UNIVERSITY OF CAMBRIDGE

THE WINTON PROGRAMME FOR THE Physics of Sustainability

ANNUAL REPORT

2014

The Winton Programme for the Physics of Sustainability was established in 2011 through the donation of £20 million by David Harding to the Cavendish. The Programme has continued to focus on "blue-skies" research that could lead to breakthroughs in areas related to the broad area of sustainability.

The Programme has established a number of schemes to bring bright young scientists to the Cavendish and provide opportunities for existing researchers to explore new directions of research, both in the Department and with collaborations across the University and beyond. This report provides a summary of these activities and some of the scientific outputs that have been generated and also looks forward to how the Programme will develop in the future.

REVIEW

Richard Friend, Cavendish Professor of Physics

The Winton Programme has now been operating for three years and has grown close to its projected scale. The Programme has given direct support to a majority of the research groups in the Cavendish for new projects, through 'pump prime' grants, and 21 Winton Scholar PhD students. The scientific reach continues to grow beyond the Cavendish, with jointly funded projects and jointly supervised PhD students in the Departments of Chemistry, Materials Science and Metallurgy, Plant Sciences, and Biochemistry. The mission of the Winton Programme is to find and support the fundamental new physics that can make a big impact on the challenges around 'sustainability'. The reach of the research now supported within and outside the Cavendish gives us additional opportunities.

One area, broadly-framed as 'Energy Efficient IT', is where such fundamental changes are most quickly adopted. This provides a focus for the Winton Programme that is a natural complement to 'condensed matter physics' in the Cavendish. The field of IT, interpreted broadly, offers some of the largest opportunities for radical technology changes, most of which will be driven by energy efficiency. Energy, its consumption, generation and storage, is often the performance-constraining factor across many IT sectors, from main-stream computing and massive data storage, to mobile electronics, and, increasingly, to remote sensing and the 'internet of things'. The potential for performance enhancement is often very large, with a factor of a million still to be gained for computation and data transmission, but this will require fundamental science breakthroughs. Technology developed for IT does of course work its way to other applications which enable energy efficiency on a large scale, for example, lithium ion batteries for transportation and nitride semiconductors for lighting.

Construction of the Maxwell Centre has now started and we look forward to moving the whole of the Winton Programme research activities into the new building towards the end of 2015.

PROGRAMME UPDATE

Nalin Patel, Programme Manager

The Winton community has continued to grow 'bottom-up', with the focus on bringing the brightest minds to work on science that could lead to breakthroughs in areas broadly related to 'sustainability'. With the Programme now well established both in the Department and with increasing links across the University, we are well placed to move to the next phase and consider introducing 'top-down' activities into new areas of research with potential for impact on some of the 'Global Challenges' we face.

Overview

The Winton Programme for the Physics of Sustainability has continued to grow this year with more bright scientists associated with the programme, and those in post making rapid progress in developing their research activities and producing scientific outputs of significance. The Programme has now been running for over three years with the fourth cohort of Scholars and Fellows to start later in the year. In this time, the Programme has continued to interact widely with groups at the Cavendish as well as strengthening links with other departments through joint supervision of Winton Scholars and Winton Pump Prime awards.

The research activities supported by the Programme have remained very broad focusing on 'blue-skies' research that could have a future impact on sustainability related issues. The emphasis has been on expanding into new directions of physics related research; examples include quantum biology, battery research and modelling swimming micro-organisms that has applications for bioremediation and photo-bioreactors. This work has involved collaborations with researchers from a spectrum of backgrounds from chemists and mathematicians to materials and life scientists; the need for interdisciplinary research is critical to address many of the challenges we face and this has historically been a particular strength of the Cavendish and is an important theme of the Programme.

Looking forward, the Programme will continue to support new areas of research through a 'bottom-up' approach. At the same time we are moving into the next phase of the Programme and are considering 'top-down' activities; what are some of the biggest challenges we are facing and how do we target ones where the Programme can make a real impact? Related to this discussion, the theme of this year's Winton Symposium is 'Global Challenges for Science and Technology", which will explore some of the scientific advances that will be needed to tackle the demands of a growing population with declining natural resources.

Programme Activities

One of the major themes for the Winton Programme this year has been 'Materials Discovery', which was also the title for the last Winton Symposium. Experimental work in this area has substantially grown with Dr Siân Dutton (1st cohort of Winton Fellows) and Dr Suchitra Sebastian (Winton affiliated lecturer) expanding their growth and characterisation facilities for research in new materials for a range of applications from batteries to superconductors. They have designed bespoke laboratories to be housed in the new Maxwell Centre with a range of state-of-the-art facilities that will boost the research capabilities for materials research. Modelling of new materials is also a significant part of the Programme with Dr Andrew Morris and Dr Nicholas Hine (both

2nd cohort of Winton Fellows) working closely with other theoreticians and experimentalists to develop advanced simulation techniques and apply them to a range of problems. Some of these are described in the Fellows' summary section.

This year a further nine Winton Scholars started research, two having joint supervisors from other departments. A further eight Scholars are set to join later this year which will bring the total to 29. The 1st cohort of Scholars is coming to the end of their third year and they are busy completing their PhDs and planning their next steps. Their research is summarised in the Scholars section.

An appointment has also been made of a new Winton Fellow, Dr Amalio Fernández-Pacheco. He will develop a new technique based on focused ion beam induced deposition and patterning to produce complex nanostructures for exploring fundamental science and potential new applications. In addition, the Programme will provide support for two further researchers who will be working on "quantum science and technology with opto-mechanical systems" and "photovoltaics and artificial photosynthetic systems".

The award of Winton Pump Prime grants also facilitates the exploration of new science. These are available for junior and senior staff at the Cavendish along with collaborators in other departments. There is no deadline for submission of proposals with grants available up to £50k. A further two awards have been made this year; details of these and some completed grants can be found in the Pump Prime section.

Winton Scholars that started in 2013/14

Mr Jan Beitner
Supervisor: Dr Mete Atatüre
Atomic, Mesoscopic and Optical Physics Group
"Strong coupling of nitrogen-vacancy colour centres in nanodiamonds"

Mr Felix Benz
Supervisor: Prof Jeremy Baumberg
Nanophotonics Group
"Few Molecule Vibrational Spectroscopy in Plasmonics"

Miss Kerstin Göpfrich
Supervisor: Dr Ulrich Keyser
Biological and Soft Systems Group
"Rational design of artificial DNA origami lipid membrane pores"

Mr Zachary Ruff
Supervisor: Dr Erika Eiser and Prof Clare Grey
Optoelectronics Group and Department of Chemistry
"Functional Self-Assembling DNA Colloidal Systems"

Mr Florian Schroeder
Supervisor: Prof Richard Friend and Dr Alex Chin
Optoelectronics and Theory of Condensed Matter Groups
"Experimental and theoretical analysis of quantum coherence in singlet fission materials and light-harvesting complexes"

Miss Xiaoyuan Sheng
Supervisor: Prof Ullrich Steiner
Optoelectronics Group
"Structure and Function of Polymers far from Equilibrium"

Mr Hajime Shinohara
Supervisor: Dr Siân Dutton
Quantum Matter Group
"Cation order and disorder in rock-salt derivatives and its impact on their performance as electrodes in Li-ion batteries"

Mr Maxim Tabachnyk
Supervisor: Prof Richard Friend
Optoelectronics Group
"Singlet Exciton Fission Sensitized Solar Cells"

Mr Tobias Wenzel
Supervisor: Prof Ullrich Steiner and Prof Christopher Howe
Optoelectronics Group and Department of Biochemistry
"Understanding power output from photosynthetic microorganisms in bio-photovoltaic systems"

THE MAXWELL CENTRE

The Maxwell Centre will open its doors next year to academics and industrial partners to work together on world-leading research that is linked to industrial objectives and the sustainability agenda of the Winton Programme.

The construction of the Maxwell Centre will provide a centrepiece for industrial partnership with the physical sciences, which has been enabled by a £21.0M investment from the government supported by a further £4.6M from the University. A key part of the facility is the supporting funding provided by a number of industrial partners and the Winton Programme. The plans have been finalised and construction started earlier this year, with completion scheduled for late 2015. The Centre will be physically connected to the Physics of Medicine building, and be part of the Cavendish Laboratory on the West Cambridge site.

The Maxwell Centre's objectives are to carry out world-leading research in the physical sciences, and provide a vehicle for translating scientific discoveries into products of importance for the industrial sector. The Centre will build on the core of innovative activity supported by the Winton Programme, which is directed to 'blue-skies' research that is linked to the sustainability agenda.

"This will not be conventional research or 'business as usual', but a major effort to go beyond the boundaries of traditional physical science concepts", said Professor Sir Richard Friend, who will be the first Director of the Maxwell Centre.

In parallel with the construction of the Maxwell Centre, work is underway to establish an appropriate framework for operating the Centre. A liaison team will be set up that will support existing projects and forge new links. Dr Aga Iwasiewicz-Wabnig, Knowledge Transfer Facilitator at the Cavendish Laboratory who is engaging with industrial partners, said, "So far, the response to the Maxwell Centre has been overwhelmingly positive, and we are very much looking forward to it opening next year."

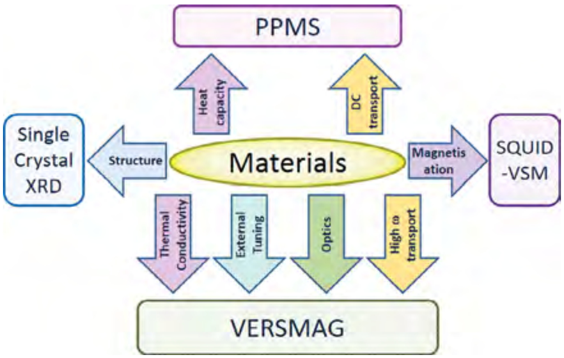
Research scientists from industry will occupy laboratory and desk space alongside academic research groups in the building. The Maxwell Centre will also house two industrially co-funded EPSRC Centres for Doctoral Training, in Nanoscience and Technology (NanoDTC) and in Computational Methods for Materials Science. Further occupants include the Winton Programme members and affiliates, the Centre for Scientific Computing, and new and existing partner companies.

Advanced materials research will form a key element of the centre's remit with state-of-the-art infrastructure available for both academic and industrial use. The Department along with collaborators in the physical sciences has been awarded funding from the EPSRC, with matched

Architect's visualisation of the Maxwell Centre viewed from the Cavendish Laboratory

funding from the University and the Winton Programme for an Advanced Materials Characterisation Suite to be located in the Maxwell Centre. Dr Suchitra Sebastian (Lecturer in Physics and affiliated to the Winton Programme) and Dr Siân Dutton (Winton Advanced Research Fellow) have completed detailed designs of the new characterisation suite and their materials growth laboratories. They will be some of the first people to move into the Maxwell Centre.

The Advanced Materials Characterisation Suite will include a high magnetic field (20 T) and low temperature facility (VERSMAG), SQUID Vibrating Sample Magnetometer (SQUID-VSM), Physical Properties Measurement System (PPMS), and Single Crystal and Laue X-Ray Diffractometers (Single Crystal XRD). The suite will enable progress to be made from directed materials discovery and characterisation to new technological applications. In particular the facilities for materials characterisation will address the measurement needs of materials whose properties are determined by 'strongly correlated electrons', the high electron density and tuneability of which maximise the potential for functionality. Measurement technologies at the core of strongly correlated materials have broad applications, and bring significant value to a much wider set of materials programs.The research enabled will include the study of a variety of functional materials, including new generation batteries, advanced electronic devices, multiferroics, novel electronic and magnetic phases, unconventional superconductors, photovoltaics, and solid-state coolants.



The facilities available in the Advanced Materials Characterisation Suite to be located in the Maxwell Centre will enable characterisation and investigation of a wide range of material properties.

FELLOWSHIP

The Winton Advanced Research Fellows have brought new directions of research to the Department and have rapidly grown their groups and collaborations. The fourth cohort will begin later this year; this includes Dr Amalio Fernández-Pacheco who will develop a new nano-structuring technique. In this section, some of the work of the second cohort of Fellows who have been developing theoretical simulations of materials and working with a range of experimental groups is summarised.

Andrew Morris

This January I was joined by new Ph.D. student, Martin Mayo. His project is to discover new materials for lithium ion batteries (LIB) using computational techniques such as AIRSS (*ab initio* random structure searching) that my group develops. 'Trial and error' plays a large part in the discovery of new materials. High-throughput computation accelerates this process by suggesting new materials, allowing us to ask 'what if?' without the time and expense of manufacturing samples.

LIB anodes traditionally comprise lithium atoms between graphite sheets. However, silicon has a theoretical capacity ten times larger than graphite and, in turn, germanium has a far faster ionic conductivity than silicon. Unfortunately silicon's increased capacity leads to unacceptably large volume expansion during charging. One recourse is to nanotexture the silicon making nanowires (SiNW). During 2014, we showed how to characterise the amorphous-crystalline phase transitions that occur during charging SiNWs [1]. This year we also published an article predicting the structures that form in a germanium anode and showing that germanium may be a safer alternative to silicon [2]. With Prof Clare Grey in the Department of Chemistry we are now using these predictions to aid understanding of the germanium anodes her group has made recently.

It is helpful to predict the behaviour of the materials we discover, under experimental conditions to enable a better comparison of our results with experiment. We have developed the OptaDOS quantum mechanical computer program for predicting optical and electron-energy loss spectra [3]. This year we released version 1.0 and provide it free to scientists. It is already being used all over the world.

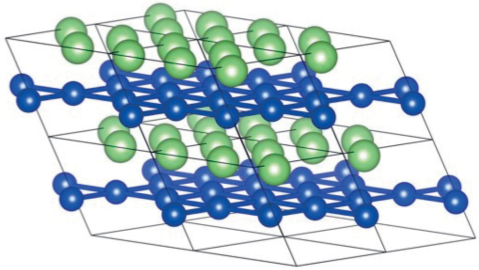


Fig. 1. During structure searching we often discover amazing new materials we weren't looking for. The image shows a high pressure phase comprising lithium and silicon layers. With the current interest in silicene, the silicon analogue of graphene, the lithiation of silicon under pressure may prove to be the route to making perfectly flat silicon sheets.

[1] K. Ogata, E. Salager, C. J. Kerr, A. E. Fraser, C. Ducati, A. J. Morris, S. Hofmann and C. P. Grey, Nature Comm. 5, 3217, (2014).
[2] A. J. Morris, C. P. Grey and C. J. Pickard, Phys. Rev. B 90, 054111, (2014).
[3] A. J. Morris, R. J. Nicholls, C. J. Pickard and J. R. Yates, Comp. Phys. Comm. 185, 5, 1477, (2014).

Nicholas Hine

During the last year I have continued to develop my research on the theory and simulation of nanomaterials, with an emphasis on materials for energy. My group has expanded considerably and I am currently working with 1 PDRA with a second starting next year, and supervising 3 PhD students and 2 MPhil students who are carrying on to PhDs next year. All our projects involve a combination of development of novel methods for computational electronic structure calculations, with exciting applications to nanomaterials of experimental interest.

Much of my research involves theoretical spectroscopy, which involves using computational tools to predict, and thus explain, the results of spectroscopic measurements of nanomaterials using techniques such as Electron Energy Loss Spectroscopy (EELS), X-Ray Absorption Spectroscopy (XAS) and optical absorption. As the structures we are capable of creating and manipulating on the nanometer scale get more complex, it is increasingly important, yet increasingly difficult, to be able to characterise them accurately. This is where simulation can help a great deal, as we can identify the possible origins of spectroscopic features and link them to features of the electronic structure. Nowhere is this more important than with EELS, which combines high energy resolution with spatial resolution, since an electron beam can be focused with near atomic-level precision.

Recent work in collaboration with microscopists at Imperial College London involved oxidised carbon nanotubes (CNTs). Acid oxidisation purifies and solubilises CNTs, which is key to their utilisation in low-power electronics. I used simulations of a range of possible oxygen-containing defects on the surface of these nanotubes to help identify the species responsible for a specific peak which was only being observed in EEL spectra after acid oxidation. By showing that this was associated with carboxyl groups on the surface of the tubes, we were able to map the features associated with oxidation and determine whether they cluster near the ends or at regions of high curvature.

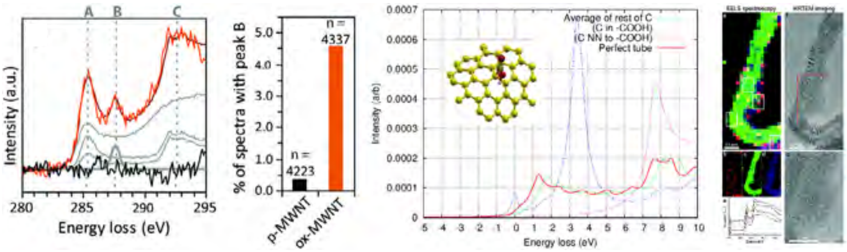


Fig. 2. Left: experimental EEL spectra for oxidised multiwall carbon nanotubes, and a histogram showing the prevalence of a new peak (labelled 'B') after oxidation. Centre: simulations showing EEL spectrum of a chosen -COOH functionalisation. Right: A map indicating the prevalence of peak B over the surface of a nanotube.

Reference: A. E. Goode et al, Chem. Commun. 50, 6744 (2014)

SCHOLARSHIPS

The first cohort of six Winton Scholars started in October 2011 and they are now approaching the end of the third year of their PhD. This is a busy time with the generation of new results, writing papers and presenting their research as well as thinking about their future plans. Each Scholar has provided a brief summary of their research.

Miloš Knežević has studied smectic liquids and nematic elastomers doped with photo-isomerisable molecules. He has developed a simple model of the photo-ferroelectric effect in chiral smectic C liquid crystals. This has led to the proposal of a charge pump, based on cyclic changes in the spontaneous electric polarisation of a photo-ferroelectric material, which allows a transfer of charge from a low to a high voltage. For a specific choice of material an efficiency of 2% was obtained (*Appl. Phys. Lett., 2013, 102, 043902*).

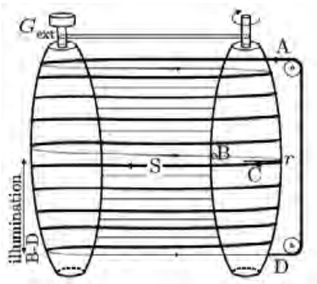


Fig.1. Schematic of an opto-mechanical turbine

He has also presented a conceptual design of two photo-elastomer based engines that extract mechanical work from light. The first of them uses a two-wheel design, while the second one is based on mechanical turbines. The engine efficiency was discussed in both cases, and showed that it is significantly improved in the latter case. For a modest choice of material and geometric parameters the efficiency of a mechanical turbine can increase to 40%.

Jan Mertens' research focuses on understanding the interaction of light with metallic nanostructures. Plasmonic effects in such structures allow for confining and enhancing light in sub-nanometre volumes that can be used for high performance sensors. In particular, he studies plasmonic coupling in the nanoparticle on mirror geometry. Nanoparticles are placed on a gold surface that acts as a mirror and produces images of the nanoparticles. Depending on the gap size between the particle and surface, different plasmonic coupling between the nanoparticle and its image can be observed.

For example graphene was used to fabricate stable sub-nanometre junctions that are defined by the number of graphene layers (*Nano Lett., 2013, 13 (11)*). For a single graphene layer, Jan found a new interaction of plasmon modes: a strongly localised plasmon in the gap mixes with the coupled nanoparticle-image plasmon so that new resonances appear. His research extends now to investigating different insulating and semiconducting thin spacer materials with the aim of actively controlling coupled plasmonic resonances using light or electronic gating.

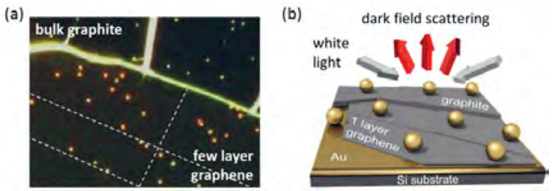


Fig.2. right: (**a**) Dark-field scattering of coupled (red) and uncoupled (green) nanoparticles on a mirror with graphene junction. (**b**) Schematic of the configuration in (**a**).

Breanndán Ó Conchúir has worked on several projects spanning a broad spectrum of topics in soft matter relevant for new sustainable technologies. In the field of non-equilibrium statistical mechanics, he successfully developed a first principles microscopic analytical theory to describe the mechanism of flow-induced macromolecular and colloidal aggregate breakup. This model elucidated, for the first time, the origins of key experimental features such as the maximum stable size of colloidal clusters under flow and the power law relationship relating this parameter to the flow rate required to break colloidal clusters apart (*Phys. Rev. E 87, 032310, (2013)*).

Recently, in collaboration with experimentalists, Breanndán investigated the influence solvent-mediated hydration forces have on the nanoparticle gelation process. The model allows one to predict the time required for the formation of a system-spanning gel network in colloidal systems where hydration effects are important, for example water-based hydrophilic polymers.

Nicholas Paul's research has focused on the Photosystem II protein and how it interacts with synthetic materials, such as metal oxides and carbon-based nanomaterials. It is the photo-active protein found in oxygenic photosynthesis, and its function is to harvest photons and convert photo-excitations into energised charges to drive the splitting of water into molecular oxygen. His studies have demonstrated that compatible materials can interact favourably and act as artificial wires or sinks for charges produced by the protein, while other materials interact less favourably and can introduce new mechanisms of exciton quenching, hence limiting the proteins efficiency for charge formation. Nick has also contributed to a review of the basic photoelectrochemistry of Photosystem II (*Chem. Soc. Rev, 2014, 43, 6485*).

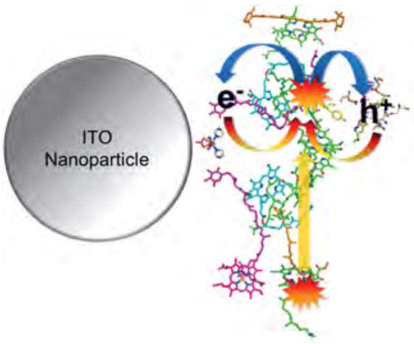
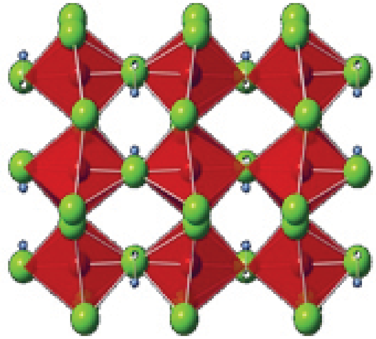


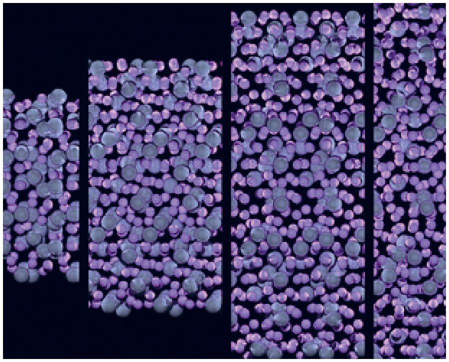
Fig.3. Simple schematic of the core elements of Photosystem II (right, main cofactors, multi-coloured) bound in the optimum orientation to an indium tin oxide nanoparticle (ITO, left, grey/shaded sphere). Red star-explosions represent excitations being transferred (pale orange arrow) to the reaction centre where charge generation occurs (blue arrows = separation, red/orange arrows = recombination).

Michael Price has been exploring the fascinating photo-physical properties of solution processed methyl-ammonium lead halide perovskite materials. These materials have been under intense study recently due to their remarkable power conversion efficiencies when used in photovoltaic cells. This work has led to the demonstration of optically pumped lasing in this material (*J. Phys. Chem. Lett., 2014, 5 (8), 1421*), where it was shown that the primary photoexcited species in the perovskites are free charges, rather than bound electron-hole pairs and that these free charges can recombine with remarkable radiative efficiency. These features are an interesting discovery in such a simply prepared, solution processable material. This has led to a broad range of further work in the Optoelectronics group, with a recent demonstration of a new type of LED made from perovskites published in *Nature Nanotechnology, 2014, 9, 687*.



Milan Vrućinić is working in the field of organic semiconductors, which are a very promising alternative to more commonly used inorganic semiconductors such as silicon. His research is focused on studying the relationship between film morphology and electrical current generation, which could lead to a decrease in the losses that are associated with the donor-acceptor heterojunctions. Near-field Scanning Photocurrent Microscopy (NSPM) can provide this information, with a lateral resolution below the diffraction limit. Using the Scanning Near-Field Optical Microscope (SNOM) system it is possible to simultaneously map photocurrent and photoluminescence, together with the topography and light intensity. A better understanding of the photoconductivity mechanism of high mobility organic semiconductors might lead to new approaches and device architectures that would minimise losses and provide better performance organic solar cells.

RESEARCH IN THE NEWS



Resolving the mystery of what happens inside batteries

Researchers have used in situ nuclear magnetic resonance (NMR) combined with density-functional theory (DFT) calculations to provide insights on the kinetics of lithiation and delithiation in high capacity Si-anode based lithium-ion batteries. The results are reported in Nature Communications, 5, 3217 (2014).

Silicon has been proposed as a replacement for carbon in battery anodes (negative electrodes) for the past 20 years, as it has roughly ten times more storage capacity than carbon. However, difficulty in managing silicon's properties has prevented the technology from being applied at scale.

The primary problem with using silicon in a lithium-ion battery is that silicon atoms absorb lithium atoms, and the silicon expands up to three times in volume, degrading the battery. Although controlling this expansion has become easier over the past decade, a lack of understanding about what is happening inside the batteries and what governs the reactions have continued to hold silicon batteries back.

Using these combined techniques, the researchers were able to develop a 'map' of how silicon transforms when it is put into contact with lithium in a battery. The insights opened up by the technology will boost further developments of silicon batteries, as it will be easier for engineers to control their properties.

Dr Andrew Morris, a Winton Advanced Research Fellow, performed the DFT calculations, with the experimental work led by Dr Ken Ogata with collaborators in the departments of Engineering, Chemistry and Material Science and Metallurgy.

http://phys.org/news/2014-02-lid-silicon-batteries.html
www.winton.phy.cam.ac.uk/news/inside-batteries

Jan Mertens wins SET for Britain award at event hosted in Parliament

Winton Scholar, Jan Mertens, wins silver prize for his poster on "Graphene Controls Colour of Plasmonic Nanoantennas" as part of the SET for Britain event in Parliament.

Jan presented his physics research to dozens of politicians and a panel of expert judges, as part of the poster competition SET for Britain, earlier this year. His

research, which involves squeezing light into tiny gaps to produce powerful sensors, was judged against 29 other shortlisted researchers' work and came out as one of the three winners.

SET for Britain aims to help politicians understand more about the UK's thriving science and engineering base and rewards some of the strongest scientific and engineering research being undertaken in the UK.

www.iop.org/news/14/mar/page_62792.html

Dr. Suchitra Sebastian explains the magic of superconductivity at Soapbox Science event

Soapbox Science is an annual event that brings science to the people via the format of London Hyde Park's Speaker's Corner, which is historically an arena for public debate. With Soapbox Science, the UK's top female scientists take to the streets to engage the general public with their latest

discoveries, and to answer their science questions. The latest event was held on The South Bank in London on 29th June.

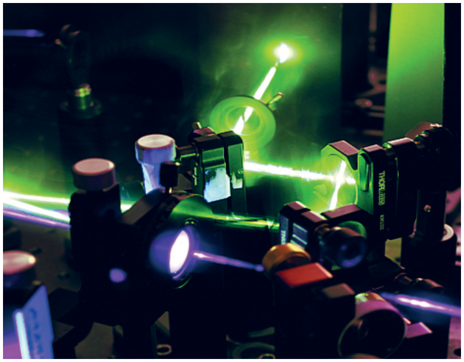
Dr Suchitra Sebastian, Lecturer at the Cavendish Laboratory, who is also affiliated with the Winton Programme, was one of the 12 scientists who were selected as this year's 'Soapbox Scientists'. Her pitch was titled "Levitating trains: the magic of superconductors", in which she used fun props to introduce to passers-by of all ages the concept of superconductivity and some of its applications.

www.theguardian.com/science/blog/2014/jun/27/women-scientists-soapboxes-london-south-bank-soapbox-science

Revolutionary solar cells double as lasers

Latest research finds that the trailblazing 'perovskite' material used in solar cells can double up as a laser, strongly suggesting the astonishing efficiency levels already achieved in these cells is only part of the journey. The work was performed by researchers from Professor Sir Richard Friend's group at Cambridge's Cavendish Laboratory working with Professor Henry Snaith's Oxford group and was reported in the Journal of Physical Chemistry Letters, 5 (8), 1421 (2014).

"We were surprised to find such high luminescence efficiency in such easily prepared materials. This has great



implications for improvements in solar cell efficiency," said Michael Price, co-author from the group in Cambridge and Winton Scholar.

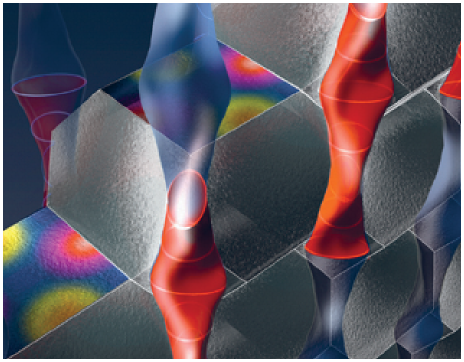
www.cam.ac.uk/research/news/revolutionary-solar-cells-double-as-lasers
www.theengineer.co.uk/energy-and-environment/news/cheap-laser-hope-from-light-emitting-perovskite-solar-cell-material/1018309.article

Superconducting secrets solved after 30 years

A breakthrough has been made in identifying the origin of superconductivity in high-temperature superconductors, which has puzzled researchers for the past three decades. The results were published in the journal Nature, 511, 61 (2014).

Harnessing the enormous technological potential of high-temperature superconductors – which could be used in lossless electrical grids, next-generation supercomputers and levitating trains – could be much more straightforward in future, as the origin of superconductivity in these materials has finally been identified.

"By identifying other materials which have similar properties, hopefully it will help us find new superconductors at higher and higher temperatures, even perhaps materials which are superconductors at room temperature, which would open up a huge range of applications," said Dr Sebastian.



http://phys.org/news/2014-06-superconducting-secrets-years.html

Inspired by Nature

Through billions of years of evolution, life on Earth has found intricate solutions to many of the problems scientists are currently grappling with. Physicists at the University of Cambridge's Cavendish Laboratory are trying to unravel nature's secrets to develop new energy-generating technologies for a more sustainable future.

Focusing on the ancient green sulphur bacteria, Winton Advanced Research Fellows Dr Alex Chin and Dr Nicholas Hine are investigating the early stages of photosynthesis – the process in which plants and some bacteria capture the sun's light energy and convert it into chemical energy, or food.

The idea is to generate broader design principles for new nanomaterials that can be used to build better types of photovoltaic device, or solar cell. "Once we understand the system, we can then move into synthetic chemistry, solid state physics and materials science, and see if we can mimic it," said Chin. "This may be in a simpler way, but hopefully a scalable one that is useful for industry."

www.cam.ac.uk/research/features/inspired-by-nature

PUMP PRIME

Pump Prime awards are available to encourage exploration of speculative new research. Many of the awards have provided opportunities for researchers in the Department to collaborate with colleagues in other departments and establish longer-term research activities with follow-on funding.

The Pump Prime scheme provides funding of up to £50k to seed new research activities, with grants available to academics in the Department and collaborators from other departments. The scheme encourages proposals that are innovative, with potential for high impact and that would be difficult to fund through conventional routes. To date, nine awards have been granted with a further two due to start later this year.

Two of the grants that have recently been completed are summarised below, in both cases the work will continue through follow-on funding; an EPSRC Early Career Fellowship obtained by Dr Malcolm Connolly and a joint PhD student to work with Dr Erika Eiser and Professor Clare Grey.

New colloidal materials for battery and photonic applications
Dr Erika Eiser (Optoelectronics Group) and Professor Clare Grey (Department of Chemistry)

For many applications, it is desirable to design porous materials containing nano-scale channels that can be controlled both in size and in chemical functionality. Examples are porous electrodes or thin films with tuneable photonic properties.

The present project aims to develop such materials, starting from colloidal particles that have been functionalised with single-stranded

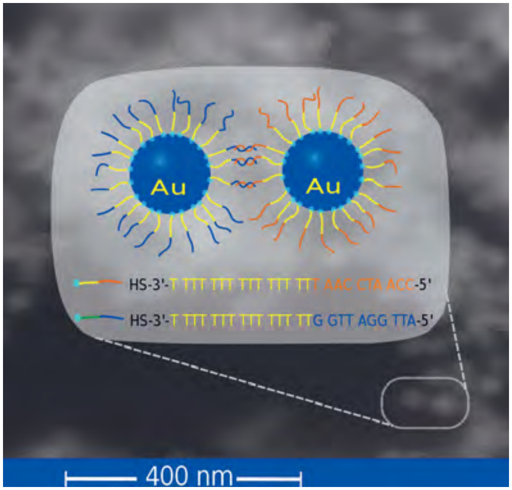


Fig.1. SEM image of a colloidal gel of DNA-functionalized gold nanopaticles taken in a liquid cell. The particles functionalization is depicted in the inset: single-stranded DNA with a flexible spacer of 15 thymines (T; yellow) is attached to the gold surface via a thiol bond. Half of the particles carry a sticky end (orange) while the other carries the complementary strand (blue), allowing for reversible binding between the colloids.

DNA. Colloids coated with complementary DNA will stick together as the DNA strands hybridise. We use short strands of DNA attached to colloids to build new functional materials.

During the past year we have explored the formation of porous structures from a variety of synthetic and natural DNA-functionalised building blocks, including gold, polystyrene and Teflon particles, and rod-like viruses.

Existing tools to predict the interaction of DNA-coated particles turned out to be too simplistic, and one part of the Winton-funded project focused on the development of better theoretical tools to predict the DNA binding strengths.

Our experimental studies of novel structures of controlled porosity resulted in three publications. Additional papers that focus on the experimental design of functional porous materials are in preparation.

Building a quantum capacitance microscope for probing coherence in molecular qubits
Dr Malcolm Connolly and Professor Charles Smith (Semiconductor Physics Group)

The aim of this Winton Pump Prime project was to build a scanning probe microscope capable of observing the dynamics of single electrons on molecules and nanoparticles attached to arbitrary substrates. There is enormous interest in developing such a tool as it would allow quantum effects in novel materials to be characterised and exploited in next-generation technologies. At the heart of our proposal is an innovation in microscope design that would allow sub-10 nm spatial resolution and nanosecond time resolution to be achieved while avoiding making direct, and potentially destructive, contact with these fragile structures. The funds provided by the Winton award have been essential for implementing and benchmarking this innovation. By working directly with the Cavendish workshop we were able to build the microscope such that features of the new readout technique were included at the design stage. We subsequently demonstrated the performance and reliability of the microscope in a low pressure environment at room temperature by making topographic images of functionalised nanoparticles on a gold surface. We confirmed that ~10 nm spatial resolution and a predicted ~100 ns temporal resolution are possible with the current design (see figure 2). The next step will involve cooling the nanoparticles to low temperature in order to detect the single-electron motion along with topography. These experiments have provided an excellent opportunity for training students in scanning probe techniques and stimulated collaborations with the Microelectronics group and Materials Science department. Plans to develop the next version of the microscope were also incorporated into several grant proposals, including a £1M EPSRC Early Career Fellowship awarded to Dr Malcolm Connolly that started in July 2014.

Two further Pump Prime awards are due to start later this year. One has been awarded to Professor Eugene Terentjev (Biological and Soft Systems Sector), on “Light driven continuous action motor”. In this project a rotary motor driven by light will be built and optimised for efficiency and power output.

The second award is for an interdisciplinary project between Professor Tony Cheetham (Department of Materials and Metallurgy) working with a number of researchers in Physics including Professor Richard Friend, Dr Felix Deschler (Optoelectronics Group) and Dr Siân Dutton (Quantum Matter Group). The project “Improving Solar Cell Efficiency by First Principle Design of Novel Light Absorbers Based on Hybrid Pervoskites” will explore the relationship between the structure and chemistry of hybrid perovskites and their opto-electronic properties. One of the aims is to develop an environmentally friendly alternative to the current system by making high efficiency lead-free hybrid devices.

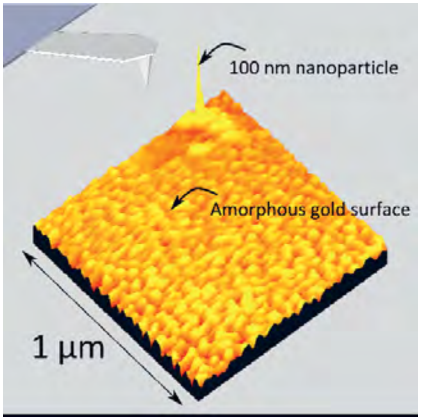


Fig. 2. Image of a gold nanoparticle on an amorphous gold surface. The colour represents the capacitance measured between the tip and the surface and is directly related to the surface topography. This image was measured at low pressure using the microscope constructed during this Winton Pump Prime project.

EVENTS

The Winton Symposium is an opportunity to open the doors of the Cavendish to bring people together from a range of disciplines to hear and engage in a topical debate. The theme for this year is "Global Challenges for Science and Technology", covering a number of topics from food, and healthcare to energy provision on a global scale.

Participants at the 2nd Winton Symposium

Winton Symposium

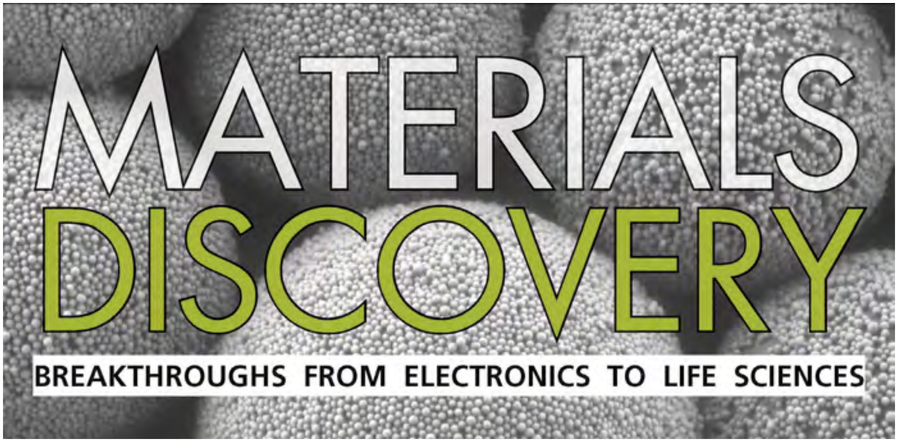
The second Winton Symposium, on 'Materials Discovery' was held on 30th September 2013. Speakers from a range of disciplines provided examples of recent breakthroughs and how they could make an impact on the needs of society. A capacity audience of 450 people at the Cavendish Laboratory were challenged to think about where the next major breakthroughs may emerge, in fields as diverse as electronics and the life sciences.

'We can make significant reductions in our materials usage but why are we not?' was the challenge put forward by **Chris Wise** of Expedition Engineering and University College, London. As a designer of several landmark buildings, he explained how the 2012 Olympic Velodrome with built with over 6 times less energy consumed than the similar sized 2008 Beijing Olympic swimming complex. The same philosophy could be applied to many structures with considerable scope for reducing material usage if we overcome inertia in industry to change and are not constrained in the design by over regulation.

Andrea Ferrari, Director of the Cambridge Graphene Centre, provided a brief history of carbon-based materials in different dimensions. The discovery that a simple 'Scotch Tape' method was able to produce graphene, a perfect 2D array of carbon atoms, has led to an explosion in research in this material. He pointed out a number of potential advantages of graphene, providing a cautionary note that even when performance is many times greater it is still difficult to displace an incumbent technology.

Paul Alivisatos, Director of the Lawrence Berkeley National Laboratory, described how we have leaned to make intricate and complex nanocrystals that have controlled size, shape, topology and connectivity. Through developing a 'stamp collection' of nanocrystals and applying scaling laws to understand their properties, new energy applications are being developed.

In biology, the number of different amino acids which are the building blocks for proteins are limited to only 20. **Jason Chin**, Head of the Centre for Chemical and Synthetic Biology at the MRC in Cambridge, explained how this basis set can be increased, limited by only the creativity of what people can make in the laboratory. The ability to label and provide new functionality to amino acids opens up a whole



Professor David Cahen

new area for monitoring processes and making 'designer' proteins.

Daniel Fletcher, from University of California Berkeley, predicted that in 10 years 'it will be possible from the bottom up to completely synthesise and reassemble the components that give a cell its function'. He described studies of simple biological systems that have revealed a number of lessons that control the self-organisation process and how these can be used to form an instruction set to create more complex structures.

Ben Feringa, from the University of Groningen, continued the theme of studying molecular assembly in nature to produce dynamic systems. He explained how through synthetic chemistry it has been possible to design a range of molecular switches and motors to ultimately make smart materials and systems. These demonstrators, although currently primitive, show how light and chemical based propulsion can be achieved, taking inspiration from how biological systems operate.

George Whitesides, Professor at Harvard University, addressed the challenge that universities face to convert the technology it develops into applications. He explained the concept of 'simplicity' where a simpler low cost solution is quicker to realise and more likely to be adopted. An example that he has developed is a paper diagnostic system, which is a low cost, easy to use device that has in six years gone from initial idea to devices in the field.

David Cahen

Professor David Cahen, The Rowland and Sylvia Schaefer Chair in Energy Research from the Weizmann Institute of Science visited the University in June 2014. His background is in physics and chemistry and he heads the alternative sustainable energy research initiative at the Weizmann Institute. During his visit he interacted with a number of people in the department, providing a Winton teatime discussion on "Energy vs materials availability. Equivalent or different?" Here he explored two issues; what amounts of energy or materials can be diverted from one to another without disrupting daily life, and can we supply the quantity of materials needed to transition to new energy sources? He also gave a Winton Lecture at the Cavendish, which attracted a large audience including attendees from a number of other departments. The title was "The amazing recent years in Solar Cells. What next?" This talk reviewed the science and the history of the development of solar cells highlighting the significant advances in efficiency and cost reduction. The future also looks promising with new cell types being explored, based on combining different materials and improving our understanding of the science. During his stay he also contributed to a publication on perovskite-based solar cells; these have made dramatic progress in device efficiency in the last couple of years and are fast approaching that of the best Si devices.

PEOPLE

International Advisory Board Members

Chair - Professor Paul Alivisatos
Director, Lawrence Berkeley National Laboratory,
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Managers of the Winton Fund for the Physics of Sustainability

Chair - Professor Lynn Gladden CBE FRS
Pro-Vice-Chancellor with responsibility for research,
University of Cambridge

Professor Sir Richard Friend FRS
Cavendish Professor of Physics and Director of the Winton Programme for the Physics of Sustainability,
University of Cambridge

David Harding
Chief Executive Officer and Chairman,
Winton Capital Management Ltd

Professor Andy Parker
Head, Department of Physics,
University of Cambridge

Dr Hermann Hauser CBE
Director and Co-Founder,
Amadeus Capital Partners

In attendance:
Professor Robert Kennicutt,
Head, School of the Physical Sciences,
University of Cambridge

Opposite page, top left to bottom right:

Prof Charles Smith, Miss Xiaoyuan Sheng, Dr Nalin Patel, Prof Sir Richard Friend, Mr Steffen Illig, Dr Ulrich Keyser, Prof Jeremy Baumberg, Mr Michael Price, Prof Eugene Terentjev, Miss Sarah Morgan, Prof David MacKay, Mr Martin Mayo, Miss Kerstin Göpfrich, Dr Andrew Morris, Prof Ulrich Steiner, Mr Jan Mertens, Dr Akshay Rao, Prof Henning Sirringhaus, Dr Nicholas Hine, Dr Siân Dutton, Mr Zachary Ruff, Mr Breanndán Ó Conchúir, Mr Jan Beitner, Dr Ottavio Croze, Dr Erwin Reisner, Mr Maxim Tabachnyk, Dr Alessio Zaccone, Mr Nicholas Paul, Miss Wenting Guo, Dr Alex Chin, Mr Felix Benz, Miss Hannah Stern, Prof Tony Cheetham, Dr Jason Robinson, Mr Adrien Amigues, Dr Erika Eiser, Mr Tobias Wenzel, Mr Andreas Jakowetz, Dr Suchitra Sebastian, Mr Florian Schroeder, Dr Malcolm Connolly, Mr Miloš Knežević, Mr Sam Smith, Dr Mete Atatüre, Mr David Turban, Prof Christopher Howe, Dr Andrew Ferguson, Mr Milan Vrućinić, Mr Vahe Tshitoyan, Mr Hajime Shinohara, Prof Clare Grey, Prof Mark Warner, Mrs Monika Szumiło, Mr Felix Deschler

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Physics of Sustainability

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