolecular Experimental Reactor. The development of high-critical-current superconducting A-15 conductors able to carry a current in very high magnetic fields (25-30T) is recognised as an enabling technology for the construction of second-generation NMR magnets operating at frequencies well above 1GHz. This project will involve the study of changes of critical temperature (T_c), critical current (J_c (B)) and lattice parameters of the Nb₃(Al,Ge) phase formed during the diffusion process of wires manufactured by advanced infiltration processes of the porous Nb-based rods manufactured by Direct Electrochemical Reduction in collaboration with Prof. D.Fray. The understanding of the correlation between the diffusion of Al and Ge from an internal reservoir to the niobium filaments, and of the uniform properties of intermetallic diffusion Nb₃(Al,Ge) layers formed during multistage heat treatment, is essential for further improvement of the superconducting properties of conductors manufactured world-wide. This project if continued as a PhD project will involve interaction with numerous International companies and research institution including visits to two famous Japanese Research Centres. This project is expected to have a full industrial support. For further information contact Dr BA Glowacki (baq10@cus.cam.ac.uk).

The continuous infrared zone melting process for production of superconducting coatings

Yttrium-based superconducting coatings, such as YBa₂Cu₃O_{7-?} can be successfully fabricated using a semi-wet extrusion process and on-line infrared zone melting technique. The aim of this project is to achieve continuous superconducting coating, characterised by a high transport critical current. The study will consist of optimising the phase composition, microstructure, texture and electromagnetic properties of coatings by varying the processing parameters, such as, melting velocity, and temperature and atmosphere of post-annealing. The successful, optimised process for manufacture of the coatings, characterised by the highest transport critical current, will be publicised and could be used to wind the first high T_c superconducting YBCO conductor for underground energy power transmission. For further information contact Dr BA Glowacki (baq10@cus.cam.ac.uk).

Development of High Critical Temperature Superconducting and Magnetic coatings by ink-jet printing

Continuous spray pyrolysis and sol-gel ink-jet printing of superconducting suspensions on metallic substrates is one of the cheapest and successful methods of making superconducting tapes which are capable of carrying very high currents in a high magnetic field. The technique appears to be very promising and is covered by a patent. The novel technique of deposition of acid solutions (nitric, propionic and acetic) of nitrate salts of "YBCO" and "Bi-2212" composition, has been developed on the base of commercially available ink-jet printing equipment. This project will involve detailed study of the influence of the chemical composition of the solutions to optimise the nominal cation stoichiometry in respect to minimising the amount of the impurity phase and maximisation of the critical temperature using combinatorial methodology. Optimisation of the quality of the high temperature superconducting films will need to take thermodynamics, and the structure and chemistry of the matching materials into account. At the same time a great deal of fundamental work is needed to understand the mechanisms of textured growth. The deposition technique will be fully computerised with the existing interface unit to create a virtual laboratory working environment. Wide applicability of the developed technology can be easily transferred to other area of electroceramic devices and even rapid prototyping. This project will

involve research visits to Gent University and participation in EU funded Interdisciplinary and international Brite-Euram project. This project is expected to have a full industrial support. For further information contact Dr BA Glowacki (bag10@cus.cam.ac.uk).

Formation of native cube textured oxide on a flexible NiFe tape substrate for superconducting coated conductor applications

The oxidation behaviour of NiFe tape with a well developed cubic (100)<1001> texture will be investigated in an attempt to develop buffer layers suitable for deposition of well aligned superconductors. An initial research conducted in the vacuum chamber indicates that reoxidation of the tape leads to the formation of a nickel-iron oxide with an excellent cube texture, having in-plane and out-of-plane X-ray FWHMs of around 8 degrees. The project will demonstrate how an oxide layer with an excellent cube texture may be produced on the surface of the NiFe tape by a simple two-stage oxidation process. For further information contact Dr BA Glowacki (bag10@cus.cam.ac.uk).

Changes of critical temperature and stoichiometry of the superconducting Nb₃Sn phase formed during the reactive diffusion process in superconducting wire

A multilayer jelly-roll wire manufactured by the "internal tin" will be investigated. The project involves in-situ studies of the formation of the superconducting Nb₃Sn layers (using differential thermal analysis and electric measurements) in relation to critical temperature (measured by ac susceptibility) and conductor morphology. The results will be assessed on the basis of microscopic observations of the development of Nb-Sn phases during multi-stage diffusion processes. Magnetic properties, in correlation with the cross-sectional microstructure, will be studied in order to define interfilamentary bridging and phase formation during heat treatment. The results will be published as a part of the on-going research on the development of a new generation of intermetallic low temperature superconducting conductors for the Large Hadron Collider in CERN. For further information contact Dr BA Glowacki (bag10@cus.cam.ac.uk).

Superconducting properties of Cu-MgB₂ and Fe-MgB₂ conductors

The new exciting class of recently discovered Mg-B superconducting conductors will be prepared using the standard in-situ and ex-situ powder-in-tube, PIT, method where Mg+2B mixture will be used to fill the copper and iron tubes. Study of the intergranular current, grain connectivity and superconducting phases in wires were conducted by AC susceptibility measurements and direct four point transport measurements. Using SQUID magnetometer, magnetisation versus magnetic field (M-H) curves of the round wires after reactive diffusion will be measured at temperatures 5K and magnetic field up to 5T to define the magnetic critical current density J_{cmag} . The direct current density measurements of the in-situ Cu-MgB₂ and Fe-MgB₂ will be performed at 4.2K and expected in the range of 1010 Am⁻². The results will be published as a part of the on-going research on the development of a new generation of intermetallic medium temperature superconducting conductors Magnetic Resonance Imaging, MRI magnets. For further information contact Dr BA Glowacki (bag10@cus.cam.ac.uk).

Development of a simultaneous pulse transport current and pulse magnetic field measurements method for characterisation of high field superconductors

The high temperature superconducting, HTS, conductors are already used in hybrid magnets to produce fields enhancing the fields of conventional magnets made from A-15 type low temperature superconducting, LTS, wires. Therefore for usage of HTS superconductors in high-field applications, it is vital that the interdependence of the critical parameters such as critical current vs magnetic field can be mapped under high field and high current conditions. However, the latest superconductors have high currents even at fields over 20T, making accurate measurements very difficult due to the thermal and mechanical problems. This project is focused on further development of the pulse-pulse system where analysis of the voltage signal from superconducting conductors and samples in pulsed conditions may be used to extract the critical current density in quasi-stationary conditions. This innovative pulsed high transport current and pulsed high field technique will be compared with DC current and DC magnetic field measurements using a Bitter type magnet. This project will involve research visits to Clarendon Lab, Oxford University and International Laboratory of High Magnetic Fields and Low Temperatures in Poland. For further information contact Dr BA Glowacki (bag10@cus.cam.ac.uk).

Basic Oxide Interface studies

In the last few years, there has been a plethora of very exciting reports in the top journals on new properties at the interface between two oxides having dissimilar functions. New kinds of interfaces, new ways to control them, and state-of-the-art probing of them are needed to understand what is going on and how to tune them. This project involves growth of oxides by different physical and chemical methods, and their measurement by a variety of means including basic electrical measurements and atomic force microscopy (scanning probe) techniques. For further information contact Prof J Driscoll (jld35@cam.ac.uk).

Photovoltaics

Achieving stable, efficient, cost-effective photovoltaics is at the heart of a greener world. 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 J Driscoll (jld35@cam.ac.uk).

Vertical Checkerboard Multifunctional Thin Films

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. Utilising vertical heteroepitaxial nanocomposite (VHN) films to create new, self-assembled device architectures and multifunctionalities is a novel concept having emerged only in the last five years or so. This project will explore a range of functional nanocomposites for achieving enhanced and novel multifunctionalities, e.g. obtaining a better ferroelectric or a new magnetoelectric. For further information contact Prof J Driscoll (jld35@cam.ac.uk).

Improving materials for nitride single photon sources

Quantum dots are nanoscale crystals which exhibit atom-like properties. We aim to exploit these characteristics in the development of optoelectronic devices based on single InGaN quantum dots. For example, we have demonstrated the first quantum dot single photon source emitting in the blue spectral region. This device is based on the quantised nature of the energy levels in the InGaN quantum dot structure, which prevent it from emitting multiple photons simultaneously. However, in order to develop a practical device from our prototype, a number of aspects must be improved including increasing the extraction efficiency of photons from the device, reducing the time-jitter on the photon emission and achieving reliable operation from an electrically-driven device. These challenges can only be overcome by making significant improvements to the quantum dot materials themselves and the layers that surround them in the device. New device processing routes are also required. For further information contact Dr RA Oliver (rao28@cam.ac.uk).

Multi-microscopy imaging of nitride semiconductors

Nitride semiconductors have widespread application in optoelectronic devices and are being developed for high power electronic devices. In order to improve the performance of these devices we need to understand their structural and electrical properties on a micro- to nano-metre scale. The key strategy of microscopy work in the Oliver group is to combine multiple microscopy techniques to develop a comprehensive understanding of nanostructures and defects in the nitrides, and to link these discoveries to nanoscale measurements of the optical and electrical properties. This requires a synergy of different techniques, ranging from techniques commonly used on metals (such as atom-probe tomography) to techniques which focus exclusively on semiconductors (such as scanning capacitance microscopy). It also requires the development of new approaches to the application of these techniques, to allow the same nanoscale regions of material to be assessed in multiple microscopes, so that the structure and composition of a specific nanostructure may be linked directly and unambiguously to its electrical and optical properties. Overall, the aim is to provide a much more complete picture of nitride materials science than has ever previously been achieved, and to apply this new understanding to engineering improved materials for nitride optoelectronic devices. For further information contact Dr RA Oliver (rao28@cam.ac.uk).

Highly efficient polarised light emitting diodes

Non- and semi-polar nitride materials have potential application in polarised light emitting diodes for future display technologies. This project will aim to reveal the fundamental issues that control the optical properties of non- and semi-polar nitride structures, and hence to develop highly-efficient polarised light emitters. A key question is the impact of the microstructure of the light emitters on their properties, in particular the effect of defects such as stacking faults and dislocations, and of the nanoscale structure of the quantum wells which form the active region of the devices. Microstructural data will be linked to measurements of the optical and electrical properties of the materials, and used to guide future materials development. For further information contact Dr RA Oliver (rao28@cam.ac.uk).

Growth and characterisation of GaN-based high temperature devices

Gallium nitride not only emits intense light, it should also be possible to make transistors from this material, which operate at a much higher temperature than Si or GaAs transistors. There is a considerable need for such transistors to be used as the control electronics in high temperature aerospace engines, for example. This project is to study the materials factors that limit the high temperature operation of GaN-based devices and to grow such devices in our GaN growth system, and to characterise the materials using advanced electron microscopy and other techniques. This is an exciting project to produce transistors which operate at much higher temperatures than Si transistors. For further information contact Prof CJ Humphreys (colin.humphreys@msm.cam.ac.uk).

Atomic resolution studies of gate oxides and Interfaces in devices

As semiconductor devices shrink in size it becomes increasingly important to measure gate oxide thicknesses, for example, with atomic scale precision. It is also necessary to understand in detail the bonding at the interface between Si and its oxide. In this project a highly focused electron beam will be used to image interfaces in semiconductor materials at atomic resolution, and electron energy loss spectroscopy will be used to determine the changes in chemistry and bonding on going across interfaces in semiconductor devices. The research will be performed in part on state-of-the-art electron microscopes in our Department, and will also use state-of-the-art electron microscopes at a new facility which has recently been constructed at Daresbury Laboratory. This exciting project combines electron microscopy and analysis at atomic resolution with state-of-the-art electronic devices in which the gate oxide thicknesses are only about 1nm thick. For further information contact Prof CJ Humphreys (colin.humphreys@msm.cam.ac.uk).

Growth and characterisation of ultra-bright GaN-based LEDs

Gallium nitride is probably the most important new semiconductor material since silicon, and it is generating huge international interest. The department has recently had installed the latest state-of-the-art growth system for GaN (a Thomas Swan MOCVD system) and this project is to grow ultra-bright LEDs. GaN emits intense blue light, and if alloyed with In to produce InGaN, light of any colour can be produced. Red, yellow and green LEDs are already more efficient than thermionic light bulbs and are being used in traffic lights. However, white LEDs are currently less efficient than light bulbs. This exciting project is to study how to increase the efficiency of white LEDs, and to make such devices. The device structures will be characterised by advanced electron microscopy and other techniques. If really successful, this project will enable all the light bulbs in the world to be replaced with GaN-based LEDs! These last 100 times longer than light bulbs and will consume less energy thus reducing electricity consumption and CO2 emissions from power stations. For further information contact Prof CJ Humphreys (colin.humphreys@msm.cam.ac.uk).

Contacts to GaN-based devices

An absolutely key element of fabricating devices is the metal-semiconductor contact. To obtain good contacts on GaN and AlGaN, multilayer metals such as Au/Ni/Ti/Al must be deposited on top of the GaN or AlGaN and then annealed. The metals react with each other and with the GaN to form a range of compounds (for example TiN, NiAl, etc.), and the reason why a particular contact is good is poorly understood. This project will use a range of advanced electron microscope techniques to characterise the complex microstructures and phases present in contacts on GaN/AlGaN and to understand the

factors that are important in producing good ohmic contacts, so that these contacts can be optimised. For further information contact Prof CJ Humphreys (colin.humphreys@msm.cam.ac.uk).

Electron holography of GaN structures

GaN and InGaN are piezo electric and when internal strains are present in the materials, internal voltages are developed. Hence voltages are developed at dislocations, which are highly charged, at strained quantum well layers of InGaN grown in GaN, etc. The effect is very strong in GaN and it is important to understand this for its effect on device operation. Electron holography is a powerful method of measuring the internal electric fields present in materials, and this exciting project will apply the technique of electron holography to solve a variety of problems in gallium nitride-based structures. For further information contact Prof CJ Humphreys (colin.humphreys@msm.cam.ac.uk).

Electron energy loss spectroscopy (EELS) of defects in GaN

Dislocations and other defects in gallium nitride are believed to have states in the band gap which act as recombination centres and reduce the light emission. This project will use EELS to measure these defect states. This important project will require a very good understanding of the theory of EELS and very careful experiments using our state-of-the-art equipment. For further information contact Prof CJ Humphreys (colin.humphreys@msm.cam.ac.uk).

Doping contrast from semiconductors

As semiconductor devices shrink in size it becomes increasingly important to develop new techniques to measure doping levels, and image p-n junctions, from very small regions. Recently a new technique has been developed for this, which is causing considerable world-wide interest, which uses a field emission gun scanning electron microscope (SEM). The intensity of the secondary electrons scattered from a semiconductor is a very sensitive function of the doping concentration, and p-n junctions can be mapped out using this technique. However, the theory of what is happening is not well understood and the technique is not yet quantitative. This project is to develop the theory and make the effect quantitative. For further information contact Prof CJ Humphreys (colin.humphreys@msm.cam.ac.uk).

Fabricating nanowires and nanostructures using electron beams

This exciting project is to make nanowires possibly only one atom thick. If wires are very thin, their electrical properties change dramatically, for example, even a law as fundamental as Ohm's Law no longer holds for very thin wires. The wires will be fabricated using intense electron beams in an electron microscope. Their electrical properties will then be measured. It is then planned to make single electron transistors (SETs) using such wires which will operate at room temperature. These nanoscale devices may replace 'conventional' Si chips in future computers etc. because they will be much smaller and much faster than current devices. For further information contact Prof CJ Humphreys (colin.humphreys@msm.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

Fabrication of a new class of biosensors

This research project is concerned with developing composite ionic and electrodic materials for a new class of "biosensor" aimed at better monitoring of a disease to clinical treatment. In this project there will be opportunity to work in close collaboration with the Institute of Biotechnology at University of Cambridge and Department of Chemistry at Queen Mary University of London. It is aimed to use this glucose sensor as the model for the next generation of biosensors for detecting cancer using synthetically derived detecting agents ("synzymes") which are currently being developed. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

High conductivity solid electrolytes for solid oxide fuel cells for operating at a low temperature

The aim of this research project is to investigate the possibility of developing a suitable solid electrolyte system that can help lower the operating temperatures of solid oxide fuel cells from over 1200 K to possibly lower than 1050 K. This will allow the replacement of expensive and fragile ceramic interconnects with metallic interconnects in a fuel cell stack making substantial differences to the capital and the operating costs. It is envisaged that the electrolyte systems will be based upon multi-doping and/or multi-layering.. Multi-doping will be used to optimize the defect chemistry such that ionic conductivity is maximized, while multi-layering can provide the opportunity to select the most stable layer for contacting the fuel at the anode and the oxidant at the cathode with the intermediate layers for grading. Industrial collaboration is available with Henson Ceramics Ltd. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

A novel type of CO sensors

Despite a great progress in gas sensing technology, there is no suitable CO sensor available that can be used for in-situ detection of CO in gas mixtures, such as in hot exhaust gases in automobiles or stacks. Using a novel approach, CO will be measured indirectly by allowing CO to react and come to equilibrium with oxygen adsorbed on a catalytic surface attached via an electrode to a suitable solid electrolyte. In this project, an optimum combination of the solid electrolyte, electrode containing the catalyst and the operating temperature will be developed. Such a sensor, it is envisaged, will result in rapid industrial usage. Industrial collaboration with Environmental Monitoring & Control Ltd is available. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Opto-ionic Sensors

A novel approach is being investigated that can utilize the optical properties of ionic compounds for non-destructively evaluating the performance, quality and properties of ceramic coatings. A doping strategy will be evaluated for a selected ceramic such as partially or fully stabilized zirconia. This new method can have a major impact in manufacturing, operation and maintenance in many areas such as fuel cells, turbine blades, sensors and other engineering structures/ components. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Li-S Battery

Using novel ideas , batteries using Li anode and Sulphur cathode will be developed in order to achieve ultra high levels of energy and power density for the next generation of applications. Particular focus will be made on optimising the S composite cathode using nano-particles with a view to increase sulphur utilization and minimize fading with cycle life. This work will be carried out in close collaboration with Oxis Energy Ltd. 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. 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 $PbSO_4$ in the spent battery and releasing large quantities of sulphur dioxide and Pb fumes along with CO_2 into the atmosphere. Other new solutions being trialled 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. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

Novel sulphurous sensors

Despite more than 2 decades of research using solid electrolytes, sulphurous sensors for detection of gases such as SO_2 , SO_3 , H_2S have not progressed beyond the laboratory. Some recent developments in this Department has offered new opportunity for translating the scientific work into an industrial practice. In collaboration with Environmental Monitoring & Control Ltd and Greenbank Ltd, it is intended in this project to develop the sulphur suite sensors for application in exhaust gases. For further information contact Dr RV Kumar (rvk10@cam.ac.uk).

The aluminium/air battery

The aluminium/air battery is a device which is capable of supplying high currents. Its anodic reaction consists of oxidising aluminium to give dissolved aluminium ions, the cathode being reduction of oxygen from air. In order to dissolve the aluminium, aggressive electrolytes are used; typically these would be chloride solutions or strongly caustic solutions. Because of the high energy density and power density of aluminium, the battery has potential applications in a variety of fields. This project will investigate both the aluminium anode and the air cathode reactions with the object of improving the devices. Aluminium anode will be made of designed alloy composition in order to lower the anode potential as much as possible, as well as to raise the anodic current. One of the problems with activating the anode too far is that a degree of self-corrosion can dominate the reaction. Self corrosion is caused by cathodic decomposition of water and dissolution of aluminium. This parasitic reaction reduces the anode efficiency and its lifetime. By suitable alloy design and electrolyte composition, the self corrosion process can be reduced significantly. The project is suitable for graduates in materials science, metallurgy or chemistry. Applicants should have an interest in electrochemistry. For further information contact Prof GT Burstein (gtb1000@cus.cam.ac.uk).

New methods of detection and measurement of sensitisation of stainless steels

Stainless steels are notoriously prone to sensitisation of the grain boundaries to corrosion. The phenomenon arises because under appropriate heat treatment, the carbon and chromium components precipitate in the metal phase to form chromium carbides, and an associated depletion in chromium in the alloy matrix around the precipitate. The problem is exacerbated by the presence of a high carbon content, but can be observed in lower carbon steels as well. Such sensitised steels are prone to intergranular corrosion and to stress-corrosion cracking. Because the grain boundary region can show composition variation over very small dimensions, testing for sensitisation can sometimes be difficult. The present project will investigate new methods of measuring sensitisation. The work will focus on the behaviour of microelectrodes in aggressive solutions. Measurement of the thermal response of the corrosion system will also be carried out using a technique specially developed in the laboratory. The

research will generate new methods of analysis, more sensitive than has hitherto been possible. It will also develop a better understanding of the mechanisms involved. The research will be carried out in the corrosion laboratory. For further information contact Prof GT Burstein (gtb1000@cus.cam.ac.uk).

Electrocatalysts made from base materials as electrodes for fuel cells

Low temperature fuel cells currently require platinum based materials to function as the electrocatalyst, both for the anodic oxidation of the fuel and for the cathodic reduction of oxygen. Whilst these catalysts work well, they suffer from some disadvantages. The cost of platinum is huge, and large-scale use of the metal as might be anticipated by for example, fuel-cell powered vehicles, would make the cost even higher. One potential solution to this is to research into possible electrocatalysts made from base materials. This difficult task requires the candidate materials to have a number of properties. Apart from catalytic activity, the material must also be resistant to corrosion in the potentially aggressive fuel-cell electrolyte. Resistance to corrosion for an acidic electrolyte requires passivity. This project will carry out research into possible electrocatalysts made from base materials which are both electrocatalytic towards the reactant, as well as passive towards corrosion. Preliminary work has shown that materials based on metal carbides can show a low degree of electrocatalytic activity. Although the electrocatalytic activity is currently very low, the mechanisms of anodic oxidation of fuel are different for these materials, and further developments can be made. For example, some can be tailored to catalysis for hydrogen or for methanol. These materials also show a remarkable degree of resistance to poisoning by carbon monoxide, a problem that arises with platinum based catalysts. For further information contact Prof GT Burstein (gtb1000@cus.cam.ac.uk).

Corrosion in reinforced concrete in oil wells

This project will investigate corrosion of steel as well as some other materials as might be used in oil wells. Of particular interest is the behaviour within the concrete well casing, and the interaction with sea water at elevated temperature. The research will consist of electrochemical examination of the problem, including anode and cathode reactions, as well as analytical methods of microscopy and x-ray diffraction. Some aspects of systems design will also be involved. Possible methods of inhibition will be investigated through variations in alloy composition as well as by modification of the concrete mix. This project is of interest to anyone with a first degree in metallurgy, materials science or chemistry, with an interest in electrochemistry and/or corrosion. For further information contact Prof GT Burstein (gtb1000@cus.cam.ac.uk).

Materials Modelling

First principles modelling of the surface reactivity of fuel cell electrodes

This project involves performing density functional theory (DFT) calculations of the surface structure, chemistry and reactivity of selected anode materials associated with the design of new high temperature electrolyser/fuel cell systems. Possible materials include $\text{La}_x\text{Sr}_{1-x}\text{MnO}_{3-\delta}$, $\text{La}_x\text{Sr}_{1-x}\text{FeO}_{3-\delta}$, $\text{La}_x\text{Sr}_{1-x}\text{Co}_y\text{Fe}_{1-y}\text{O}_{3-\delta}$ and $\text{Ba}_x\text{Sr}_{1-x}\text{Co}_{0.8}\text{Fe}_{0.2}\text{O}_{3-\delta}$. The calculations will proceed in parallel with experimental studies on the same materials performed in collaboration with groups at MIT and Tsinghua University. The combined project aims to develop high-efficiency, regenerative solid oxide cells and stacks for liquid fuel production from the co-electrolysis of steam and carbon dioxide using nuclear energy as the high-temperature heat source. This is a new technology that enables nuclear plants to store energy and to operate in a load-following mode. The research focuses on materials behaviour and process design, using advanced experimental and computational methods, to optimize the longevity and cost-effectiveness of the technology. The Tsinghua group are performing the electrochemical testing and performance optimisation, the MIT group are characterising the oxide surfaces and gaseous reactions and the Atomistic Simulation Group at Cambridge are performing the density functional modelling to address the key issues of electrode stability and degradation. For further information contact Dr P D Bristowe (pdb1000@cam.ac.uk).

Atomistic and density functional modelling of transparent conducting oxides

The emergence of impurity-doped ZnO and SnO₂ as attractive alternatives to indium tin oxide for use in transparent conducting (TCO) electrode applications (e.g. solar cells) has produced a flurry of experimental measurements but no clear strategy based on theory for fabricating the materials so as to obtain the best electronic and optical properties. The problem is that the key electrical parameters of the TCO, i.e. the resistivity, the carrier mobility and the carrier concentration are strongly dependent of the deposition conditions which include the oxygen atmosphere (affecting stoichiometry), film thickness (affecting crystallinity and grain size) and the deposition rate (affecting stress state). In this project, a combination of classical atomistic simulations and first principles quantum mechanical calculations will be used to investigate the effect of stress and chemical environment on the microscopic properties of various donor and acceptor doped alloys of ZnO and SnO₂ in both crystalline and amorphous form. For further information contact Dr PD Bristowe (pdb1000@cam.ac.uk).

Atomistic simulations of interfacial complexions

The presence of internal interfaces in a material whether intergranular or heterophase and can have a significant effect on mechanical, electrical and optical properties. Until recently only the simplest interfaces having clean, abrupt and periodic structures have been characterised experimentally and simulated at the atomic level. It is known, however, that most interfaces are not simple and can exhibit their own phases which have a complex structure and chemistry depending on processing environment. Intergranular films, for example, have often been observed to form in ceramic materials, particularly oxides, and have characteristic features such as an equilibrium thickness. Recently, the types of interfacial phase that can form in general have been categorized using thermodynamics and kinetics and are called "complexions". Six different types of complexion are proposed ranging from a clean grain boundary to an amorphous intergranular film. In this project, classical atomistic simulations will be used to investigate the existence and properties of the range of proposed complexions and the conditions necessary for complexions to transform from one type to another. For further information contact Dr PD Bristowe (pdb1000@cam.ac.uk).

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, microstructural 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 Dr 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).

Polymers and carbon nanotubes

Smart carbon nanotubes fibres

Modern intelligent materials, or *smart materials*, are materials especially designed to respond to an external stimulus, which could be mechanical, electrical, chemical, thermal or magnetic. Examples include shape memory alloys, photonic fibres and polymer electronics. On the other hand, carbon nanotubes have been well recognized as one of the most promising emerging materials for the next generation of commercial products. This project aims to exploit the potential of carbon nanotube fibres prepared by a unique process developed in this Department to be used as smart fibres. In particular, the project is aimed at understanding the coupling between mechanical stress and electrical and thermal conductivities, in terms of the internal structure of the nanotube fibres. Such knowledge is an essential precursor to opening up the market potential for sensor and actuator applications. Physical properties of the carbon nanotube fibres will be measured as a function of process parameters and the relationship between these properties will be assessed. Microstructural changes will be followed by scanning and transmission electron microscopy, X-ray diffraction and Raman spectroscopy. For further information contact Prof AH Windle (ahw1@cam.ac.uk).

Nanotube fibers spun from liquid crystalline suspensions

It has recently been demonstrated in this laboratory that suspensions of carbon nanotubes can form liquid crystalline phases. This project aims to develop a process to spin nanotube fibers from liquid crystalline suspensions, which is similar to that used in making the world's strongest widely available polymer fiber, Kevlar. One application for nanotube liquid crystals is high tensile strength fibers. The objective of this project is to develop our understanding of liquid crystallinity of nanotube suspensions with the objective of developing a new route to nanotube fibres. Defect interactions, rheologies and external field effects will be studied in the context of the appropriate phase diagram using microscopic, Raman and scattering techniques. Exploring the parameter space of processing conditions will provide key factors to control nanotube alignments in the fibres. For further information contact Prof AH Windle (ahw1@cam.ac.uk).

Nano materials for the hydrogen economy

Global warming is becoming a key issue which is beginning to influence national science strategies. The problem with CO₂ emissions from motor vehicles is that it is not as economic to trap the CO₂ as at centralised power stations. There is thus a drive towards hydrogen fuelled fuel cell powered vehicles. The challenge is to find a sensible, on board, hydrogen storage technology. Nanotubes and nanofibrous materials have opened up the possibility of using lightweight, nano-scale structures for the purification and storage of gases. If realised, these high surface area materials could be used in a variety of environments as filters and/or membranes, or as sponge-like materials storing gaseous products as part of a storage system.

Apparatus that has been purpose built for the investigation of gas storage properties will be used to identify those structures capable of reversibly adsorbing combustible gases at room temperature. The objective is now to explore the gas absorption (and adsorption) properties a wide range of nano materials, many of which are being synthesised in the department. The project will involve the development of measurement techniques, the modifications of nanoparticulate materials, and their structural and chemical characterisation. For further information contact Prof AH Windle (ahw1@cam.ac.uk).

Electro-magnetic energy transfer into the carbon nanotubes

Many standard thermoplastic materials that could be used for enclosure of electronic systems (computers, televisions, mobile phones, etc.) are transparent to the low frequency electromagnetic radiation (eg. radio frequency). The fascinating property of electro-magnetic energy adsorption by carbon fibre materials have been already exploited in many applications ranging from computers to building structures. There is initial evidence that carbon nanotubes, especially single wall carbon nanotubes, could be extraordinarily effective material for electromagnetic energy transfer. If this prediction is correct, it will significantly affect the packing and casing industry since shielding could be produced easily and cheaply from injection moulded nanotube-polymer composites. However, the work may suggest new, ultra-efficient ways of heating polymers, and also has relevance where the modification of radar

absorbency might be of interest. The conversion of low frequency electromagnetic radiation into the thermal energy within a range of carbon nanotube materials will be measured as a function of nanotube loadings and structure. The objective will be to create materials with very high levels of coupling into radio frequency energy, and develop a robust method of making such measurements. For further information contact Prof AH Windle (ahw1@cam.ac.uk).

Development of the physical properties of carbon nanotube fibres by post-spinning treatments

The newly developed continuous spinning process for carbon nanotube fibres, generates fibre which has promising mechanical and electrical properties. One objective is the creation of a cheap electrical conductor where the promising levels of electrical conductivity are balanced by high strength. Attention is now focusing on the improvement of these properties, in the quest to move the fibre performance up to the levels of the strongest types of fibres known. One strategy is to back diffuse a polymer into the directly spun fibre with a solvent to achieve two objectives. The first is to obtain a measure of self order in the form of a liquid crystalline lyotropic phase. The second is to exploit the enhanced mobility provided by the solvent to enable the nanotubes to align with the tensile axis on further drawing. The objective is to optimise electrical conductivity and strength through the development of structure and alignment in the continuous nanotube fibres. For further information contact Prof AH Windle (ahw1@cam.ac.uk).

Production of functionalised, aligned carbon nanotubes by substrate growth

Carbon nanotubes show considerable promise for a wide range of applications due to their unique combination of properties. However, there are still significant challenges in realising these applications due to the difficulties in producing straight, unentangled nanotubes, functionalising them and then processing them into the desired structures. One successful approach has been growing mats of aligned nanotubes by the decomposition of ferrocene and a hydrocarbon. These mats have subsequently been used in composites and supercapacitors.

This project will build upon the success of this production route by developing methods for producing single-walled mats rather than the conventional multiwalled mats. Furthermore, the mats represent a useful surface and studies will be made on functionalising the nanotubes without destroying their arrangement. Finally, the science of the mat growth will be investigated, with the benefit of learning on how to keep catalyst activated and hence grow as long nanotubes as possible. This PhD will use a broad range of experimental techniques, including catalytic vapour deposition, TEM, SEM, TGA and Raman spectroscopy. For further information contact Prof AH Windle (ahw1@cam.ac.uk).

SKF University Technology Centre for Steels

None available at present.

Rolls-Royce University Technology Centre

Weblink to RR UTC PhD vacancies

<http://www.msm.cam.ac.uk/utc/wikitest/pmwiki.php?n=PmWiki.Vacancies>

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