New and Traditional Ways of Making Bubbles, Particles, Capsules and Fibres: A New Frontier in Biomedical Materials  
Professor Mohan Edirisinghe FREng, Department of Mechanical Engineering, University College London

Biomaterials are usually discussed in terms of metals, ceramics, polymers and composites, with the aim of developing more traditional materials and structures which are appealing for biomedical applications, particularly in terms of cellular interactions. However, more recently, a new frontier has emerged; finer biomaterial entities such as microbubbles, nanovesicles, porous and solid particles, different types of capsules and smart nanofibers. These are increasingly playing a crucial role in the application of engineering in medicine and for which there is a significant industrial demand. But a striking limitation has been the lack of commercially viable methods to reproducibly generate such structures with adequate process control. This talk will focus on novel methods and devices created by exploiting the well-known principles of phenomena such as electrophysics, microfluidics and gyration to prepare such fine entities containing the desired contents including active pharmaceutical ingredients, with clear possibilities of controlled mass production.

Sustainable Carbon Materials for Renewable Energy  
Professor Magdalena Titirici, School of Engineering and Materials Science, Queen Mary University of London

One of the grand challenges facing humanity today is access to sustainable materials and chemicals, which are at the heart of sustainable technologies. The production of materials, chemicals and fuels from abundant and renewable resources will eliminate our dependence on petroleum/critical metal based supplies and will provide access to a new economy based on available reserves.

Carbon is the most versatile element known. It combines with other (carbon) atoms giving rise to new carbon materials with astonishing properties. The versatility and potential of carbon has attracted top recognition in the last decade for the work in fullerenes (1996 Nobel Prize in Chemistry), CNTs (2008 Kavli Prize in Nanoscience) and grapheme (2010 Nobel Prize in Physics). However, the mystery and wonder of carbon offers more to discover.

While carbon is widespread on Earth, it has been mainly synthesised from fossil fuel based precursors with sophisticated and energy consuming methodologies that generate toxic gases and chemicals. The preparation of carbon materials from renewable resources is a key research challenge in terms of sustainability, climate change and economics. Since the beginning Nature created carbon from biomass.

We have demonstrated that it is possible to mimic the natural process of carbon formation and prepare carbon nanomaterials from biomass using mild hydrothermal processes. Along with amorphous carbon materials (denoted HTC), this procedure also enables biomass transformation into useful chemicals such as 5-hydroxymethylfurfural (5-HMF) or levulinic acid (LA). Recently, we have discovered a third product of Hydrothermal Carbonisation - a crystalline form of carbon - arising at the interface between the amorphous HTC microspheres and the aqueous phase containing the biomass-derived chemicals.
In this talk I will present some of the fundamentals governing the production of carbon nanomaterials and chemicals. We will also discuss the application of HTC materials in electrocatalytic reactions such as Oxygen Reduction Reaction and Oxygen Evolution Reaction. Finally, some of the photo-physics governing the optoelectronic properties of the new family of fluorescent hydrothermal carbon nanocrystals and their applications, as sensitizers in solar cells will be presented.

**Putting the 'Nuclear' Back into Nuclear Magnetic Resonance**

**Dr Ian Farnan**, Department of Earth Sciences, University of Cambridge

Nuclear magnetic resonance (NMR) is particularly useful in examining structurally and compositionally complex materials because it is element specific.

Materials that arise in the management of nuclear wastes, and in nuclear materials in general, are often composed of compositionally complex mixtures of amorphous and crystalline regions whether pristine or significantly restructured.

NMR is well-adapted to examine these types of materials as it is equally sensitive to crystalline or amorphous samples. However, the application of high-resolution solid-state NMR requires the sample to be rotated at high speed during the experiment, which imposes extreme safety concerns when the materials contain highly radioactive elements. Protocols for safely performing these experiments for materials containing actinide elements will be described with examples given of the unique information on experimentally quantifying the numbers of displaced atoms due to radiation damage events in nuclear waste forms and the local ordering in mixed oxide nuclear fuels.

**From Mobile Phones to Russian Dolls to MASERs**

**Professor Neil Alford MBE FREng**, Imperial College London

In this talk we will look at the problem of dielectric loss (the tan δ) in oxides and how this led us to the world’s first room temperature MASER. Why are we interested in dielectric loss? Almost all of us have a mobile phone and dielectric resonators form essential parts of communications systems. The term “Dielectric Resonator” was first used by Richtmeyer in 1939 who showed that a dielectric ring could confine high frequency electromagnetic waves and thus form a resonator. The idea of a dielectric material confining EM radiation dates back to 1897 when Lord Rayleigh described a dielectric waveguide and in 1909 when Debye described dielectric spheres. With the astonishing growth in the cellular communications industry the market is now very approximately 2BN sales of mobile phones each year (that’s about 60 each second) the market for microwave ceramics is huge.

One of the key properties is the dielectric loss or tan delta. The inverse of this is called the Quality factor or Q. Imagine a tuning fork. When you strike it, it resonates for a long time – it has a high Q and if it were made from e.g. wood it would be damped severely, would not resonate and have a very low Q. Now imagine hitting a dielectric (like alumina or sapphire) with an electromagnetic wave – a microwave – it resonates and what we need is a very high Q so that we can build good filters. The dielectric loss is limited by the dielectric loss of the material - the dielectric limit - but suppose you could exceed this. This is what we did by some cunning engineering using a Bragg reflector (a bit like a Russian doll) in which the sapphire layers of the Russian doll (called Bragg layers) are not the usual equal thickness but are aperiodic. Remarkably, if the layers are aperiodic in thickness the Q factor rises quadratically to reach extraordinarily high values of Q=0.6x106 at 30GHz (world record).

This result suggested that it might be possible to reach the threshold for masing and indeed we demonstrated that in P-terphenyl doped with pentacene when located inside a very high Q sapphire resonator maser action can be observed. This is the first time a solid state maser has been demonstrated at room temperature and in the earth’s magnetic field. Recent work has shown that miniaturisation is feasible and considerable reduction in pumping power is possible by
using a strontium titanate resonator which by virtue of a higher relative permittivity leads to a factor of over 5 in size reduction. Importantly, the Purcell factor which is the ratio of the Q factor to the mode volume, remains high and this is a key factor in the ability to exceed the threshold for masing. In this system we have observed strong Rabi oscillations in the strong coupling regime also at room temperature and this may have implications for quantum engineering.

1) R. D. Richtmeyer, J Appl. Phys. 10, 391-398 (1939)
2) Lord Rayleigh, Phil. Mag. S.5 43, 125-132 (1897)
4) Better than Bragg: Optimizing the quality factor of resonators with aperiodic dielectric reflectors Breeze Jonathan; Oxborrow Mark; Alford Neil McN APPLIED PHYSICS LETTERS Volume: 99 Issue: 11 Number: 113515 2011
5) Room Temperature Maser NATURE, 16 August 2012 Mark Oxborrow, Jonathan Breeze and Neil Alford

Application of Neutron Scattering to Materials Science and Engineering
Professor Xun-Li Wang, Department of Physics and Materials Science, City University of Hong Kong

Modern materials science is based on the premise of the structure-property relationship, i.e., the properties of a material are determined by the underlying multi scale structures, from angstrom to nanometers. The wavelengths of thermal neutrons are in the same range. The matching length scales, combined with the highly penetrating capability of neutrons, makes neutron scattering a powerful tool in material research, particularly for in-situ study of materials response at temperatures, under stress, or in an electric or magnetic field. As an example, interplanar lattice spacing has been used as an atomic strain gauge to measure the deformation and hence the stress in engineering materials. We illustrate the applications in manufacturing science with an example of in-situ welding study. The same method can be applied in fundamental studies. We show how in-situ loading measurements, on a neutron diffractometer, are used to gain insights of deformation crossover in nanostructured materials. Phase transformation introduces structural changes and is therefore an effective method to manipulate the structure of a material. Neutron scattering is well suited to studying the structural evolution during a phase transformation. An example is illustrated for phase transformation in amorphous alloys, a particularly challenging problem because structural changes over different length scales are coupled. Knowledge gained from in-situ studies have contributed a great deal to our understanding of the complex structure and stability of glassy materials. Finally, an outlook is given for future applications.

The 19th Kelly Lecture

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

Very dense suspensions can undergo a sudden jamming transition from a fluid to a solid state known as discontinuous shear thickening (DST). As I will demonstrate, this leads to remarkable material properties that can easily be observed by adding a small amount of water to cornstarch (or custard powder) to make a smooth paste. DST can sometimes be exploited, for instance to make bullet-proof vests. More often, it is a serious nuisance when processing particle-laden fluids: maximizing the solid content risks catastrophic equipment failure. I will summarize recent advances in our physical understanding of DST, which, despite its discontinuous nature, can be explained by a smooth increase in the average friction at interparticle contacts when stress is increased. This understanding offers a clear strategy for decreasing or even eliminating the risk of jamming. However, difficulties arise when translating this new qualitative understanding into a quantitative theory, and if time allows, I will outline some of these difficulties.
Past Kelly Lectures have been given by:

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<th>Year</th>
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| 2016 | Professor R Parker CBE FREng | Director of R&T, Rolls Royce  
Advanced Materials – Flying High |
| 2015 | Professor A Belcher | WM Keck Professor of Energy, MIT  
Giving New Life to Materials for Energy, the Environment and Medicine |
| 2014 | Professor ND 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 A Taub | Global R&D, General Motors  
Materials Challenges for a Sustainable Automotive Industry |
| 2011 | Professor A Fert | Nobel Laureate for Physics 2007, Unité Mixte de Physique CNRS-Thales, Palaiseau  
Spintronics: Electrons, Spins, Computers and Telephones |
| 2010 | Professor K 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 G Olson | Northwestern University  
Materials by Design: Frankensteels Driving Innovation in Research and Education |
| 2007 | Professor M Ashby CBE FRS FREng | University of Cambridge  
Environmentally Informed Material Choice: Strategies, Tools, Data and Difficulties |
| 2006 | Professor JMD Coey FRS | Trinity College, Dublin  
Magnetic Materials – Where are the Limits? |
| 2005 | Professor D Morse | UCSB-MIT-Caltech Institute for Collaborative Biotechnologies, University of Cambridge  
Biologically Inspired Routes for Materials Synthesis and Nanofabrication: High Performance with Low Environmental Impact |
| 2004 | Professor H Gleiter | Institute for Nanotechnology, Karlsruhe, Germany  
Nanostructured Solids: A Gateway to Elements that Lie ‘Between’ the Elements of the Periodic Table |
| 2003 | Professor A Inoue | Institute for Materials Research, Tohoku University, Japan  
Bulk Nonequilibrium Alloys by Stabilization of Supercooled Liquid |
| 2002 | Professor J Edington | formerly Alcan and British Steel  
Commercialisation of Materials Science - Entrepreneurship - Creating Wealth - Enjoying your Life |
| 2001 | Professor S 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 |