Armourers and Brasiers' Cambridge Forum, 18 June 2024

ABSTRACTS

Electrifying Bones: Osteogenic tissue engineering with electrical stimulation

Prof. Sarah Cartmell, Vice Dean and Head of the School of Engineering, University of Manchester

The growth of new bone tissue *in vitro* requires a variety of different factors that need to be controlled and optimized. Given that bone is piezoelectric in nature, it is feasible to assume that local electrical regimes have an effect on osteogenesis. There are clinical products currently on the market that deliver electrical currents locally via a cathode to fracture sites. These products demonstrate significant clinical improvements in bone repair. We have recently designed a variety of different bioreactors to both house the developing tissue and also control the applied electrical stimuli in either capacitive or direct contact methods to *in vitro* cultures. These bioreactors have enabled us to assess the potential use of this stimuli for *in vitro* bone tissue engineering purposes. It has also allowed us to further study the mechanism by which the activity of primary human mesenchymal stem cells is altered both in terms of cell proliferation and differentiation. A novel finding of the importance of the faradic by product of H_2O_2 proximal to the cathode as result of the direct electrical stimulus will be presented and its subsequent role in influencing primary mesenchymal stem cell proliferation. The use of conducting polymers and piezoelectric materials to apply electrical regimes to the cells will be presented.

Sarah joined the University of Manchester in the School of Materials in 2010 and was appointed Professor of Bioengineering in 2014. She received a B.Eng. in Materials Science with Clinical Engineering (1996) and a Ph.D. in Clinical Engineering (2000) from the University of Liverpool, and then was a postdoctoral research fellow at GeorgiaTech, Atlanta for two years. She joined Keele University in 2002 where she continued her postdoctoral studies until becoming a Lecturer and then Senior Lecturer in orthopaedic tissue engineering in 2008. Her research has a common theme of orthopaedic tissue engineering with a particular focus on X-ray evaluation of tissue-engineering constructs and biomaterials and the response of orthopaedic cells to a variety of stimuli (e.g. mechanical, electrical, statins) and a variety of different novel materials to support their growth into the correct tissue type/shape. She has recently created a spin-off company Retendon Ltd to translate her tendon-repair product portfolio.

Molecular Materials for Technology: from solar to quantum

Prof. Sandrine Heutz, Head, Department of Materials, Professor of Functional Molecular Materials, Imperial College, London

Molecular semiconductors, carbon-based materials where the presence of conjugated bonds decreases the band-gap into the visible range, hold the promise of low-cost, easily processed, flexible and light-weight electronics. After several decades of scientific research, the promise has been fulfilled and attractive consumer goods based for example on organic light-emitting devices (OLEDs) are firmly in the marketplace, with examples of flexible solar cells also entering the market. More recently, molecules have also been identified as useful components in spintronics and in quantum technologies, where the electronic spin of radicals, transition metals or photoexcited species is exploited. This presentation will focus on the materials science that underpins the performance of molecules in technology, in particular polyaromatic systems such as phthalocyanines and pentacene. For example, charge transport, light absorption and magnetic coupling are highly anisotropic, and new methodologies have been developed to control the orientation of molecules onto substrates. Film crystal structure influences the spin-coupling, enabling a switch between different magnetic states using identical molecules. Finally, co-deposition of isostructural systems of paramagnetic and diamagnetic molecules enables the tuning of spin coupling, ultimately leading to ultra-long spin lifetimes that, together with the unique interplay between degrees of freedom, offers attractive perspectives in quantum applications.

In addition to her Professorial and Head-of-Department roles at Imperial College, Sandrine is co-Director of the London Centre for Nanotechnology. She obtained her degree in chemistry from the University of Liège, Belgium, and the University of Sherbrooke, Canada (1998). She then moved to the UK for her PhD at Imperial College London (2002), focusing on the growth and characterization of molecular-semiconductor thin films, followed by a post-doc investigating the application of molecular materials in photovoltaic cells. She was awarded a Royal Society Dorothy Hodgkin Fellowship to develop molecular magnetic biosensors in 2004, at Imperial and University College London. Her group focuses on functional molecular films, nanostructures and their interfaces. She is particularly interested in characterizing and exploiting the electronic spin of molecules in spintronic and quantum applications.

Climate Constructive Carbons: Can we turn waste to wonder?

Prof. Adam Boies, Head of the Energy Faculty Group, Professor of Nanomaterials & Aerosol Engineering
Department of Engineering, University of Cambridge

The flux of CO_2 is the planet's largest waste stream, primarily as a result of combustion for electricity and heating needs. However, carbon materials are among nature's most versatile structures and thus provide opportunities for using carbon from natural gas and biogases as materials that sequester carbon, produce hydrogen and prevent release of CO_2. There is a burst of activity seeking to pyrolyze methane into hydrogen with two emerging fronts of activities characterized as *Hydrogen First* and *Carbon First* approaches. This talk with discuss the various merits of methane pyrolysis in light of the emerging need for both CO_2-free hydrogen and bulk carbon materials. The presentation will focus on the various techniques for production of functional carbons that serve as useful materials alongside turquoise hydrogen. The functional properties of nano-carbons are well known, but only in the last five years have large-scale materials composed of nano-carbons demonstrated strength, thermal and electrical properties that exceed high CO_2 intensity materials, such as steel, aluminium and carbon fibre. Macroscopic materials composed of carbon nanotubes (CNTs) form networks of bundles that serve as the functional unit that spans the extent of the material. Advances over the last decade have resulted in a doubling of ultimate tensile strength every three years, largely as a result of bundle densification and alignment. This presentation will discuss the worldwide race for advanced carbon materials production by enhancing CNT fibre strength, electrical conductivity and thermal conductivity. A new production facility is being built for materials production in St. Helens, UK at 5 t/yr with a market for Li-ion batteries. Larger questions remain regarding whether bulk materials can be produced at sufficient density for global-scale materials needs and displacement of other bulk processes. New techniques for measuring the rates of catalyst formation and kinetics of CNT growth will provide a means for studying the ultimate limitations of reaction density and reactor throughput. These techniques are applied to study new CO_2 net-sequestering carbon materials when produced from new sources of methane, such as gasified biomass and landfill gas.

Adam's research focuses on characterizing the evolution, dynamics and impacts of gas-phase nanoparticles with an emphasis on energy applications, nanomaterial structuring and morphology and particle sensing. Adam serves as director of the Advanced Nanotube Application and Manufacturing Initiative and is Partnership Director of the Aerosol Doctoral Training Centre. He is a Fellow of Trinity College and has over 100 publications and 14 patents. He heads the University of Cambridge Strategic Interest Group on Hard to Decarbonize Sectors and has led research activities with >$50M in funding. His group has valued technical innovation and transfer with past group members forming four successful spin-outs: Echion Tech. (battery), Catalytic Instruments (sensors), AetoSense (sensors) and Atmose Tech. (sensors). Adam serves on several editorial and advisory boards including the journals of Aerosol Science & Technology and Energy Findings, and as chief scientific advisor for Catalytic Instruments, Q-Flo (CNTs), and Baro-Mar (energy storage).

Beyond Crystallinity and Throughput: Machine-learning-accelerated materials discovery for energy conversion and storage

Prof. Karsten Reuter, Director of the Theory Department, Fritz Haber Institute (FHI) of the Max Planck Society, Berlin

More performant and durable materials are urgently needed to further drive the transition to a sustainable energy system. Unfortunately, accelerated materials discovery in this field is presently still more claim than practical reality. Computational-screening approaches hinge on efficient descriptors that reflect only nominal materials properties of the crystalline bulk, simple bulk-truncated surfaces, or idealized lattice-matching interfaces. They can thus not account for the substantial, complex and continuous structural, compositional and morphological transitions at the working surfaces or interfaces of catalysts, electrolysers or batteries. Accelerated experimental discovery in turn still suffers from severe throughput limitations, as it is rare for easily automatable human steps to limit the overall workflows. The talk will illustrate how modern machine-learning (ML) approaches help to overcome these challenges. ML surrogate models, in particular in conjunction with agile active learning-based training, boost the capabilities of predictive-quality multiscale modelling. Starting to tackle the true complexity of working interfaces, the derived mechanistic understanding promises to establish improved descriptors for more reliable computational screening campaigns. For experimental discovery, ML-guided experiment planning allows to optimally use available throughput capacities. In particular most data-efficient adaptive design of experiment (DoE) requires only a limited number of experiments to provide a global (trend) understanding of the materials search space, while simultaneously allowing to batchwise modify and refine both this search space or even the original research objective on the basis of the hitherto accumulated information.

Prof. Karsten Reuter works on multiscale models that combine predictive-quality first-principles techniques with coarse-grained methodologies and machine learning to achieve microscopic insight into the processes in working catalysts and energy-conversion devices. Karsten did his doctoral studies on theoretical surface physics in Erlangen, Madrid and Milwaukee. Following research experience at the FHI in Berlin and the FOM Institute in Amsterdam, he headed an independent Max Planck Research Group. From 2009 to 2020 he was Chair for Theoretical Chemistry at the Technical University of Munich (TUM). He recently held visiting professorships at Stanford (2014), MIT (2018), and Imperial College London (2019), and is a Distinguished Affiliated Professor at TUM as well as Honorary Professor at the Free University and Humboldt University in Berlin.

The 25th Kelly Lecture

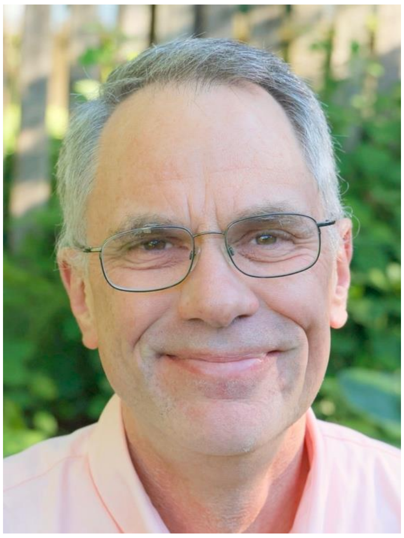
Glasses, but not as you know them!

— surface-mediated assembly of ultrastable and structured states

Prof. Mark Ediger, *Department of Chemistry, University of Wisconsin-Madison, USA*

Physical vapour deposition (PVD) can produce glasses with remarkable properties, including high density and high kinetic stability. By some metrics, these are the most stable glasses on the planet. The properties of PVD glasses can be explained by the surface equilibration mechanism. Even though the substrate is held below the glass-transition temperature T_g, the glass surface is highly mobile and this allows incoming molecules to sample many packing arrangements before being buried by further deposition. In this process, the sample can equilibrate well below the conventional T_g. Initial work with organic glasses has now been extended to show aspects of ultrastability in metallic and chalcogenide glasses.

The primary application of PVD glasses is organic light-emitting diode (OLED) displays, which are used for almost every mobile phone. High-stability glasses make displays that last longer. During PVD, equilibration occurs in an anisotropic environment (the free surface) and this creates the opportunity to form anisotropic glasses. For OLEDs, controlling anisotropy leads to brighter displays. Co-deposition allows controlled preparation of domain structures and this may be important for organic photovoltaic devices. The surface equilibration mechanism allows an understanding of all these examples.



Mark Ediger received his Ph.D. from Stanford University in 1984 and moved to the University of Wisconsin-Madison as an assistant professor in the Department of Chemistry. He is currently the Hyuk Yu Professor of Chemistry at UW-Madison. His research is focused on organic glasses, both polymeric and low-molecular-weight materials. Current research projects include mobility induced in glasses by deformation and the formation of ultrastable and anisotropic glasses by physical vapour deposition. Ediger has served on advisory boards for Macromolecules, the Journal of Polymer Science B: Polymer Physics Edition, and the Journal of Chemical Physics, and is currently an Associate Editor for the Journal of Chemical Physics. He has served as Chair of two Gordon Conferences: Polymer Physics and Chemistry and Physics of Liquids. He received the American Physical Society's Dillon Medal in 1993 and also the Polymer Physics Prize in 2015, as well as the American Chemical Society Hildebrand Award for the Experimental and Theoretical Chemistry of Liquids in 2013. He is a Fellow of the American Association for the Advancement of Science.

Past Kelly lectures have been given by:

2023 **Professor Victoire de Margerie**, Founder and Vice-Chairman, *World Materials Forum*
Materials Science: Key opportunities and challenges by 2035

2022 **Professor Emily Shuckburgh OBE**, Director of *Cambridge Zero*, Professor of Environmental Data Science, University of Cambridge
Towards a Zero-Carbon Future

2021 **Professor Dierk Raabe**, Director, Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany
Sustainable Metals

2020 no Forum

2019 **Professor Yves Bréchet**, Grenoble Institute of Technology
Teaching Science to Politicians, the example of materials science: a hopeless, but unavoidable challenge?

2018 **Professor Peter Bruce FRS**, Department of Materials, University of Oxford
Materially Better Batteries

2017 **Professor Mike Cates, FRS**, Lucasian Professor of Mathematics, University of Cambridge
Bulletproof Custard: Discontinuous Shear Thickening in Very Dense Suspensions

2016 **Professor Ric Parker CBE FREng**, Director of R&T, Rolls Royce
Advanced Materials – Flying High

2015 **Professor Angela Belcher**, WM Keck Professor of Energy, MIT
Giving New Life to Materials for Energy, the Environment and Medicine

2014 **Professor Nic D Spencer**, ETH Zurich and President, ETH Research Commission
Made-to-Measure Surfaces

2013 **Professor Sir Colin Humphreys CBE FRS FREng**, University of Cambridge
Lighting the Future

2012 **Dr Alan Taub**, Global R&D, General Motors
Materials Challenges for a Sustainable Automotive Industry

2011 **Professor Albert Fert**, Nobel Laureate for Physics 2007, Unité Mixte de Physique CNRS-Thales, Palaiseau
Spintronics: Electrons, Spins, Computers and Telephones

2010 **Professor Ke Lu**, Chinese Academy of Sciences, Shenyang
Nano-Twinned Materials

2009 **Professor CNR Rao FRS**, Jawaharlal Nehru Centre, Bangalore
Doing Nanoscience Research in Emerging India

2008 **Professor Greg B. Olson**, Northwestern University
Materials by Design: Frankensteels Driving Innovation in Research and Education

2007 **Professor Mike Ashby CBE FRS FREng**, University of Cambridge
Environmentally Informed Material Choice: Strategies, Tools, Data and Difficulties

2006 **Professor J Michael D Coey FRS**, Trinity College, Dublin
Magnetic Materials − Where are the Limits?

2005 **Professor Daniel Morse**, UCSB-MIT-Caltech Institute for Collaborative Biotechnologies
Biologically Inspired Routes for Materials Synthesis and Nanofabrication: High Performance with Low Environmental Impact

2004 **Professor Herbert Gleiter**, Institute for Nanotechnology, Karlsruhe, Germany
Nanostructured Solids: A Gateway to Elements that Lie 'Between' the Elements of the Periodic Table

2003 **Professor Akihisa Inoue**, Institute for Materials Research, Tohoku University, Japan
Bulk Nonequilibrium Alloys by Stabilization of Supercooled Liquid

2002 **Professor Jeff Edington**, formerly Alcan and British Steel
Commercialisation of Materials Science - Entrepreneurship - Creating Wealth - Enjoying your Life

2001 **Professor Subra Suresh**, Department of Materials Science and Engineering, MIT
Nano- and Micro-Scale Mechanical Properties for Miniature Technologies

2000 **Professor A Evans**, Princeton University, USA
Mechanisms Controlling the Durability of Thermal Barrier Coatings

1999 The Inaugural Lecture was given by **Professor Anthony Kelly CBE FRS FREng**, formerly Vice-Chancellor, University of Surrey
Fibre Composites - The Weave of History
