Cambridge materialeyes

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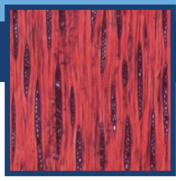
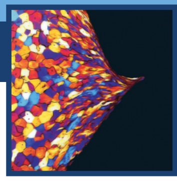
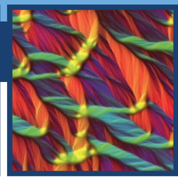

European success

The European Research Council (ERC), established in 2007, aims to stimulate "scientific excellence by supporting and encouraging the very best, truly creative scientists" through two types of grant: Starting Independent Researcher Grants ("Starting Grants") for individuals 2-12 years after obtaining their PhD and Advanced Investigator Grants ("Advanced Grants") for individuals with a record of at least 10 years of significant research achievements. Significantly, the ERC is looking to support "investigator-driven" research and will also provide "proof-of-concept" funding. Grant winners can come from anywhere in the world, but must work in the EU or an associated country while holding their grant, which can be substantial. Gaining one of these grants represents a significant badge of excellence for the investigator involved. In September, the European Commissioner for Research, Innovation and Science, Máire Geoghegan-Quinn, commenting on the most recent announcement of Starting Grant awards, said, "ERC grants are now highly coveted in the research community, not least among younger researchers who often struggle to find funding."

This scheme has attracted a very large number of applications in both categories, but so far the University of Cambridge, and our Department in particular, have enjoyed very pleasing success. Since 2009 four Starting Grants (totalling about 6 million Euros) and four Advanced Grants (totalling about 7.5 million Euros) have been awarded to individuals for work in the Department. In the first category they are Caterina Ducati, Krzysztof Koziol, Rachel Oliver and Stoyan Smoukov, and in the second Mark Blamire, Tony Cheetham, Judith Driscoll and Paul Midgley. Apart from Stoyan, who will be joining us shortly from the USA, the others are already based here. The eight successful projects range widely over the Department's fields of interest: spintronics, oxide electronics, hybrid inorganic-organic framework materials, nanomaterials, active materials, sustainable energy use and imaging techniques.

Editorial

Where once the Head of Department was happy to be familiar with such terms as Bravais lattice, spinodal decomposition and EXAFS, he now has to contend with DSEAR compliance, reinforcement ripple and BREEAM ratings – such are the joys and tribulations of being involved with the construction of the new building for the Department. The concrete pour for the ground slab of the electron microscopy suite was successfully completed on 4 September 2011. The volume of 1350 m³ was poured without interruption in one of the largest such operations in England since the foundation for "The Shard" building in London. Despite some delays due to high winds (something we may have to learn to like at West Cambridge), the work on the building is progressing well with "topping out" expected early in the spring, and completion likely to be on schedule in February 2013. Thus the current academic year will be the last to be completed in our present quarters.

I'm pleased to note continued progress in raising funds for the new building and for the Cottrell Appeal (current supporters list at: www.msm.cam.ac.uk/alumni/cottrell/supporters.php). The IOM3 Royal Charter Prize is the highest award for a UK Materials graduate, and in 2011, goes to Ed Pickering for his performance in Part III. Ed is embarking on PhD studies in the Department, where he joins two other Charter Prize winners, Rowan Leary (2010) and Sonya Pemberton (2008). Similarly the 2011 winner of the IOM3 AT Green Award for best graduate specializing in ceramics, Caroline Goddard, has come to us from Manchester to start her PhD, and joins previous winners Caroline Humphrey (2008) and Oliver Croft (2010) – a remarkable collection of top talent choosing to pursue research with us.

Professor Lindsay Greer, Head of Department

The Department's new building taking shape on the West Cambridge Campus. For more on the concrete slab for the electron microscopy suite (left photo), see: http://news.admin.cam.ac.uk/news/2011/11/30/200-lorry-loads-of-concrete-in-one-day-a-construction-challenge

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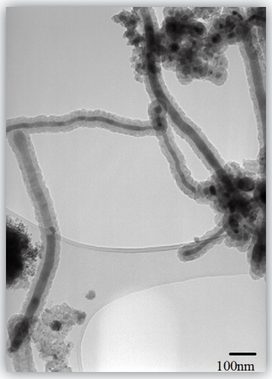
Inside:

Nanotechnology to enhance electrical batteries

Noticed only when they become "flat", electrical batteries are essential to the functioning of so much that we now regard as indispensable, from mobile phones to motor vehicles, but are they as good as they could be? With ever increasing emphasis on sustainability and environmental impact, the answer has to be "No". Although first studied almost 100 years ago, lithium-ion batteries are relative newcomers in the commercial field. Importantly, they offer an appreciably higher electrical energy storage density than other existing rechargeable batteries (0.46 MJ kg^{-1} *vs* 0.36 MJ kg^{-1} for the recently introduced NiZn batteries, for example), and this could be enhanced if more lithium could be stored in the anode. It has been established that the presence of tin or silicon significantly increases the amount of lithium that can be stored, but with present anodes the movement of larger amounts of lithium into and out of the anode during charging and discharging leads to such large volume changes that the anode breaks up.

Derek Fray and Carsten Schwandt in the Department have developed a novel method of making tin-filled carbon nanotubes and nanoparticles from graphite at much lower cost and 2500 times faster than the present (rather slow) methods, and have shown that this material can store significant amounts of lithium with minimal change in volume. Typical material is shown in this TEM image (below) from Raj Das Gupta's Ph.D thesis. The same process can also be used to make silicon-filled nanotubes and nanoparticles, which could lead to an even greater increase in battery performance.



To develop this work further, Derek and Carsten have teamed up with Morgan AM&T in a project partly funded by the Technology Strategy Board in which Morgan AM&T will perfect the graphite and the Department team will optimise the process for producing tin-filled nanotubes and nanoparticles. The project team will then scale-up the process in order to supply materials for use in lithium-ion batteries.

Electrons, spins et bien plus

The Kelly Lecture forms the highpoint of each Armourers & Brasiers' Cambridge Forum. This year's broke new ground in two respects; Prof. Albert Fert (pictured), from the Université Paris-Sud (Orsay), is the first Nobel Prize winner to deliver a Kelly Lecture and also the first to start the lecture by quoting a memorable and personal newspaper headline: "Former Otley Rugby player wins Nobel Prize" (from the *Wharfedale Observer*); evidently pleasing recognition of achievements outside the laboratory while working at the University of Leeds in the mid-1970s!

Starting from the discovery of giant magnetoresistance (GMR), for which he shared the Nobel Prize for Physics in 2007, his lecture on "Spintronics: Electrons, Spins, Computers and Telephones" proved to be a magnificent, copiously illustrated *tour d'horizon* covering the scientific principles and a range of actual or potential applications, only some of which are mentioned here. We also heard that some recent work has included collaboration with Neil Mathur in the Department. Although the basic physics governing the influence of electron spin orientation on conductivity in magnetic materials had been known for some years, not least through Prof. Fert's earlier research, it was not until it became possible to make magnetic nanostructures, notably multilayers with layer thicknesses comparable with the electron spin diffusion length (typically a few nm), that GMR was discovered. Applications of GMR in computers became very significant, although they are now being superseded by TMR (tunnelling magnetoresistance). A much more recent development (by Wang at Stanford) uses GMR to detect magnetically tagged proteins in blood, providing much-improved sensitivity for detecting early signs of cancer.

When two magnetic layers are separated by a very thin insulating layer (e.g. magnesium oxide) TMR is observable. This opens up the possibility of creating a magnetic random access memory (MRAM) that, once written, requires no power to preserve the memory. A promising development uses spin-transfer torque (STT) to create an STT-RAM, in which the magnetisation of one magnetic layer in a memory element is switched by passage of spin-polarised electrons. "Pure spin currents", in which equal and opposite flows of electrons with opposite spin polarisation lead to spin transport without charge transport, were also described, along with prospective applications.

Other materials in which spintronic effects can occur include the ferromagnetic semiconductor GaMnAs (although its Curie temperature is inconveniently low for applications) in combinations of a ferromagnetic metal and a semiconductor, and in hybrid structures involving graphene and carbon nanotubes; some particularly interesting results have been obtained in ferroelectrics. Prof. Fert concluded by describing arguably the ultimate development so far: application as memristors in neuromorphic computing, potentially opening up possibilities of yet-denser integrated circuits.

In proposing the vote of thanks, Tony Kelly commented on the great breadth and interest of the topics covered during the day and then turned to "spin", pointing out that there is no single word for "spin" in French or German whereas in English the word "spin" has several meanings – in cricket and politics as well as in science, for example. Moving rapidly via Zeeman and Dirac he thanked Prof. Fert most warmly, commending him on a lecture that had demonstrated that "spin" is now a real subject and a new resource.

Materials pairing

In furtherance of the Royal Society Pairing Scheme for MPs and scientists, Cambridge MP Dr Julian Huppert visited the Department in December to meet his "pair", Cathie Rae, following previous meetings in Cambridge and Westminster (they are pictured here in Portcullis House). The pair were interviewed about the scheme on *Material World* on Radio 4 later that month. For further information about the scheme see: **royalsociety.org/training/pairing-scheme**

ABC Forum 2011

Before the Kelly lecture we heard five talks, looked at research posters, and applauded the winners of the Armourers & Brasiers' Venture Prize.

Prof. Simon Cox (Aberystwyth University) discussed "Structure, Dynamics, and Applications of Foams". Recalling that foams are elasto-visco-plastic materials, he described three applications to demonstrate how mathematical modelling and visual representation of their behaviour, for example when flowing past obstacles, improve our understanding of how they work. Examples included foam used to enhance the extraction of oil from a well by pumping it through oil-bearing porous rock, industrial and domestic cleaning, and mineral extraction by froth flotation. He compared the results of modelling with experimental data acquired using synchrotron radiation.

On the topic "Chronic, Debilitating Back Pain – a Materials Science Solution to a Mechanical Problem" Dr Geoffrey Andrews (Ranier Technology) addressed the challenges of creating an artificial disc to replace a slipped disc in the human spine, including appropriate response to the complex pattern of loads experienced during a target lifetime of 40 years. Each Cadisc™ L disc is made of carefully synthesised polyurethane coated with calcium phosphate to encourage bone integration. Properties vary systematically through the disc, the modulus at the surface matching that of bone. Metal-to-bone fixing is avoided. After successful clinical trials the discs are now commercially available."

Dr Nikolaos Vlasopoulos (Novacem) introduced us to "Carbon Negative Cement for the Construction Industry". Replacing a carbonate with magnesium silicates (widely available around the world) as starting materials and using relatively low temperatures, Novacem have developed a new cement in a process that absorbs about 100 kg of carbon dioxide more than it emits per ton of cement produced. This cement has a compressive strength approaching 65% of that of Portland cement with further improvements expected. A pilot plant has been commissioned and material is being tested in applications.

Continuing with environmental impact, we heard about "Materials, Sustainability and London 2012" from Dr Peter Bonfield (BRE and the Olympic Delivery Authority [ODA]). From the outset, the ODA set ambitious sustainability targets for all aspects of the Games, including construction of the sporting venues, the media centre and the athletes' village. He described the application of the various categories of BREEAM criteria (BRE's "Environmental Assessment Method") to the project and ranged over the "soil hospital" for cleaning thousands of tons of contaminated soil, the reusability of the legacy buildings, and passive environmental control of the velodrome – amongst others.

Finally Prof. Sir Richard Friend (Cavendish Professor) spoke on "Charge Generation from Excitons in Molecular Semiconductors: the Role of Spin". He led us swiftly through the classes of polymeric electronic materials to photovoltaics where the creation of excitons (bound electron-hole states) by incident photons is important, the electron-hole spin combination determining whether a singlet or a triplet state is formed. Noting that green leaves use incident light more efficiently than silicon, he outlined the prospects for mimicking nature by printing polymeric solar cells on plastic tape to make low-cost photovoltaic generators, a task being developed by a new company, Eight19 (sunlight takes 8 minutes 19 seconds to travel from sun to earth).

This year's Armourers & Brasiers' Venture Prize was presented by Prof. Sir Colin Humphreys, Master of the Armourers & Brasiers' Company, to Dr Hywel Jones of Sheffield Hallam University (SHU) and Dr Anthony Pick, consultant of KeramTech, assisted by Mr Robert Evans, SHU Commercial Exploitation Manager, for the invention of an economical, light body armour consisting of environmentally friendly ceramics. The prize will enable the team to move to pilot-plant production prior to full-scale production.

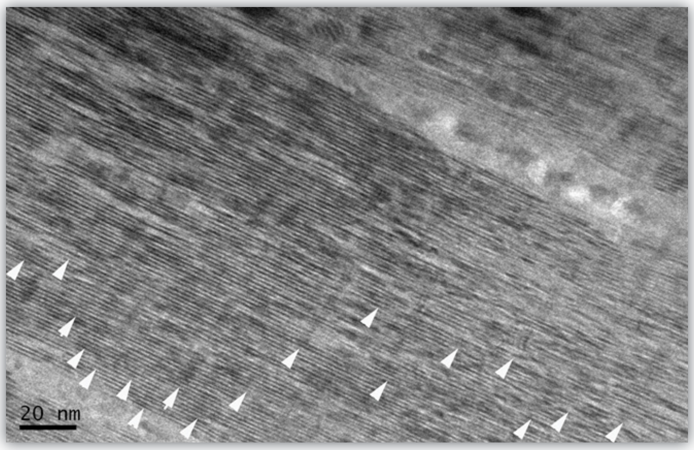
Date for your diary:

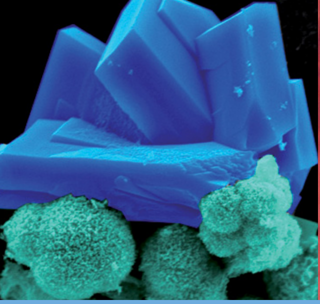
Next year's Forum will be held on 27 June 2012.

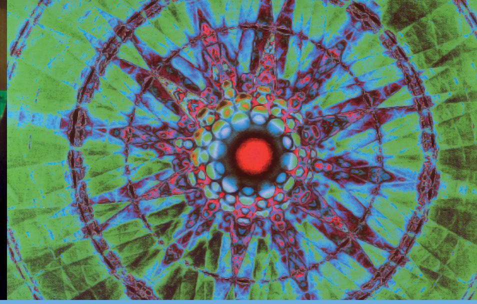
Significant enhancement of YBCO critical current density

Useful superconductors for power applications carry very high currents and have magnetic flux lines threading through them along isolated regions of normal material within a continuous matrix of superconducting material. When the current density reaches a "critical" value the material becomes fully normal and superconductivity is lost. To increase this critical value, the flux lines must be pinned so that they cannot migrate through the material. One way is to introduce suitable nanoparticles. Success was first achieved in this area by Prof. Driscoll when she worked at Los Alamos National Lab in 2003. She incorporated barium zirconate nanoparticles and chains of nanoparticles into the high-temperature superconductor, $YBa_2Cu_3O_7$ (YBCO), and showed that currents could be increased by nearly an order of magnitude. That work has been licensed by industry in the US, where they are now selling long lengths of high temperature wire for a variety of applications, such as in very high field magnets (>25 T). From 2007 onwards, she has designed new nanoparticle compositions, based on rare earth tantalates and niobates, and with her PhD students Sophie Harrington and Giorgio Ercolano, has demonstrated the effectiveness of these when incorporated into YBCO films grown by pulsed laser deposition. This achievement is protected by US patent US-2011-0136670-A1, which has been assigned to Cambridge Enterprise. The particles, which have no significant effect on the superconducting transition temperature, are mostly in the form of self-assembled nanorods about 5 nm wide, extending throughout the film and aligned parallel to the YBCO c-axis, which is oriented perpendicular to the film – some are arrowed in the cross-sectional TEM image shown below (courtesy of H. Wang, Texas A&M). They act as strong pinning centres over a wide range of temperatures and magnetic fields, giving the highest critical current superconductors in the world. Prof. Driscoll has recently been awarded a large EU grant to work with 15 partners to make long conductors incorporating tantalates in collaboration with industry in Europe. Additional commercial partners are being sought through Cambridge Enterprise.

Prof. Driscoll has also demonstrated successful nanocomposite inventions in other functional systems (e.g. strongly enhanced Curie temperatures in ferroelectrics and the creation of near-room temperature magnetoelectrics). This exciting new area is sure to grow strongly in the coming years.





Congratulations

Bill Bonfield (pictured right), Doctor Honoris Causa, Turku University.
Tim Burstein, Lee Hsun Award, Institute of Metal Research, Chinese Academy of Sciences.
Judith Driscoll, Fellowship of the American Physical Society.
Derek Fray, 2012 Max Bredig Award in Molten Salt Chemistry, The Electrochemical Society.
Lindsay Greer, 2012 Bruce Chalmers Award, TMS.
Sohini Kar Narayan, Royal Society Dorothy Hodgkin Research Fellowship.
James Curran, Royal Society Industry Fellowship.
Noel Rutter, Fellowship, Jesus College.
Ed Pickering, IOM3 Royal Charter Prize. 2011 Science, Engineering and Technology Student of the Year Awards. Best Materials Student.
Caroline Goddard, IOM3 AT Green Award.

Super-Conductor – Noel Rutter

The recent rapid increase in undergraduate numbers in the Department, coupled with taking on full responsibility for the Part IA course instead of sharing it with the Department of Earth Sciences, has inevitably generated significant increases in the tasks associated with teaching. Able demonstrators have to be found for substantially larger practical classes; extra projects are required in higher years; and so on. Forty or so years ago, when numbers were also very high, the undergraduate course extended over just three years and there were very few graduate courses, none being compulsory. Now the teaching schedule includes four years for undergraduates, an MPhil graduate course and mandatory courses for other graduate students. Maintaining our tradition of personal attention and ensuring that everything runs smoothly for the undergraduates falls to the Director of Undergraduate Teaching, Noel Rutter.

Noel came to St John's in 1994, graduating in Part II Materials Science and Metallurgy in 1997. He then gained a PhD with Bartek Glowacki, developing interests in the fabrication, modelling, and microstructural and electromagnetic characterization of functional thin-film materials, in particular superconducting wires and tapes – for example thin films of the high-temperature superconductor YBCO on highly aligned NiFe tapes. Subsequently he worked for two years at the Oak Ridge National Laboratory in the USA, returning to the Department in 2003 to spend two years working with Judith Driscoll on electrical characterisation of thin films, before a second stint in the USA, this time at SuperPower, a spin-off from GE, in Schenectady NY. This involved scaling up production of superconductor-coated metallic tapes to kilometres per week His next move brought him back to the Department in 2006 as our first-ever Departmental Teaching Fellow, a category of post initiated in Cambridge by the Department of Chemistry a few years previously. Initially, Noel took over Judith Driscoll's teaching while she was setting up the NanoFen project, later taking on the post of Director of Undergraduate Teaching from Rob Wallach in 2008. This summer, he was elected a Fellow of Jesus College and appointed Director of Studies for first-year physical scientists. In parallel with all his commitments to teaching, where his own lectures are highly appreciated by his audiences, Noel continues to investigate superconductors in a project with David Cardwell and John Durrell in Engineering on bulk superconductors for magnets in flywheels.

Another of Noel's major interests – cricket – featured in *Material Eyes issue 18*. For well over a decade (with interruptions during his spells in the USA) Noel has energetically sought to keep cricket in the Department not only alive but also successful – sadly an increasingly difficult task despite the ever increasing graduate student population! Will interest in cricket now rise as interest in Materials Science amongst undergraduates has risen?

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