UNIVERSITY OF CAMBRIDGE

THE WINTON PROGRAMME FOR THE

Physics of Sustainability

ANNUAL REPORT

2018

The Winton Programme for the Physics of Sustainability was established through the donation of £20 million by David Harding to the Cavendish Laboratory to explore new research that could impact how we cope with our depleting natural resources whilst reducing the long-term impact on our climate.

The Programme has focussed on attracting bright researchers and offering an environment where their ambitious new ideas can be tested. Schemes such as the Pump Prime awards and the Exchange Programme with the Kavli Energy NanoScience Institute are amongst mechanisms for researchers across disciplines to collaborate on new projects. This is the seventh annual report which provides an overview of some of the activities of the Programme and highlights of the year.

REVIEW

Richard Friend,
Cavendish Professor of Physics

The Winton Programme has generated a vibrant and diverse research community, centred on physics but linked very strongly to other sciences and engineering. The funding schemes for the Winton Fellowships and Scholarships undoubtedly attract the best researchers from around the world, who bring energy, vision and new research ideas. The breadth of the current research portfolio is very evident in the exciting accounts of activities in this year's report. Many of the Winton community are based in the Maxwell Centre where the building's spaces naturally facilitate contact, enabling new collaborations for Winton researchers, and bringing together ideas for research from different fields, for example, from batteries, solar cells, thermoelectrics and membranes. Experimental research has moved closer to modelling and theory, providing a stronger base for generating new research areas.

We set up the Winton Programme to allow 'blue skies' research in areas where there is the potential to make a big difference to 'sustainability'. In particular, we have identified where the laws of physics reveal potential for vastly better efficiency than current engineering solutions. We have explored this in detail for the materials technologies used in the computing and information technology industries, since historically these have been very effective in introducing disruptive technologies. We have investigated the very real potential to transform the efficiencies of energy generation, for example of solar cells and thermoelectrics, energy storage in lithium ion and other batteries and energy use in memory and logic circuits. This has provided the theme out of which the Cambridge component of the Henry Royce Institute for Advanced Materials has been built. We officially opened the Cambridge Royce Institute on 17th October 2018 and now have a range of unique research facilities, many in the Maxwell Centre, for use both within the university and nationally.

This year's Symposium explores the mechanical world, from instruments which explore the very largest events on the cosmic scale to those exploring the very smallest on the molecular scale. Between these lie the very practical worlds of biomechanics and of electric motors; the latter is, of course, a critical component of the de-carbonised economy that we need to achieve urgently.

PROGRAMME UPDATE

Nalin Patel, Programme Manager

Overview

This is the seventh year of the Winton Programme for the Physics of Sustainability, which is now firmly embedded into the Maxwell Centre, where the majority of the Fellows and Winton affiliated Lecturers are based. The interdisciplinary nature of the activities that operate throughout the Maxwell Centre and the open spaces for chance meetings and discussions are perfectly suited to the aims of the Programme to generate and cultivate new science and modes of operation. The Programme has also set up a number of schemes to attract new researchers as well as to engage with existing scientist from across the University and beyond.

People

Winton Advanced Research Fellows

This has been one of the key parts of the project, enabling researchers to grow their own independent research with an opportunity to take science in new directions. An important part of the scheme has been the generous start-up packages that have been available to the Fellows, to build their groups and infrastructure that is required to kick-start new activities. This has seeded over the years a number of activities which have continued to be part of the Cavendish agenda, including that of Dr Siân Dutton who is now a reader in Physics and is assisting with developing the Energy Material strategy. The scheme has also enabled the Fellows to establish permanent positions elsewhere. For example, the Alumni section of the report describes the successes of Dr Nicholas Hine who now leads a theory group at Warwick University and of Dr Amalio Fernández-Pacheco who has more recently taken up a permanent position at Glasgow University. Two new Fellows, Dr Giuliana Di Martino and Dr Bartomeu Monserrat, have been appointed this year and a summary of their research is included in this report.

Winton Scholars

The Scholarship scheme is extremely competitive and continues to attract top candidates from across the globe. As funding for studentships, and in particular overseas ones, becomes tighter in the University, the Scholarships have become increasingly important, with the annual intake increasing from 6 in the first years to 8 last year. The Scholars' research is spread across the Cavendish with several having joint supervisors in other departments. This report has summaries of the research topics of the fourth cohort who are about to complete their third year and starting to publish results in scientific journals.

Engagement

Berkeley Exchange Programme

The Exchange Programme has been set up to enable exchange visits between the Winton Programme and the Kavli NanoScience Institute at University of California, Berkeley. PhD students, postdoctoral researchers as well as faculty members from both institutions are able to participate to facilitate new interactions. The second set of exchanges has been completed and examples of some of the science that is emerging from these are included in this report.

Pump Prime Awards

Pump Prime awards of up to £50k have continued to attract research proposals from members of the Cavendish as well as collaborators across the University to explore new ideas, which would otherwise be difficult to fund through existing research funding. Around four projects are funded per year, with some examples of projects provided in this report. The scheme accepts proposals on a rolling basis.

Winton Symposium

The Annual Winton Symposium is now a major event in the Cavendish calendar, attracting a large audience from the University and outside to hear world-leading speakers and debate sustainability and related topics. Last year's theme concerned Energy Storage and Distribution and is described later in this report: this year the theme is Machines.

WINTON SCHOLARS ARRIVING IN 2017/18 (7TH COHORT)

Haralds Abolins
Supervisors: Dr Felix Deschler and Professor Richard Friend
Optoelectronics and Nanophotonics Groups
"Charge Carrier Transport in Back-Contacted Perovskite Solar Cells"

Kareem Al Nahas
Supervisor: Professor Ulrich Keyser
Biological and Soft Systems Group
"Optofluidic Quantification of Membrane Active Antimicrobials"

Alan Bowman
Supervisor: Dr Samuel Stranks
Optoelectronics Group
"Charge separation at perovskite/singlet fission interfaces"

Elaine Kelly
Supervisors: Dr Rachel Evans and Dr Siân Dutton
Department of Materials Science and Metallurgy and Quantum Matter Group
"Hierarchically Structured Porous Metal Oxide Nanoparticles for Environmental Remediation"

Can Kocer
Supervisor: Dr Andrew Morris
Theory of Condensed Matter Group
"Advanced theoretical techniques for energy materials modelling"

Nora Martin
Supervisor: Dr Sebastian Ahnert
Theory of Condensed Matter Group
"A Coarse-Grained Network Description of Protein Tertiary Structure"

Diana Sobota
Supervisor: Professor Ulrich Keyser
Biological and Soft Systems Group
"DNA-based ion channels"

Attila Szabó
Supervisor: Dr Claudio Castelnovo
Theory of Condensed Matter Group
"Signatures of spin liquid behaviour out of equilibrium"

BERKELEY EXCHANGE

The Winton Cambridge-Berkeley Exchange Programme has been set up to facilitate scientific engagement between the Winton Programme at the University of Cambridge and the Kavli Energy NanoScience Institute at University of California, Berkeley. Funding is available for exchanges in both directions for PhD students, postdoctoral researchers and sabbatical visits that are connected to the two Programmes, including researchers at the Lawrence Berkeley National Laboratory. The second round of Exchanges has now taken place, some examples of which are described below.

Professor Stephen Elliott Sabbatical Exchange

Stephen Elliott spent the month of May 2018 at Berkeley during his sabbatical year as part of the Winton Cambridge-Berkeley Exchange Programme. His host for the visit was Professor Jeff Neaton, Director of the Molecular Foundry at the Lawrence Berkeley National Laboratory (LBNL). One of the aims of the visit was to learn more about the work being carried out at Berkeley and LBNL on materials for thermoelectricity generation, the latter being allied to the Winton's mission for sustainability.

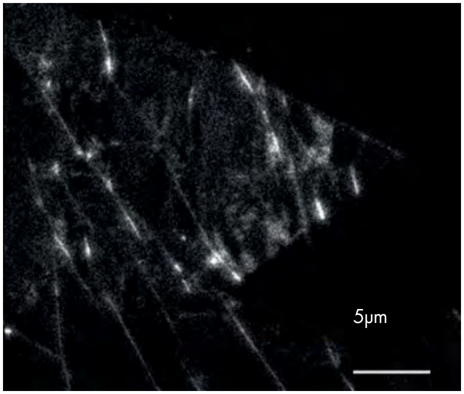
Another area of interest was work in the Physics Department in the group of Professor Frances Hellman on the preparation of amorphous silicon (a-Si) films which have extremely low values of mechanical loss. This work is directly relevant to some of Stephen's very recent computer-simulation work [1], in which he has used a recently-developed linear-scaling (O(N)) interatomic potential for Si, derived using a machine-learning approach, to generate models of a-Si with unprecedentedly high degrees of structural order, and hence correspondingly low values of mechanical loss. It is hoped that a collaborative effort can be initiated between the two groups to make a-Si in glassy form, directly from the liquid, which should have the highest degree of structural order, and thus the lowest value of mechanical loss, for this material.

[1] J. Phys. Chem. Lett. 9, 2879-2885 (2018)

Dr Hannah Stern Postdoctoral Exchange

Hannah Stern visited the group of Professor Naomi Ginsberg at UC Berkeley for three months from May- July 2018, as part of the Winton-Berkeley exchange. The aim of the visit was to use high spatially-resolved techniques in the Ginsberg group to explore emission from optically active defects in monolayers of hexagonal Boron Nitride (hBN). h-BN is a 2D wide bandgap semiconductor that is of interest for quantum technologies due to the newly-discovered single photon emission behaviour at room temperature.

During the visit, cathodoluminescence (CL) spectroscopy was used to explore UV



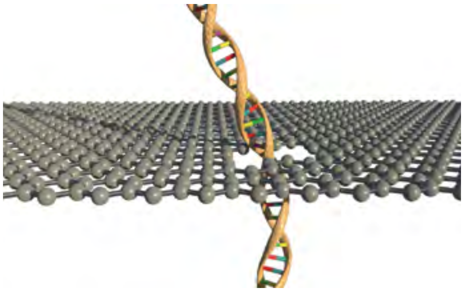
emission in the 2D material, confocal and widefield microscopies were performed to investigate emission from atomically thin samples, and work was started towards correlative imaging, to combine TEM with photoluminescence. During the exchange Hannah worked with students from the groups of Professor Alex Zettl (TEM) and Professor Norm Yao (confocal), as well as conducting experiments in the Lawrence Berkeley Labs. Ongoing work will continue to develop correlative imaging to match atomic structure with emission properties.

Mustafa Caglar PhD Exchange

Keyser Group (Cambridge) and Zettl Group (Berkeley)

Two dimensional materials have garnered an incredible amount of interest since the isolation of graphene in 2004. Methods of using these materials as membranes is a highly populated research area with attention focused toward filtration/separation barriers and nanopore sensing. Controlling the membrane selectivity and, related, creation of controlled pores are some of the key barriers to overcome for graphene.

Mustafa's efforts have been toward demonstrating controlled ionic selectivity and, increasingly, controlling nanopore creation across graphene. However, characterisation of these pores and controlling the pore termination is difficult in our setup in Cambridge. The Zettl group in Berkeley have a similar interest and have shown controlled pore termination in membranes. Using their expertise in material preparation and TEM imaging we are working towards imaging and manipulating the intrinsic graphene surface whilst also introducing pores into the membrane.

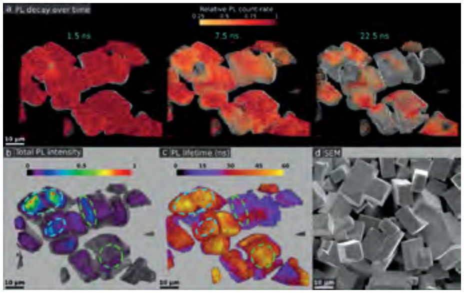


Following his visit to Berkeley, we have set up a collaboration which is mutually beneficial and maximises each group's expertise. We hope to create pores in our graphene and send samples to Berkeley for imaging and also receive samples with controlled pore termination for us to attempt nanopore sensing.

Camille Stavrakas PhD Exchange

Stranks Group (Cambridge) and Barnard Group (Berkeley)

Perovskite solar cells and light-emission devices have yet to achieve their full potential owing in part to microscale inhomogeneities and defects that act as non-radiative loss pathways. These sites have been revealed using local photoluminescence mapping techniques but the short absorption depth of photons with energies above the bandgap means that conventional one-photon excitation primarily probes the surface recombination. Thanks to her collaboration with Dr Edward Barnard at Molecular Foundry, Lawrence Berkeley National Laboratory, she was able to use two-photon time-resolved confocal photoluminescence microscopy to explore the surface and bulk recombination properties of perovskite structures that



aren't captured in conventional one-photon mapping experiments. This work, published in Energy & Environmental Science [2018, 11, 2846], highlighted a heterogeneity in the optoelectronic properties of single crystals. During Camille's time in Berkeley, she improved the capabilities of the experimental setup and developed a method of visualising the diffusion of charges in the bulk of such crystals and recording it with a very fine time resolution. This data set will allow testing recombination models proposed in recent work for the first time, and help to tackle pending questions relating to the importance of photon re-absorption and defects, which will ultimately allow further improvements to the efficiency of solar cells.

Left to right: Luminescence from wrinkles in multi-layer hexagonal Boron Nitride, imaged using cathodoluminescence at Lawrence Berkeley Labs; A visualisation of a graphene nanopore with a translocating DNA molecule; Time-resolved 3D tomography PL images of a micro-crystal film of $MAPbBr_3$

ENERGY MATERIALS

Siân Dutton, Winton Affiliated Lecturer

This summer the UK had a complete 24 hours without requiring electricity generated from fossil fuels and has a target to reduce carbon emissions to 80% of 1990 levels by 2050. Achieving this goal isn't going to be possible using current technologies and disruptive changes are required. Underpinning these technological devices will be new materials or paradigms which have yet to be developed. Within the Winton Programme and wider Cavendish community, efforts to address these challenges are grouped within the Energy materials theme.

Energy materials research can be divided into three main areas, energy generation, storage and transmission and use. Broadly interpreted this covers many areas of condensed matter physics and the Winton Programme has invested heavily in this area funding 13 Winton Advanced Research Fellows and 42 Winton Scholars. Over the 7 years of the Winton Programme this has expanded the research base of the Cavendish and through jointly funded students and infrastructure built links across the physical sciences and engineering. This spirit of collaboration can be seen within the Winton Programme where projects involving fellows with complementary research backgrounds are increasingly common. Much of the new activity generated by the Winton Fellows is underpinned by access to facilities within the Maxwell Centre. These include the EPSRC Advanced Materials Characterisation Suite co-funded by the Department of Physics and the Winton Programme, and the Cambridge spoke of the Royce Institute focused on Materials for Energy Efficient ICT.

The deployment of renewables at scales capable of generating a quarter of the UK's energy in 2017 has resulted in a drive for improved efficiency, for example by increasing the solar energy converted in next generation solar cells. Within the Winton Programme **energy generation** has a strong focus on photovoltaics and has overlaps with the quantum biology through the use of femto-second spectroscopies to explore electron transfer processes. An example of collaborative work in this area is the theoretical work of **Dr Alex Chin** (Winton Fellow 1st cohort, current position Group Leader, l'Institute des NanoSciences de Paris, CNRS) who has worked closely with experimentalist **Dr Akshay Rao** (Winton Fellow, 4th cohort) on understanding the underlying mechanism of singlet fission which could open up new ways to make more efficient solar cells. This project has involved joint supervision of PhD students **Florian Schröder** (Winton Scholar) and **Leah Weiss** (Winton Scholar).

Realising energy generation entirely from renewable energy sources will require the deployment of energy storage on a scale far beyond that of today. Within the Winton Programme, **Energy Storage** has focused on the development of secondary batteries, with both experimental and theoretical programmes. Here the work is highly interdisciplinary and involves interactions across the physical sciences and engineering. The group of **Dr Alpha Lee** (Winton Fellow, 6th cohort) aims to design materials by combining physics with machine learning. Recent research highlights include developing methods inspired by statistical physics and random matrix theory to predict protein-ligand affinity, inferring probabilistic models using a liquid state theory approach, and deriving a scaling theory for the structure of battery and supercapacitor electrolytes. He has secured funding from the Faraday Challenge fast start project on battery degradation, which is led by **Professor Clare Grey** to elucidate physical mechanisms of battery degradation by using machine learning algorithms to analyse large experimental datasets.

To meet our ever increasing energy use, efficiency in transmission and computing will increasingly become the metric by which advances are assessed. **Energy Use and Transmission** is a wide field encompassing many areas of research within the Cavendish.

Within the Winton Programme one focus is on the development of new spintronic devices. The groups of **Dr Chiara Ciccarelli** (Winton Fellow, 6th cohort) and **Dr Hannah Joyce** (Department of Electrical Engineering) have recently installed a new tetrahertz facility in the Maxwell Centre. This will enable studies of the charge and spin dynamics on the femtosecond timescale of a range of systems.

Collaborative Research Highlights:

Hine and Chin: Evidence of Correlated Static Disorder in the Fenna–Matthews–Olson Complex J. Phys. Chem. Lett. 8, 2350 (2017)

Morris and Grey: Theoretical and Experimental determination of intermediates formed during sodiation of battery anodes J. Am. Chem. Soc., ***2018****, 140 (25), pp 7994–8004*

Monserrat, Dutton and Grey: Ab initio studies of the electronic structure, defects and Mg-ion motion in Mg_3Bi_2 *J. Mater. Chem. A, 2018,6, 16983-16991*

Dutton and Deschler: Structural, bulk thermodynamics and photophysical properties of hybrid pervoskites J. Am. Chem. Soc., ***2017****, 139 (51), pp 18632–18639 and Winton Pump Prime award "Photo-induced changes in heat capacity of hybrid perovskites"*

THE WINTON PROGRAMME FOR THE
Physics of Sustainability

Energy Generation

Bronstein
Chin
Collepardo-Guevara
Deschler
Euser
Hine
Monserrat
Rao

Energy Storage

Dutton
Lee
Morris

THE FARADAY INSTITUTION

Energy Use & Transmission

Ciccarelli
Croze
Di Martino
Fernández-Pacheco
Nunnenkamp
Sebastian

42 Winton Scholars hosted in Physics, Chemistry and Materials.

Maxwell Centre

CAM-IES
Centre of Advanced Materials for Integrated Energy Systems

HENRY ROYCE INSTITUTE

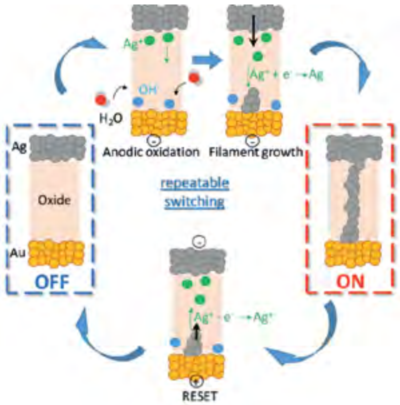
FELLOWSHIPS

Dr Giuliana Di Martino - Winton Advanced Research Fellow

One of the most promising contenders for ultralow-energy electronic devices is resistive switching memory (RRAM) which delivers sustainably-scalable 'neuromorphic' computing, potentially capable of reducing energy consumption in IT by >50%. Understanding the nanoscale kinetics of the switching mechanisms is needed to enable high-endurance devices – only this can unlock their integration into fast, low-energy, logic-in-memory architectures. RRAMs are currently studied by electron microscopy but this is destructive, invasive, and under drastically different conditions, so is not sufficient for developing true understandings.

My research group uses the ultra-concentration of light to develop innovative, fast ways to study real-time movement of individual atoms that underpins this new generation of ultra-low energy memory nano-devices, thus overcoming the limitations of traditional investigation techniques and opening up new routes to sustainable future IT.

In RRAMs a wire is formed within a gap by anode ions migrating to their cathode when voltage is applied, switching between high resistance and a low resistance states to represent the logical "0" and "1", respectively (Fig.1).



RRAM research is a strong focus of academic and industrial research as can be appreciated from the dramatic increase of publications and citations and from the growing number of companies and start-ups working in this area. However, they have as yet inferior device endurance, that is, their maximum achievable programming cycle is a significant drawback. How the conductive filament is created is still an open question, restricting implementation of higher device endurance and reproducibility.

My research links the fields of low-energy nanoscale device engineering and plasmon-enhanced light-matter interactions by implementing optically-accessible memristive devices. We develop resistive switches arranged in a configuration where we confine an enormously enhanced light (or 'plasmonic') field between the two electrodes. Using this geometry provides unique possibilities for studying isolated plasmonic junctions reliably [Small 2016, 12, 1334]. The ultrahigh sensitivity to morphological and conductivity changes occurring in the tightly confined nm^3 plasmonic hotspot allows us to investigate switching materials, as well as ferroelectric and perovskite thin films. My research provides evidence for the filament growth versus dissolution mechanism debate through a non-destructive dynamic technique. By using visible light, electron-induced perturbation of the switching process present in all traditional electron microscopy techniques is avoided.

For this research, the Winton Programme and the Maxwell Centre are the ideal places where material scientists, spectroscopists, engineers and theorists can all interact to develop a new generation of optically accessible devices.

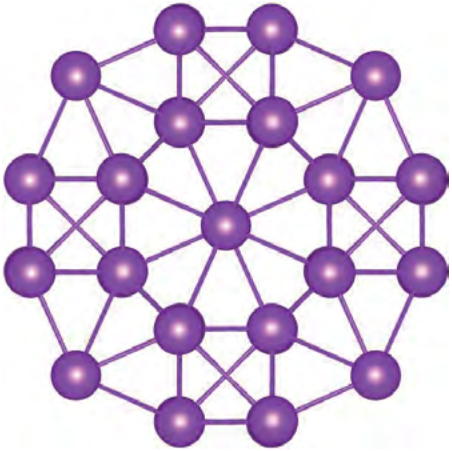
Since I joined the Winton Programme, I have established collaborations with Professor Judith Drisoll (Materials Science), Professor Stephan Hofmann (Engineering) and Dr Chiara Ciccarelli (Winton Fellow, Cavendish).

Above: Simple schematic of the electrochemical metallization cell (ECM) resistive switching effect.

Dr Bartomeu Monserrat - Winton Advanced Research Fellow

Our research focuses on using computer simulations based on quantum mechanics to understand and predict the properties of novel materials for technological applications. Areas of current interest include the study of semiconducting materials for optoelectronic devices such as solar cells or transparent conductors [1], the study of topological materials for applications ranging from dissipationless electronics to quantum computing [2], and the investigation of superconducting materials for use in efficient energy transmission [3].

Quantum mechanical computational design provides a fast platform to explore the vast space of materials to optimise their properties for technological applications. However, current computational methods are restricted to zero temperature, which limits their predictability. We develop novel computational methods to include the effects of temperature in our simulations, allowing us to explore material properties directly under relevant operating conditions. Examples of our recent work include the first prediction of the role of temperature in topological materials and the microscopic understanding of superconductivity in incommensurate crystals. Looking ahead, our objectives include the design of a room temperature



Chern insulator, which would enable dissipationless electronics with the associated reduction in energy use, the study of superconducting materials to enhance their critical temperatures, and the optimisation of semiconducting materials for applications in solar cells.

The success of our research depends critically on the exploitation of high performance computing resources, and the Winton Programme has funded our local cluster with hundreds of CPUs, used to develop and test our computer codes.

Beyond our local resources, we also use national and international computing centres to preform the calculations that drive our research.

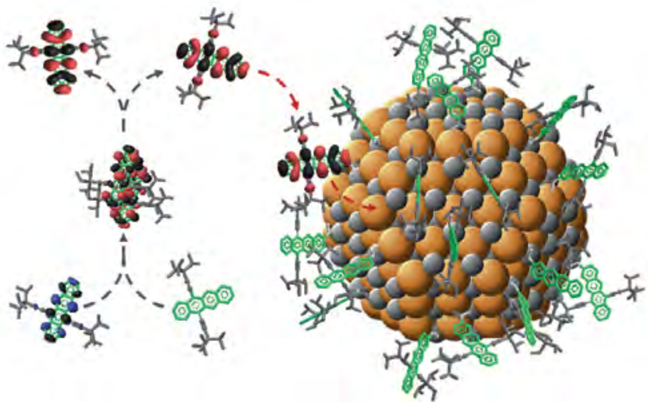
Since I joined the Winton Programme as a Winton Fellow, two PhD students and a Master's student have joined the group, Ivona Bravic (Winton Scholar), Siyu Chen (Materials modelling CDT), and Kemal Atalar (MPhil in Scientific Computing), and we are also hosting a visitor from Fudan University in China, Bo Peng. In addition, we have established fruitful collaborations with Professor Malte Grosche (Cavendish) on superconductivity, Dr Felix Deschler (Winton Fellow, Cavendish) and Dr Akshay Rao (Winton Fellow, Cavendish) on solar cells, and Dr Siân Dutton (Cavendish) and Professor Clare Grey (Chemistry) on batteries.

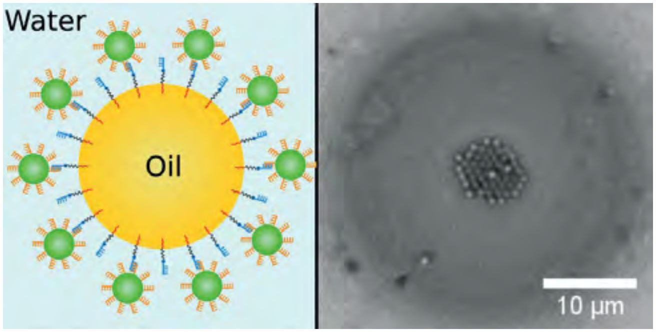
[1] Saidi, Ponce, and Monserrat, J. Phys. Chem. Lett. 7, 5247 (2016)
[2] Monserrat and Vanderbilt, Phys. Rev. Lett. 117, 226801 (2016)
[3] Brown, Semeniuk, Wang, Monserrat, Pickard, and Grosche, Science Advances 4, eaao4793 (2018)

Above: Part of the structure of incommensurate host-guest bismuth III, a phase of bismuth which exhibits strong coupling superconductivity arising from a freely sliding chain of atoms in the crystal structure.

SCHOLARSHIPS

Cohort starting 2015/16



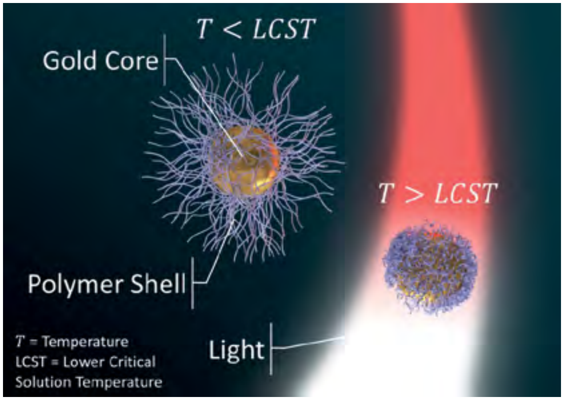


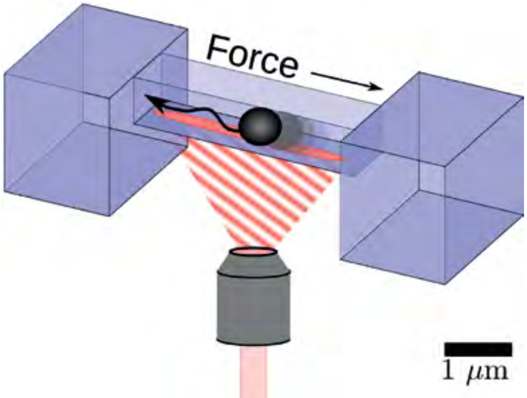
Jesse Allardice is investigating organic-inorganic hybrid optoelectronic systems, where the transfer of excited electronic states is of interest. Such organic/inorganic systems have promising application in a wide array of technologies from solar cells, sensing, bio-imaging to 3D printing. He is studying the transfer of excitonic states between different materials using ultrafast spectroscopy. As part of a ongoing collaboration he recently measured the generation and exchange of triplet excitons between organic molecules and the inorganic quantum dot to which they were anchored [*J. Phys. Chem. Lett.*, **2018**, *9* (6), pp 1454–1460]. This novel process could be of use to future solar cell designs with increased efficiencies.

Above: Illustration showing the transfer of a triplet exciton on an organic molecular ligand, to an inorganic quantum dot.

Alessio Caciagli's research is on DNA functionalised soft colloids, such as emulsion droplets and surfactant micelles. DNA functionalised colloids can be used as building blocks for the programmed sequential self-assembly of micro and macrostructures, where the resulting structure can be designed *a priori* by changing the properties of the DNA coating. Having developed a novel functionalisation protocol that is scalable and can be applied to a vast class of soft materials, he focused on proof-of-principle applications of functional soft colloids such as complex hierarchical structures, thermally responsive gels, controlled-release systems and biomaterials with designed mechanical properties. He has also been interested in the role of DNA-functionalised interfaces as a support for colloidal monolayers. He studied the reversible crystallization of colloidal particles grafted to a liquid-liquid interface by DNA under light exposure. This feature could be exploited in the creation of responsive monolayer films for new functional nanomaterials.

Above: Illustration of a DNA-functionalised oil droplet coated with colloids as an example of hierarchical structure (left). Reversible crystallization under light exposure for a monolayer grafted to a DNA-coated liquid-liquid interface (right).





Sean Cormier's research concerns reversible expanding and contracting soft plasmonic composites for optically controlled nanomechanical actuators. These actuators are capable of controlled programmable work and act as a new tool for manipulating objects at extremely small scales. They can help change how we interact with nanoscale objects which play key roles in biological processes.

He has investigated plasmonic nanoparticles coated with thermoresponsive polymers that exhibit fast mechanical actuation from the synergistic combination of plasmonic heating and the temperature-dependent coil-to-globule phase transition of particular polymers. He has studied various light-induced behaviours of these particles, including reversible aggregation and disaggregation in solution, single nanoparticle fast oscillations, dynamic films for object manipulation, and DNA origami flexing nanomachines [1-4].

[1] Turek, V., Cormier, S. et al. (2018). The Crucial Role of Charge in Thermoresponsive-Polymer-Assisted Reversible Dis/Assembly of Gold Nanoparticles. AOM. 6. 1701270
[2] Cormier, S. et al. (2018). Actuating Single Nano-Oscillators with Light. AOM. 6. 1701281
[3] Cormier, S. et al. (2018) Dynamic- and Light-Switchable Self-Assembled Plasmonic Metafilms. AOM. 1800208
[4] Turek, V., Cormier, S. et al. (2018). Thermo-Responsive Actuation of a DNA Origami Flexor. AFM. 1706410

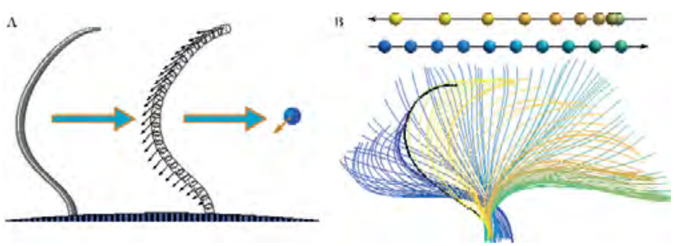
Above: Schematic of actuating nanoparticles with light.

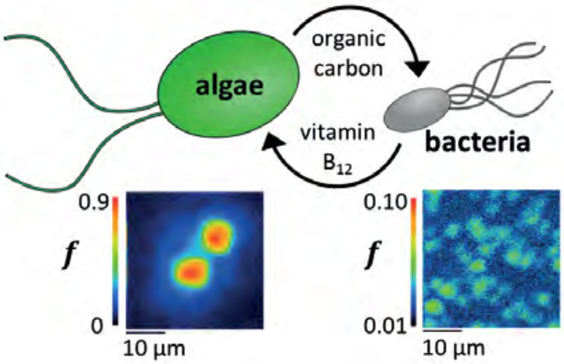
Jannes Gladrow's research is focused on micro- and nanoscale thermodynamics. In particular, he studies fundamental symmetries and optimality conditions of first-passage times of Brownian particles in microfluidic channels. His tool of choice is a holographic optical tweezer, which allows him to shape laser light into arbitrary patterns on the microscale. The laser intensity and phase can be tuned to exert forces on the femtoNewton-range on the particles and are therefore suitable for statistical studies of Brownian motion. The setup is fully automated and is able to carry out measurement protocols without human supervision for up to a week. This allows for acquisition of large amounts of data and a reliable detection of rare events in stochastic equilibrium and out-of-equilibrium processes.

Above: Holographic optical tweezers can be used to study fundamental laws underlying thermal motion in microscale environments in unprecedented detail.

SCHOLARSHIPS

Cohort starting 2015/16





Evelyn Hamilton's research focuses on understanding the role hydrodynamic coupling plays in the coordination of motile cilia. Cilia are hair-like organelles that protrude off many eukaryote cells; motile cilia are the subset that beat and synchronise. They are involved in several crucial processes in the human body, including mucous clearance, a critical aspect of defence against microbes and dust in the lungs.

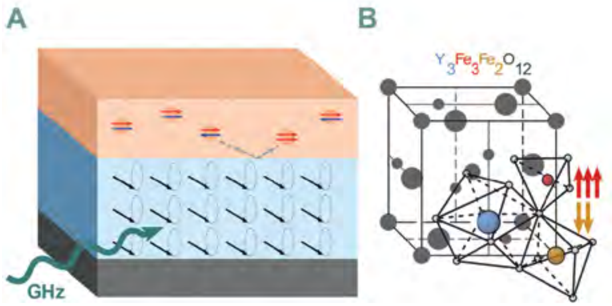
The coordination between cilia dramatically enhances their effectiveness. To understand the role of hydrodynamics in their cooperation, she investigates generic features of synchronisation facilitated by interactions dominated by viscous forces. To do this she studies groups of highly simplified cilia. This has revealed fascinating cases that simultaneously display coherence and incoherence, and other exciting examples of bi-stability.

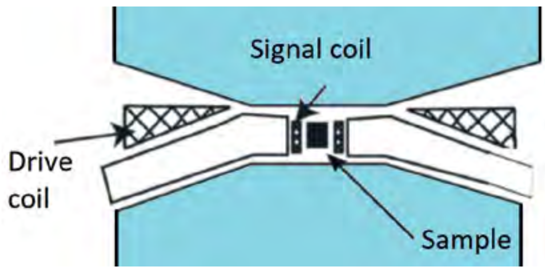
Hannah Laeverenz Schlogelhofer's research explores the carbon dynamics between algae and bacteria. Microorganisms affect biogeochemical cycles in ecosystems across our planet, but studying the interspecies nutrient dynamics is challenging due to the multitude of interactions that exist within natural microbial communities. Hannah's research uses isotope labelling and Secondary Ion Mass Spectrometry to trace carbon at the single cell level for a two species symbiosis, in which both species depend on the other for essential nutrients. Hannah has also developed a mathematical model to test how current understanding of the carbon metabolic processes that underpin this microbial interaction account for experimental observations.

To see a video of her work follow this link:
www.vignettes.nanodtc.cam.ac.uk/new-page

Above: A) a cilium is replaced by a sphere representing its centre of drag. B) The sphere is driven along a simplified trajectory representing the cilium beat.

Above: Diagram of the nutrient exchange in an algal-bacterial mutualism and example Secondary Ion Mass Spectrometry images for the atomic fraction of ^{13}C, i.e. $f = {}^{13}C/({}^{12}C+{}^{13}C)$, in algal and bacterial cells that illustrate carbon uptake and exchange





Lauren McKenzie-Sell investigates thin film structures of magnetic and superconducting layers. The interface of these layers hosts surprising states that could combine spin memory with lossless transport for efficient 'spintronic' (spin-electronic) information technology.

Using microwave-frequency ferromagnetic resonance, she probes the magnetic layer and its response to the superconducting state. She has used this technique as a new view on the temperature-dependent spintronic properties of this sub-100 nm magnetic layer. By bringing spintronic, magnetic, and structural properties together, the research is now shaping growth of these films for low-temperature spintronics.

Currently, she is also developing sensitive low-temperature ferromagnetic resonance that uses a superconducting resonator to couple to microscale magnets.

Above: A) Using microwaves to probe spintronics in nanoscale multilayers; B) An insulating garnet material for ultrathin magnetic films.

Sofia Taylor studies copper-oxide superconductors, which can be tuned chemically between two regimes: overdoped and underdoped. The overdoped regime of high-temperature superconductors is thought to represent conventional superconductivity emerging from a Fermi liquid. In contrast, there are several remaining challenges to be addressed regarding the evolution of the electronic structure and the robustness of superconductivity in the underdoped regime.

Although much could be learned by comparing the two regimes, the difficulty, and sometimes chemical constraint, to produce pristine overdoped samples have so far impeded this comparison. She uses anvil pressure cells to access the overdoped regime of copper superconductors and to gain information on the normal state that precedes superconductivity with the help of high magnetic fields.

Above: In an anvil pressure cell, the faces of two anvils (diamond, moissanite) are pressed against each other generating ultra-high pressures

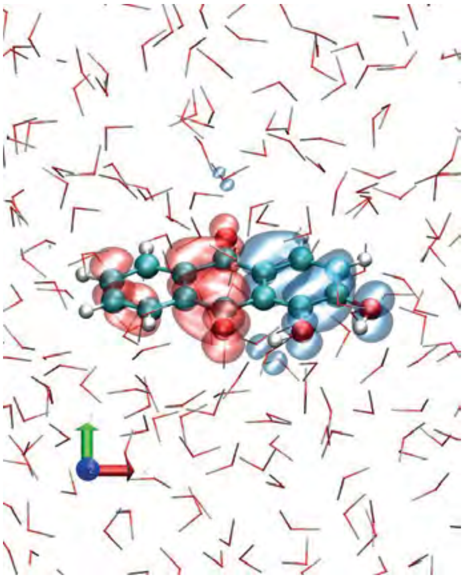
ALUMNI

The Winton Scholars have a difficult decision to make after completing their PhDs; continue in academia or move to industry. Scholars have successfully taken both paths, some examples being described here. In contrast the Fellows have all continued in University research, taking up positions at various institutions.

Dr Nicholas Hine (Winton Fellow 2nd cohort)

Following his move to the Department of Physics at the University of Warwick in 2015, Nick has now successfully established a thriving group, continuing many of the research themes he developed as a Winton Fellow. His research on heterostructured 2D materials has expanded, with a productive collaboration supported by EPSRC (EP/P01139X/1) involving experimentalists both at Warwick (Prof Neil Wilson) and at the University of Washington (Professors Xiadong Xu and David Cobden). Two PhD students at Warwick, Nelson Yeung and Siow Mean Loh, have investigated the properties of 2D heterostructures using electronic structure calculations, specifically lateral heterstructures, gated vertical heterostructures, and doped and alloyed TMDC materials within these structures. The results have promising applications in the field of low-power electronics.

Nick's other main research area is electronic excited states of molecules in complex environments such as solvents, surfaces and biological systems. He is PI of a CSE Software Flagship grant from EPSRC (EP/P02209X/1) to continue development of the ONETEP linear-scaling DFT code



to improve its ability to handle these calculations, particularly by enabling embedded high-accuracy calculations of chromophores in realistic environments. Two PhD students, Matt Turner and Daniel Corken, and a PDRA, Dr Joly Aarons, are working on topics involving excited state calculations in the group.

Dr Kerstin Göpfrich (Winton Scholar 3rd cohort)

Kerstin has been awarded a Marie Skłodowska Curie Fellowship combining microfluidics and DNA nanotechnology to assemble life-like cellular systems from molecular building blocks. Success in the bottom-up construction of a synthetic cell would not only provide a profound understanding of living systems, but also the ability to engineer autonomous cellular machines. Her project is hosted at the Max Planck Institute for Medical Research in Stuttgart, Germany, in the group of Professor Spatz. Beyond that, she promotes web videoconferencing to bring scientists live into the classroom (www.ring-a-scientist.org).

Dr Florian Schröder (Winton Scholar 3rd cohort)

Florian works as a Data Scientist for the new Global Data Science team of Boehringer Ingelheim. He has projects across all parts of their business, ranging from supply chain management, budget forecasting, portfolio management and marketing and sales with the overall aim of increasing profitability through data-driven decision making. In his day-to-day work he makes use of the scientific problem solving, mathematical and statistical modelling, as well as numeric simulation and optimisation techniques that he acquired during his physics degree, and apply them to solve long-standing business problems that can save the company millions of euros.

Dr Amalio Fernández-Pacheco (Winton Fellow 4th cohort)

Amalio moved in July 2018 to the University of Glasgow, joining the Materials and Condensed Matter Physics group, where he will become a Senior Lecturer next year.

In Glasgow, Amalio continues developing the research lines that he started in Cambridge as a Winton and EPSRC Fellow into the investigation of new effects in 3D nanomagnets for application in future spintronic devices. His recent works include the first successful data transfer in 3D nanowire systems [1], the development of a new magneto-optical method to characterise 3D nanostructures [2] and new theoretical [3] and computational [4] frameworks for advanced 3D nano-printing (see far-right image [2]). Now in Glasgow, the next steps in his research are focused on exploring unprecedented properties in topological 3D spin textures, as well as emerging phenomena in spin networks for neuromorphic computing applications [5].

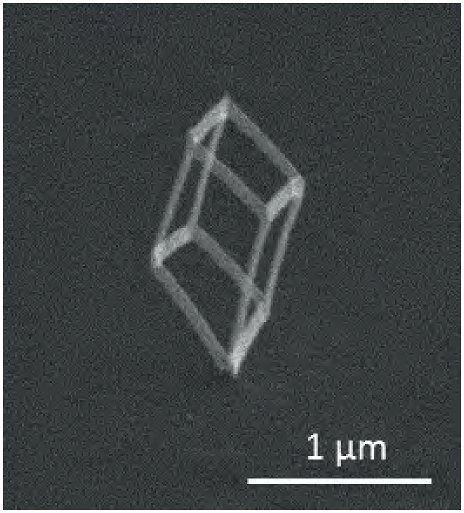
[1] Sanz-Hernández et al, ACS Nano 11, 11066-11073 (2017).
[2] Sanz-Hernández et al, Nanomaterials 8, 483 (2018).
[3] San-Hernández et al, Beilstein J. Nanotechnol. 8, 2151 (2017).
[4] Fowlkes et al, ACS Appl. Nano Mater. 1, 1028 (2018).
[5] Fernández-Pacheco et al, Nature Comm. 8, 15756 (2017).

Dr Leah Weiss (Winton Scholar 4th cohort)

Leah Weiss has recently completed her doctoral research, which focused on spin-sensitive probes of excited-state dynamics in molecular systems with Professor Richard Friend. She has now taken up a Junior Research Fellowship at Clare College, where she will be investigating the coupling of spin to nuclear and mechanical degrees of freedom in nanoscale excitonic systems. This work will combine microwave spin resonance and optical spectroscopy with local structural probes to explore novel materials for efficient spin-based quantum technologies.

Dr Johannes Richter (Winton Scholar 4th cohort)

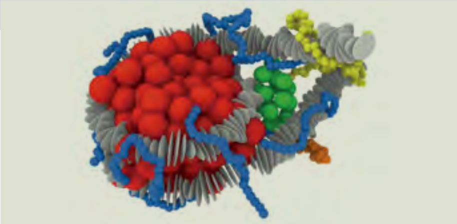
Johannes is now working in the Automated Driving department at Bosch. Driverless taxis are soon expected to transform our concept of mobility - from privately owned cars towards mobility as a service and ride sharing. Johannes' work is at the interface between the sensor development and software development. He is in particular focusing on lidar sensors - laser scanners that create a 3D environmental model of the car's surroundings. His tasks include deriving sensor requirements, testing of novel sensors as well as implementing sensors in the car's algorithms.



Left: Alizarin, a typical organic dye molecule, in water, showing an excitation partially delocalising into a solvent environment.

Right: 3D printed free-standing hollow nanocube fabricated at Amalio's group.

PROGRAMME HIGHLIGHTS



Rosana Collepardo wins €1.5 million ERC starting grant

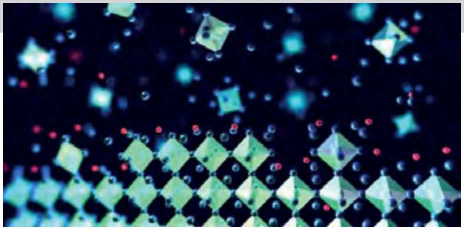
Winton Advanced Research Fellow, Dr. Rosana Collepardo has been awarded a €1.5 million ERC starting grant to develop a novel multi-scale computational method to investigate the organization of the genome with sub-nucleosome resolution.

While sequencing our genome today is easy, finding out how it functions remains an urgent unsolved problem crucial to rationalise normal and aberrant cell behaviour. The 3D organization of the genome is intimately linked to its function. However, the next big challenge in the field of genomic sciences is deciphering (a) how the genome is organized in space and (b) how this organization influences its function. This ERC project aims at driving the transformation of our ability to understand how genomes function by pushing the current limits of realistic computational modelling of in vivo chromatin structure.

Bartomeu Monserrat wins Psi-k Volker Heine Young Investigator Award

Dr Bartomeu Monserrat who has recently been appointed as a Winton Advanced Research Fellow has been awarded the prestigious Psi-k Volker Heine Young Investigator Award for his research on "*Temperature effects in spin-orbit physics from first principles*"

The award is for research in any type of condensed matter, materials or nanoscience research involving electronic structure calculations, with the five finalists presenting their work at a special session at the Berlin DPG meeting on 13 March 2018. The photo shows Professor Volker Heine presenting the first prize of €2,500 to Bartomeu.



Potassium gives perovskite-based solar cells an efficiency boost

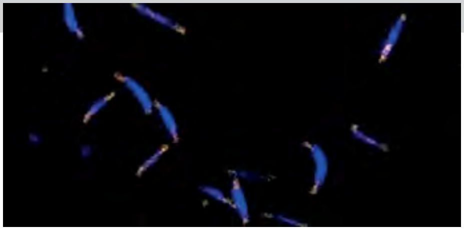
An international team of researchers led by Dr Sam Stranks at the University of Cambridge found that the addition of potassium iodide 'healed' the defects and immobilised ion movement, which to date have limited the efficiency of cheap perovskite solar cells. These next-generation solar cells could be used as an efficiency-boosting layer on top of existing silicon-based solar cells, or be made into stand-alone solar cells or coloured LEDs. Tandem cells made of two perovskite layers with ideal bandgaps have a theoretical efficiency limit of 45% and a practical limit of 35% - both of which are higher than the current practical efficiency limits for silicon. Two Winton Scholars, Zahra Andaji-Garmaroudi and Johannes Richter were co-authors of the resulting paper in *Nature* [555, 497-501 (2018)].

Royal Society Summer Science Exhibition - Mind the (nano) Gap

Dr Giuliana Di Martino, recently appointed a Winton Advanced Research Fellow, coordinated the "Mind the Nano Gap" showcase at the Royal Society Summer Science Exhibition. The event highlighted cutting-edge biosensing research from the Centre for Doctoral Training in Nanoscience and Nanotechnology, which attracted more than 15,000 people.

Giuliana said: "Just like we have different senses to perceive the world around us – sight, smell, taste, touch – we need different sensors to solve the puzzle of which bio-molecules we're dealing with. In our exhibit, we show how nanogaps in gold nanoparticles, graphene and nanopores can sense mass, electrical charge, size and composition of molecules. By implementing these really sensitive techniques in our futuristic Intelligent Toilet we will be able, in the future, to detect even really tiny amounts of specific biomarkers in our urine, leading to better and personalised healthcare directly into our homes."

http://nanogap.nanodtc.cam.ac.uk



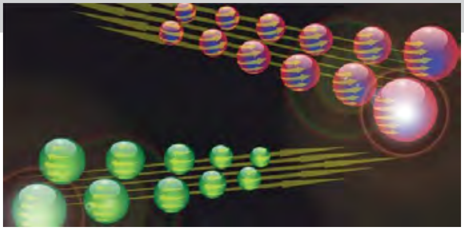
Plastic crystals hold key to record-breaking energy transport

Scientists from the Universities of Cambridge and Bristol have found a way to create plastic semiconductor nanostructures that absorb light and transport its energy 20 times further than has been previously observed, paving the way for more flexible and more efficient solar cells and photodetectors.

The researchers including Winton Scholars Michael Price and Johannes Richter and Winton Fellow Akshay Rao, whose work appears in the journal *Science* [360, 6391, p 897 (2018)], say their findings could be a "game changer" by allowing the energy from sunlight absorbed in these materials to be captured and used more efficiently.

The research team now plans to prepare structures thicker than those in the current study and greater than the optical absorption depth, with a view to building prototype solar cells based on this technology. They are also preparing other structures capable of using light to perform chemical reactions, such as the splitting of water into hydrogen and oxygen.

www.cam.ac.uk/research/news/plastic-crystals-hold-key-to-record-breaking-energy-transport



Some superconductors can also carry currents of 'spin'

Researchers have shown that certain superconductors can also carry currents of 'spin'. The successful combination of superconductivity and spin could lead to a revolution in high-performance computing, by dramatically reducing energy consumption. The research was led by Professor Mark Blamire of Cambridge's Department of Materials Science and Metallurgy and collaborators included Winton Advanced Research Fellow, Dr Chiara Ciccarelli and was reported in the journal *Nature Materials* [**17**, 499–503 (2018)].

"If we used only a superconductor, the spin current is blocked once the system is cooled below the temperature when it becomes a superconductor," said Blamire. "The surprising result was that when we added a platinum layer to the superconductor, the spin current in the superconducting state was greater than in the normal state."

www.cam.ac.uk/research/news/some-superconductors-can-also-carry-currents-of-spin

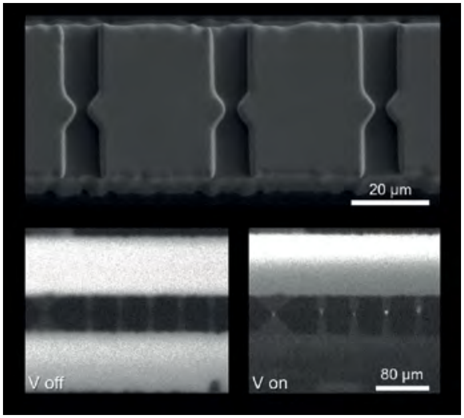
PUMP PRIME

To explore radically new ideas is often difficult without some initial seed funding; the Winton Pump Prime scheme has been established to support these high-risk, high-reward ideas. Funding up to £50k is available with applications accepted on a rolling basis. Some examples of funded projects are provided here, with details on application process and other awards that have been made at www.winton.phy.cam.ac.uk/pumpprime

Selective Molecular Traps in a Microfluidic Platform

Professor Tuomas Knowles (Chemistry) and Professor Ulrich Keyser (Biological and Soft Systems)

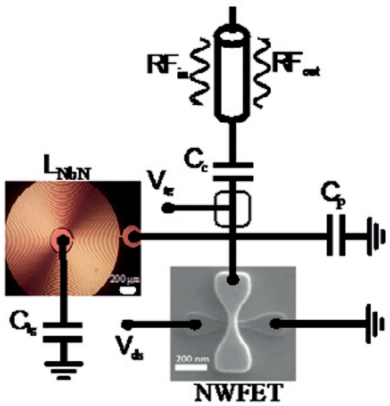
Proteins are the active molecules in the cell and form the nanoscale machinery of life through self-assembling into complexes. This process underpins biological function and, when assembly doesn't occur in the intended manner, is also the origin of the onset and progression of a number of human disorders, including protein aggregation diseases such as Alzheimer's and Parkinson's diseases. We have been working towards an advanced microfluidic platform for selectively trapping individual proteins and their complexes and detecting them at high sensitivity. Stable trapping in free solution, under native conditions on sufficient time scales for direct observation has the potential to open up a new window into biomolecular behaviour. Dielectrophoresis can provide a powerful method of trapping protein molecules and locally enhance their concentration, potentially allowing the analysis of inherently low quantities present in biological extracts. We have already been able to demonstrate the wafer-scale fabrication of such trapping devices using UV-soft lithography. In preliminary proof-of-principle studies we showed the general suitability of the platform by focusing charged labelled nucleic acid molecules by balancing the combined effects of electrophoresis and electroosmotic flow in static electric fields (Fig. 1). Next steps include probing proteins and protein complexes with this platform, the implementation of single molecule detection approaches to probe the trapped molecules, and the use of two-photon lithography to generate nanoscale constrictions which allow stronger trapping fields to be reached.



Time-resolved gate-based sensing for scalable silicon-based quantum computing

Dr Alessandro Rossi (Microelectronics Group), Dr Fernando Gonzalez-Zalba (Hitachi Cambridge Laboratory) and Professor Jason Robinson (Materials Science & Metallurgy)

We have achieved gate-based dispersive readout of silicon-based few-electron quantum dots using lumped-element resonators with quality factors, Q, in the 400–800 range. This is a marked technical advance of more than one order of magnitude with respect to previous reports for this technique. The enhancement in Q is achieved by configuring the device gate capacitance in parallel with a superconducting (NbN) spiral inductor and coupling via a lumped-element capacitor to a printed-circuit-board coplanar waveguide (see figure). With this improved set-up, we find charge sensitivities of 7.7 and 1.3 $\mu e/Hz^{1/2}$ for resonators operating at 330 and 616 MHz, respectively. The latter represents an improvement of a factor of 30 over previous gate-based sensors sensitivity and a factor of 5 when compared to the semiconductor radio-frequency single-electron transistor[1].



Furthermore, we have demonstrated that with a tailored design of the sensor gate, we can carry out time-resolved single-spin readout[2]. This is an absolute first in the field. In these initial experiments, we have obtained a limited readout fidelity of 73%. However, this can be straightforwardly improved by combining the new gate design with an NbN spiral inductor1, and it will be the focus of the next experiments.

Finally, we have shown that gate-based sensing can be also used to readout a scaled-up array of quantum devices (4 nanowires arranged into a 2-cell layout) via a random-access memory protocol[3,4].

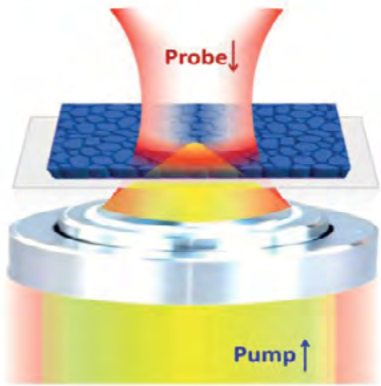
1) Ahmed et al., Radio-Frequency Capacitive Gate-Based Sensing, Phys. Rev. Applied 10, 014018 (2018) – Editors' Suggestion.
2) West et al., Gate-based single-shot readout of spins in silicon, arXiv:1809.01864 (2018).
3) Schaal et al. Conditional Dispersive Readout of a CMOS Single-Electron Memory Cell, Phys. Rev. Applied 9 054016 (2018) – Editor's Suggestion
4) Schaal et al., A CMOS dynamic random-access architecture for radio-frequency readout of quantum devices, arXiv:1809.03894 (2018).

Femtosecond Super-resolution Pump-Probe Imaging

Dr Akshay Rao (Optoelectronics)

The interaction of light with matter is fundamental to the operation of a range of devices such as solar cells, LEDs, photocatalytic and plasmonic systems. For over 30 years, ultrafast spectroscopy has served as the key tool to understand the dynamics of the quasiparticles mediating light-matter interaction such as excitons, polarons and polaritons. However, to date, ultrafast spectroscopies were designed and largely applied to species dissolved in liquids or homogeneous bulk solids. The advent of nanoscience and thin films materials with nanoscale inhomogeneity and disorder has rendered these ensemble-based methods inadequate and they continue to be used largely because of a lack of alternatives, rather than being particularly suited to address the questions of interest.

To overcome this challenge, we have with the help of a Winton Pump Prime Grant developed a world-wide unique optical microscope: one that can track optically-induced phenomena in a universally applicable fashion with a temporal resolution and spectral coverage matching some of the most sophisticated ensemble-based ultrafast experiments reported to date and a spatial precision competing with the most advanced super-resolution microscopes.



This provides us with the unprecedented capability to resolve dynamic processes with simultaneous 10 fs temporal resolution and 10 nm spatial precision. Using the capability, we have discovered new regimes for carrier and exciton transport in a range of nanoscale semiconductor materials.

Fig. 1, opposite: Molecular trapping device. Top: electron micrograph of the microfluidic constrictions used for molecular trapping. Bottom: epifluorescence microscopy data without field (left) and with electric field applied (right) showing trapping of labelled biomolecules in the junctions.

Above-left: Circuit diagram for gate-based sensing. The gate of a nanowire field-effect transistor (NWFET) is connected to a resonant circuit. This is made of a standard surface mount capacitor and a custom-made NbN superconductive spiral inductor.

WINTON SYMPOSIUM

The sixth Winton Symposium was held on the theme of Energy Storage and Distribution, a topic of growing interest as we try to manage the increase of intermittent renewable energy to provide reliable supply.

Professor Howard Wilson, Programme Director of the UK Atomic Energy Authority, described the 'Path to Delivering Fusion Power'. The most accessible reaction is the fusion of deuterium and tritium that requires temperatures that are 10 times that at the centre of the sun. Achieving these temperatures is not an issue, the issue is to control the density and confine the particles at these temperatures and manage the damage from the high-energy neutrons and extremely hot gases from the fusion process.

Nuclear fusion is very attractive; there is plenty of fuel, no greenhouse gas emissions and the process is inherently safe in that there is no chain reaction. But for fusion to be viable we need an interdisciplinary collaboration of the physical sciences, engineering and technology to tackle some major scientific and engineering challenges.

Professor Katsuhiko Hirose (above), Visiting Professor at the International Institute for Carbon Neutral Energy Research, Kyushu University, joined the Toyota Motor Corporation 35 years ago where he is now a Professional Partner. He has been involved in two major innovation projects; the Prius electric

hybrid vehicle and the Mirai hydrogen fuel cell vehicle. His presentation 'Hydrogen as a vector toward the sustainable society' focused on the latter project and the broader implications of moving towards a hydrogen-based economy.

In the last 10 years fuel cell prices have decreased markedly, with the volume power density improved by a factor of 20 and a correspondingly reduced requirement for materials. Storage with compressed hydrogen has become the most effective and simplest approach. These advances and the benefits offered of high recharge rates of only 3 minutes, long range of 600 km and zero emissions at the point of use make hydrogen vehicles commercially attractive.

Professor David Larbalestier, Director of the Applied Superconductivity Center at Florida State University, reviewed the 'Prospects for the Use of Superconductors for Energy Storage and Distribution'. Low (LTS) and high (HTS) temperature superconductors are at the technical level at which they could be used for 'green' energy applications - there are designs for energy storage in large volumes of high magnetic field, up to football stadium sized systems for energy storage on the GWh scale, but they are a long way from commercial viability. The majority of applications still use LTS such as Nb-Ti and Nb_3Sn which need cooling with liquid helium. Wider adoption of HTS materials will require materials that can be cooled by liquid Nitrogen and costs to be reduced by a factor of 10; which will be possible through clever materials engineering.

Dr Munaf Rahimo of Asea Brown Boveri (ABB) where he is Corporate Executive Engineer gave a review of 'Power semiconductors for grid system power electronics applications'. ABB is enabling stronger (higher voltages), smarter (digital power management) and greener (smaller footprint with increasing contribution from renewable energy sources) grids.

One of the key technology enablers is the shift to ultra-high DC (UHDC) systems that are more efficient than AC systems for long distance power transmission. These operate at voltages up to 500 kV, handling up to 3GW with an efficiency loss of less than 1% over distances of 1,000 km. Advances in the past has been driven by size and power, with efficiency and reliability now becoming more important. Further advances are expected through research on high bandgap alternatives to silicon such as SiC and GaN.

Professor Rosa Palacín (above) of the Institut de Ciència de Materials de Barcelona provided in her talk 'Battery energy storage beyond Li-ion' some future options for batteries. The current battery technology of choice is the lithium (Li)-ion battery. This was based on scientific studies of Li intercalation in the 1970's and 80's and commercialised by Sony in 1991.

Sodium(Na)-ion batteries are interesting as Na is more abundant than Li, and does not alloy with Al, enabling low cost Al current collectors to be produced. Another approach is to move to divalent ions such as magnesium (Mg) and calcium (Ca) to increase the energy density, the later has been the focus of the research of Rosa. In all these new systems although promising results have been obtained a number of challenges remain, but there is optimism that these will be overcome.

Professor David Greenwood leads the Advanced Propulsions Systems Group at the Warwick Manufacturing Group. In his talk on 'The future for zero emissions transport', he discussed how the only way to reach zero emissions is by reducing the carbon content in fuel.

The best solution is to switch to electric propulsion, although this depends on how the electricity is sourced; nuclear and wind energy produce lifecycle emissions of 5gm CO_2/kWh with brown coal producing up to 1000gm CO_2/kWh. The good news is that the carbon intensity of electricity is reducing in the UK with the shift to renewables and the phasing out of coal.

The transition to zero emission passenger electric vehicles will take place in the next 20-30 years as research leads to performance and price improvements. These activities are aligned with the Faraday Challenge, which is a £250M government research programme for developing batteries in the UK.

TECHNOLOGY FOR DEVELOPMENT

Technology for Development (T4D) Travel Awards

New science and technology has the potential to enhance significantly the well-being of the bottom half of the world's population. All too frequently, however, innovations intended for the 3 billion people who live on less than $3/day are not used because they are not context-appropriate. Often this is because such innovations are devised by people in developed countries who have little understanding of the daily lives of the people for whom the innovations are intended. There is a burgeoning interest in Technology for Development (T4D) in Cambridge, and some very promising innovations are being evolved. To help Cambridge innovators avoid the trap of evolving technologies that are not context-appropriate, the Winton Programme for the Physics of Sustainability, together with the Smart Villages Research Group and the Cambridge Malaysian Education and Development Trust, funded six T4D Travel Awards of £6000 each. The awards enabled University of Cambridge graduates and early career researchers to develop and test their T4D ideas in real developing world situations.

The T4D Travel Award training and support programme was delivered by the Centre for Global Equality (CGE), a Cambridge-based not-for-profit organisation that enables the evolution of innovative solutions to global challenges. CGE, which facilitates collaborations between the public and private sectors, academia and civil society, co-founded and co-directs Cambridge Global Challenges, the University of Cambridge's Strategic Research Initiative for the UN Sustainable Development Goals. The T4D Travel awards are part of the Centre's Inclusive Innovation Programme, which includes Development i-Teams and the CGE Global Goals Innovation Cultivator.

Graduates and postdocs based at the Maxwell Centre participated in two of the six T4D projects.

Bang Ming Yong and Tianheng Zhao went to Malaysia as part of Project AUVR to investigate how virtual reality technology could enhance care for autistic children. 1-2% of the world's children are identified with autism spectrum disorder, which impedes the way they think, communicate, socialize, and learn. Early interventions have shown to be effective, but treatment is very expensive as it requires many contact hours with trained specialists and dedicated facilities. Developing countries like Malaysia have a severe shortage of experts and resources, making provision of such interventions particularly challenging.

The estimated number of autistic children in Malaysia is 80000, only 1500 (<2%) of whom are catered for at any given time in the country's twenty autism centres. Project AUVR's proposed solution was to develop a reconfigurable and smart software platform using recently developed virtual reality headsets to digitize the tools and environments for interventions. This could lower the costs of delivering interventions and improving accessibility because the functionality of virtual environments can be customised easily and cheaply using software.

Project AUVR conducted a field trial to evaluate whether autistic children in Malaysia can use and interact with the project's virtual reality system comfortably

(Fig. 1). The team worked closely with their local partner Lions REACh (the second largest autism centre in Malaysia) to conduct a feasibility study with 13 autistic children. The results are promising as all the children were able to control the virtual reality system and showed great enthusiasm for it. Teachers present observed that many of the children were more expressive in their communication and expression of ideas when using the virtual reality system.

Another T4D team developed and tested a Soil Moisture Sensor to assist small holder farmers irrigate more effectively. Mike Price and Viola Introini went to Ethiopia to collaborate with colleagues at the Bahir Dar Institute of Technology on developing an improved wireless soil moisture sensor and assess the potential for using moisture sensors in East Africa. Working with Hydrology students they conducted 10 interviews and meetings with hydrogeological experts, local small-holder farmers and agriculturalists across four irrigation schemes with different soil types in the Amhara Region near Lake Tana. Through the field trip they gained valuable insights into local farming and watering practices. Although presently relatively little land is irrigated in Ethiopia, irrigation is increasing to meet the food security needs of a large and fast-growing population. There is an urgent need to enhance water management as irrigated crops presently suffer from overwatering at early development stages and underwatering when more mature. Soil moisture sensors could contribute to solving this problem, but the team found that presently it is not feasible to produce a sensor that would be affordable for smallholder Ethiopian farmers. The team is therefore developing a new sensor for government agencies and researchers that would reduce the cost of soil moisture data collection and data upload and management.

The other four T4D teams co-created new technologies elsewhere in Africa.

A plastic upcycling team explored the conversion of waste plastic into building materials as an income-generating activity for a local Community Based Organisation in Kilifi, Kenya.

Exploring a new use-case for ApRES, a radar instrument originally developed by the British Antarctic Survey, a team conducted a field trial in Kruger National Park, South Africa, to investigate the instrument's potential for monitoring the water table and enhancing groundwater management in arid areas (Fig. 2).

Blue Tap tested the performance of their chlorine injection technology on household water supply in Mbarara, Uganda. They also assessed the feasibility of their business plan, including gauging local plumbers' interest in their product.

Majico tested the first full scale prototype of their photocatalytic water purification device in Dar es Salaam, Tanzania. They also co-created a business model and undertook market research with Bridge for Change, STICLab and students from Ardhi University.

Fig. 1 (left): An autistic child playing a virtual archery game while supervised by Lions REACh teachers

Fig. 2 (right): Monitoring ground water with ApRES in Kruger National Park, South Africa

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Managers of the Winton Fund for the Physics of Sustainability

Chair - Professor Chris Abell FRS FRSC FMedSci
Pro-Vice-Chancellor with responsibility for research, University of Cambridge

Professor Sir Richard Friend FRS FREng
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

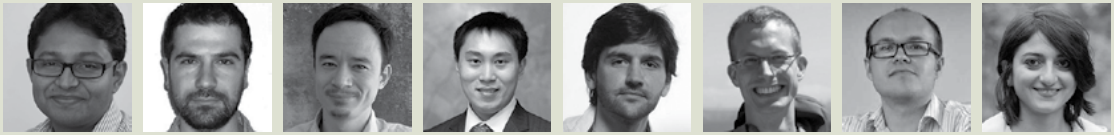
Dr Hermann Hauser CBE FRS
Director and Co-Founder, Amadeus Capital Partners

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

In attendance:
Professor Lindsay Greer
Head of School of the Physical Sciences, University of Cambridge

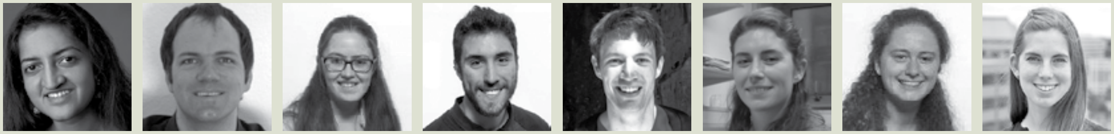
PEOPLE

Alessio Caciagli, Dédalo Sanz-Hernández, Haralds Abolins, Dr Erika Eiser, Dr Felix Deschler

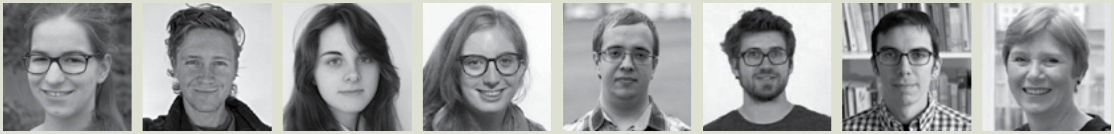


Dr Akshay Rao, Dr Alessandro Rossi, Dr Alex Chin, Dr Alpha Lee, Dr Amalio Fernández-Pacheco, Dr Andreas Nunnenkamp, Dr Andrew Morris, Dr Chiara Ciccarelli

Dr Hannah Joyce, Dr Hugo Bronstein, Dr Nalin Patel, Dr Ottavio Croze, Kareem Al Nahas, Dr Rosana Collepardo, Dr Sam Stranks, Dr Sarah Bohndiek



Dr Suchitra Sebastian, Dr Tijmen Euser, Evelyn Hamilton, Ezequiel Rodriguez Chiacchio, Alan Bowman, Elaine Kelly, Hannah Laeverenz Schlogelhofer, Hope Bretscher



Nora Martin, Jesse Allardice, Diana Sobota, Lauren McKenzie-Sell, Attila Szabó, Philippe Schwaller, Dr Bartomeu Monserrat, Prof Alison Smith

Prof Henning Sirringhaus, Prof Jason Robinson, Prof Jeremy Baumberg, Dr Giuliana Di Martino, Prof Chris Abell, Prof Neil Mathur, Prof Pietro Cicuta, Prof Sir Richard Friend

Prof Ulrich Keyser, Raj Pandya, Sam Schott, Sean Cormier, Dr Sebastian Ahnert, Sofia Taylor, Theresa Jakuszeit, Tianheng Zhao

Iria Pantazi, Virgil Andrei, Wenting Wang, Yago del Valle-Inclan Redondo, Sascha Feldmann, Zahra Andaji-Garmaroudi, Jeroen Royakkers, Dominik Hamara

Can Kocer., Jannes Gladrow, Prof Clare Grey, Prof Erwin Reisner, Dr Rachel Evans, Prof Tuomas Knowles, Dr Claudio Castelnuovo, Ture Hinrichsen

Alex Welbourne, Dr Siân Dutton, Dr Silvia Vignolini, Antonis Alvertis, Bhaskaran Nair

THE WINTON PROGRAMME FOR THE

Physics of Sustainability

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