Cambridge
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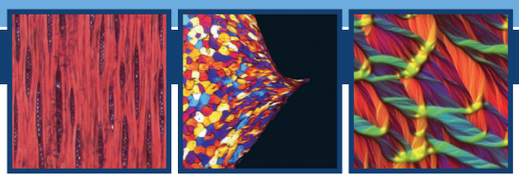
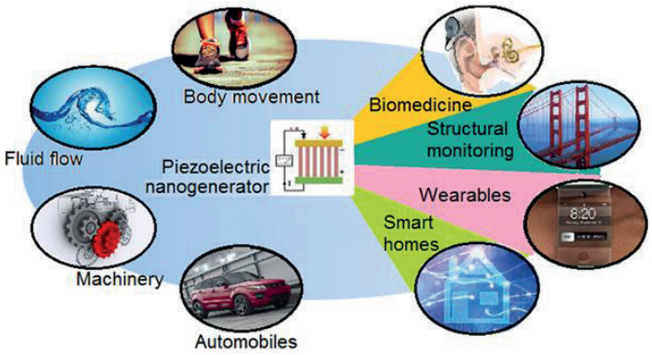


Power for smart devices



The advent of the "Internet of Things" is widely proclaimed but each of the many autonomous smart devices involved requires a (modest) source of power. Fixed energy sources have disadvantages; they need re-charging or replacing regularly. A promising solution is to harvest ambient sources of energy that are always available in the environment. Small fluctuations in stress or in temperature can be turned into electrical power using the piezoelectric or pyroelectric effects respectively. Currently the best piezoelectric materials available are ceramics along with just one family of polymers. Now a substantial ERC Starting Grant "NANOGEN" has been secured by recently appointed University Lecturer Sohini Kar-Narayan to develop novel nanocomposite piezoelectric materials.

The diagram illustrates that small fluctuations in stress arise naturally and inevitably, for example from vibration from machinery or from body movements. As the devices to be powered become smaller so the power demands decrease and nanoscale harvesters become realistic. Some ceramics have excellent piezoelectric properties but they are brittle and many contain lead. Organic polymers, though performing less well, are flexible and cheap. The challenge to be addressed is to combine the advantages of both by developing novel hybrid polymer-ceramic nanocomposites. A major component of the research will be to characterise the nanoscale structure of the materials to provide input for computer modelling of the materials and of the device parameters. An understanding of how the properties are related to the structure on that scale will help in refining the processing to optimise the properties. Another essential step will be to fabricate prototype high performance nanogenerators capable of powering commercial devices. Along with this it will be important to establish key performance indicators for the materials and the devices; these have not been specified in much of the research reported around the world so far.

Sohini and her rapidly expanding team have already made impressive progress with both fabrication and computer modelling. A small prototype nanogenerator has been demonstrated that produces an electrical output when tapped; this can be stored on capacitors and used to light a commercial LED. The modelling covers all realisable nanogenerator driving mechanisms enabling rigorous comparisons to be made between materials for the first time. As reported in a significant paper published recently, these have shown that there is an important difference between polymers and ceramics under different operational conditions: polymers perform better when stress-driven, ceramics when strain driven. For further information see http://people.ds.cam.ac.uk/sk568.

Not only is Sohini to be congratulated on winning this grant, but she has recently been an invited participant in the World Economic Forum's *Annual Meeting of the New Champions 2015* in Dalian, China.

Editorial

This issue sees the arrival of Chris Pickard as the inaugural Cottrell Chair (see back page). As well as working closely with the existing modelling group, we hope Chris will be able to collaborate closely with experimental groups within the Department and more widely across the University. We also recognise the great honour of the knighthood awarded to Harry Bhadeshia.

The Department's teaching continues to develop with a record number expected for the IB (2nd year) class in the coming academic year which is likely to particularly tax the ingenuity of the class technicians in squeezing even more people into the labs. Finally, our appeal for a memorial for Dave Duke, our former principal technician, has now raised over £4000 and will close at the end of the year, for more details see: www.msm.cam.ac.uk/alumni/Duke.

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Inside:

Anthony Kelly (1929–2014)

When he retired as Vice-Chancellor at Surrey in 1996 Tony Kelly was welcomed back to Churchill College and to the Department, remaining very active in both until his death. On arrival, he immediately made it clear that retirement meant something rather different to him compared with most people. To wide recognition and appreciation, he instantly started making major contributions on scientific, social and administrative fronts in both institutions.

Despite his long period in an essentially administrative post at Surrey, Tony had never cut back on his enormous scientific creativity. On returning to Cambridge he brought with him an international reputation in the field of Composite Materials. It was therefore natural for him to gravitate towards related areas here - on the mechanics of structural materials. As it happens, the staff involved included Bill Clegg, Bill Clyne and Kevin Knowles, all of whom had overlapped with Tony during periods they had spent at Surrey. Since none of them were really specializing in conventional (polymer) composites, Tony's interests complemented the on-going activities in a very timely and valuable way. Tony's presence was certainly a factor in the decision of DERA to set up the Gordon Laboratory in Cambridge in 1999 under the joint Directorship of Bill Clegg and Bill Clyne, with Tony amongst others being prominent in its development.

This period also saw the start of the celebrated Kelly Lecture series within what has become the annual Armourers & Brasiers' Cambridge Forum. The first lecture, given by Tony himself, coincided with the ceremonial opening of the Gordon Lab attended by Jim Gordon's widow and other members of his family. Since then, being invited to present the Kelly Lecture has become a globally-recognized accolade with, until last year, the vote of thanks given by Tony always being an inimitable and important part of a memorable day. The Forum, attended by industrialists and academics from around the world, is now a glittering fixture in the annual calendar of Materials Science.

Tony's role in the Gordon Lab was always pivotal, not least in the aftermath of the disbanding of DERA only two years after the opening, since when it has been successfully transformed into a framework for extensive industrial collaboration on a wide range of structural materials, composites and surface coatings. He offered support ranging from avuncular advice to young researchers to the provision of valuable industrial links and contacts. He remained forever interested in the details of cutting edge research, authoring many scientific papers (including a large number co-authored with academics and research students in the Department), and being active in patenting, delivery of prestigious invited talks, organizing of scientific meetings (including several at the Royal Society) and various international liaisons and joint activities.

Kevin Knowles has been a particularly active partner of Tony's, not only as a co-Fellow at Churchill, but also in co-authoring with him the new edition of "*Crystallography and Crystal Defects*", which has been very well-received.

Tony was always a gregarious and cooperative person, who became a very popular and well-known character within the Department, even to generations of students who knew little about his illustrious past. In addition to almost daily contact with everyone within the Gordon Lab, he worked closely with a number of major figures from around the Department. His mind remained lively, engaged and entertaining to the very end and he took a keen interest in national and international issues, such as climate change, as well as in the Department and the wider world of Materials Science. In many ways, he probably found the latter period of his life the most satisfying of all, with no real burdens of office but continued stimulation and recognition, combined with the freedom to contribute and participate as he wished. He grasped this opportunity in the most constructive way and he will be sorely missed.

Bonfield Cell Culture Lab

The morning immediately before this year's ABC Forum (see p.3) saw the formal opening of the Bonfield Cell Culture Laboratory. Funded by a gift from Professor Bill Bonfield the newly equipped laboratory provides a significant addition to the facilities of the Cambridge Centre for Medical Materials in the Department. Invited guests attended a number of presentations describing the work of the Centre, chaired by Professor Cameron, before assembling outside the laboratory where Professor Best emphasised the Centre's gratitude for this gift before Professor Bonfield cut a ceremonial ribbon. Following inspection

of the new facilities the group moved to the Common Room for a light lunch and a toast to the success of the venture.

Engineering atoms

Amongst the displays at the recent Summer Science Exhibition hosted by the Royal Society was a contribution showing the work of the Rolls-Royce UTC created by Cathie Rae and colleagues with sub-heading "The Great British Take Off". For an informative, illustrated display about the ever-increasing challenges faced by materials in modern jet engines and about designing materials to face those challenges go to **www.eng-atoms.msm.cam.ac.uk**

Graham Sharp (1955–2014)

Over the years many people were trained to use electron microscopes in the Department by Graham Sharp. Very sadly Graham died suddenly in 2014; a short obituary appears at: **www-hrem.msm.cam.ac.uk/hrem/ObituaryGrahamSharp.pdf**

ABC Forum 2015

The 12th Armourers & Brasiers' Cambridge Forum was held on the West Cambridge Site on 16 June. Bill Bonfield opened by thanking the sponsors for their invaluable support and Lindsay Greer for his customary efforts in assembling the programme of speakers.

Chris Pickard (UCL/Cambridge) described how the ever increasing computing power available is enabling theoretical searches for possible structures involving an ever-increasing number (up to six so far) of different elements to be carried out. Structures are sought by minimising the energy of an initially random array of atoms or molecular units taking account of chemistry, expected symmetries and other experimental data.

In an experimentally-based approach, **Paul Raithby** (Bath) focused on differences between the metastable and stable states of some crystals, pointing out that the properties (e.g. colour) may differ significantly and the difference can be exploited in applications when the crystal can be maintained in the metastable state relatively easily with the continuous input of modest amounts of energy. Ways of increasing the conversion, which can be reversible, are being investigated and the kinetics measured.

In a first for the ABC Forum, the next presentation was a progress report on a previous Venture Prize project. **Hywel Jones** of XeraCarb, winner in 2011, spoke about the development of lightweight ceramics for body armour. Aiming for a low cost process, the SiC-α,βSi_3N_4 ceramic is prepared by slip casting with sintering aids and then sintering. The resulting material has good general properties; its ballistic properties were demonstrated in impressive videos. Thicker materials and more complex shapes are now being investigated for vehicle armour and other applications.

Hazel Assender (Oxford) outlined the challenges and benefits of producing flexible electronics by roll-to-roll vacuum processing at up to 5 ms^{-1} on a polymeric web 35 cm wide. Account has to be taken of deposition rate, mechanical properties, the need for multiple layers and temperature limitations of the web. Vapour deposition and high-power impulse magnetron sputtering have been used, the latter producing coarser microstructures. Patterning of the metallisation and the need for encapsulation and problems due to gas permeation must also be considered.

Neil Greenham (Cambridge) assessed ways of making solar electricity more cheaply. The range of photon energies in the solar spectrum limits the theoretical maximum efficiency of a device with a single p–n junction to about 33%. Although silicon remains the material to beat, better photon-harvesting can be achieved, for example, with two materials (and so two band gaps) or by using a material in which absorption of a high energy photon leads to the creation of two lower energy excitons from which the charges can be extracted rapidly. Nanoparticles offer possibilities (the bulk selection rules are relaxed).

The Master of the Armourers & Brasiers' Company, Simon Archer then announced the winner of this year's Venture Prize was ***Pertinax Pharma***, a spin-out from the University of Bristol. In thanking the Company for the Prize, Michele Barbour explained that they will commercialise a method of greatly extending the active lifetime of the important antimicrobial agent chlorhexidine, incidentally explaining the company name - "pertinax" in Latin means persistent.

Materials meets Biology

Introduced by Ruth Cameron, the 17th Kelly Lecturer, **Angela Belcher** from MIT immediately made clear that this year's subject saw a return to 3-D materials but what materials! Noting that the strength of abalone shell greatly exceeds that of its principal constituent, $CaCO_3$ she addressed the question how does biology do such a good job when it is given the opportunity - and in a benign environment too? Somehow there must be genetic control of the process, so can viruses be used to create materials that we want? This is indeed possible by choosing a bacteriophage (a virus that infects a bacterium) - often "M13" - which has been artificially "evolved" to incorporate genetic material that codes for a protein that selects for a specific element or inorganic compound from the environment and self-assembles an accumulation, e.g. on the surface of the virus. As she illustrated next, very substantial libraries of viruses with different, useful genetic sequences have been established.

A relatively simple example uses the M13 bacteriophage, genetically evolved to select gold, to create a single crystal gold nanowire along its surface. With slightly different genetic make-up two elements can be selected and alloy nanowires (e.g. Au-Ag) grown. A more challenging application has been the production of electrode materials for lithium-ion batteries and catalytic materials for lithium-O_2 batteries, the latter involving the growth of nanostructured metal oxides. Rather different has been the production of single-walled carbon nanotube-TiO_2 nanocomposites which have been shown to significantly, enhance the electron collection in photovoltaic devices such as dye-sensitised solar cells. Unsurprisingly the potential for commercial exploitation of these techniques has led to the creation of spin-out companies, in this case with names that reflect Belcher's interest in geology. ***Siluria*** makes use of inorganic nanowire catalysts to effect low temperature oxidative coupling of methane from natural gas to produce higher value products, notably ethylene. ***Cambrios*** produces silver nanowires that form the basis of a transparent conducting material for use on flexible screens. These may be followed by one that exploits genetically engineered yeast to capture carbon dioxide and turn it into solid carbonates; the process works in the lab.

Finally, she described a novel method for the detection of deep tumours using the "second window" in the near infra-red that has been successfully demonstrated. M13 genetically engineered to bind to a single-walled carbon nanotube (SWNT) and to carry tumour-targeting peptides. The peptide causes the M13 and so the SWNTs to become concentrated in the tumour and fluorescence of the SWNTs when irradiated in the "second window" allows tumours as small or smaller than 1 mm and 9 cm deep to be detected.

In his vote of thanks, Alan Windle picked up on her final topic suggesting a way in which SWNTs inserted into a tumour using her method could be used to kill that tumour at the same time destroying the SWNTs thus removing any risk that they might generate subsequent problems. He congratulated her for an "amazing feast" that demonstrated a wonderful step forward.

The next Forum will be held on 14/06/16.

Cottrell Chair Crystallises - Chris Pickard

The intention of establishing a professorship in recognition of the achievements of Sir Alan Cottrell was covered in Issue 17 of *Material Eyes* and the first election to the Cottrell Chair has now been made. Chris Pickard took up the post on 1 August, initially facing the challenge of converting the contents of many boxes into an ordered array on the shelves and in the cabinets of his new office. Chris is no stranger to Cambridge; he read Natural Sciences, specialising in Physics, and then gained a PhD in the Cavendish supervised by Mike Payne and Mick Brown. Since then his career has ranged geographically between spells in Taiwan, Germany, Scotland and most recently as a Professor in Physics at UCL, all punctuated by further stints in the Cavendish. He has some interesting reflections on the different systems he has experienced and prefers those with the flexibility to support individuals with ideas and with the skills and enthusiasm to implement them without undue regard to their areas of research.

Starting with his PhD, the thread running through his research links first principles computations to practical applications. In several instances this had led to software packages that have become widely used around the world. For example, the updated CASTEP (Cambridge Serial Total Energy Package) code, on which he worked intensively in the past, has about 1000 commercial users and brings a significant benefit to Cambridge University through licence fees. Applications of his work have led to advances in understanding data from EELS and NMR. More recently he has developed a method for discovering structures - including some at terapascal pressures - and some non-periodic features such as defects and interfaces by first principles energy minimisation of an initially random array of atoms (see page 3). Chris's approach to research is to have a relatively small group of his own - just one postdoc is coming with him from UCL - and to concentrate on collaborations with colleagues locally and internationally. He is already looking forward to collaborating with several groups in his new Department and to setting up some Part III projects. Clearly such work needs substantial computing capacity involving thousands of parallel core processors. A system for initial investigations will be built in the University's Data Centre; subsequent refinement of calculations will make use of the University's High Performance Computing Service and the national ARCHER supercomputing service.

Chris, his wife Sylvie and their young son Luke (pictured with Chris growing crystals at home) were already living in Cambridge so that Chris will no longer have to commute but Sylvie will not escape; she teaches law at UCL. In his spare time Chris enjoys fishing but dare one wonder if that mainly provides more scientific thinking-time? We are delighted to welcome him into the Department and look forward to illuminating and productive collaborations.

Congratulations

Harry Bhadeshia, Knighthood for contribution to Science and Technology and the Albert Sauveur Achievement Award for 2015, ASM International
Chris Pickard, elected to the Cottrell Chair, August 2015 and the IOP Rayleigh Medal
Lindsay Greer, Head of the School of Physical Sciences, January 2016
Cathie Rae, Personal Chair, October 2015
Judith Driscoll, IOP Joule medal and Fellowship of the MRS
Tony Cheetham, Honorary degree, University of Warwick
Derek Fray, IOM3 Futers Gold Medal
Rachel Oliver, RAEng/Leverhulme Trust Senior Research Fellowship
Jess Gwynne, College Fellowship, St Catharine's
Cate Ducati, College Fellowship, Trinity

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