CDT SUMMER CONFERENCE 2017

on the Science and Technology of Graphene and Related Materials

12th–15th June

Wyboston Lakes,
Bedfordshire, UK


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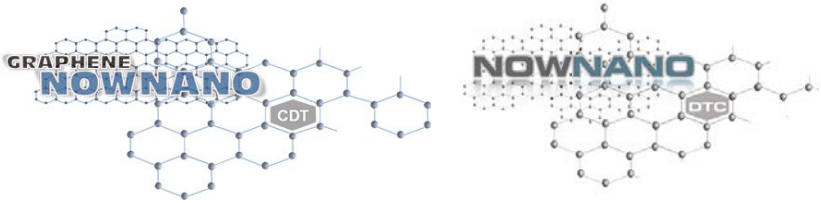
GRAPHENE
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CDT
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DTC


Spinograph
Spintronics in Graphene

Welcome

A very warm welcome to Wyboston Lakes for the CDT Summer Conference 2017 on the Science and Technology of Graphene and Related Materials.

The conference is a student-led event, organised between the University of Cambridge-based CDT in Graphene Technology, the NOWNANO CDT of the University of Manchester and Lancaster University, and the Spinograph project, coordinated by INL, Spain.

It will include talks from both eminent, world renowned scientists and CDT students, as well as posters, industry talks, panel discussions and a range of social activities and opportunities for networking.

Over the conference, across the 4 days, we will focus around five main subject areas within the field of two-dimensional nanomaterials; fundamental research, biomedical and sensing applications, solution-phase processing, optoelectronics/ photonics and spintronics.

We very much hope you enjoy your time.

CDT summer conference 2017 committee

Contents

Conference Information

Upon arrival at the conference venue, please register at the CDT Summer Conference 2017 registration desk at the hotel reception. You will then receive your name badge and information regarding conference proceedings.

Check-in and Check-out

All room keys will be available by 3pm on the day of arrival, and some may be available before this time. You may leave your luggage in a store room until your room becomes available. On Thursday, we advise you check out before the first talk at 9am, though the latest check-out time is 11am.

Session Location (map at the end of the booklet)

The main talks and activities will take place in Willows Conference Room. Poster sessions will take place in WT1.

Catering

All food at Wyboston Lakes will be buffet style, served in the Willows Restaurant. Breakfast will be from 7:00-9:00, lunch from 12:30-14:00 and dinner from 18:30-19:30.

Cambridge Day-Trip on Tuesday

The coaches will leave Wyboston Lakes at 1:45pm – please make sure you are on time. You should bring clothes to change into for that evening's formal dinner, to be held in Queens' College's Old Hall. On arrival, there will be room in the college to store any bags. Afternoon activities will include punting, a walk to Granchester Orchard Tea Rooms and Museum tours, depending on the weather.

Facilities

The available facilities at Wyboston Lakes include State of the Art Gym, Group Exercise Classes, Personal Training, Sauna and Steam Room, 12m Lap Pool for Lane Swimming. These are open 6am-10pm. Day passes for the Health and Leisure Club are available from reception for hotel guests free of charge.

Prizes

Student Talks

3rd and 4th year students will be presenting their progress in 12-minute talks, followed by 3 minutes of Q&A throughout the conference. Prizes have been generously sponsored by Keysight Technologies, The Royal Society of Chemistry and IOP Women in Physics group. All the prizes except for the student-choice prize will be judged by a committee of academics.

1st place: Samsung Tablet *sponsored by* **Keysight Technologies**

2nd place: £75 Amazon voucher *sponsored by* **The Royal Society of Chemistry**

3rd place: £25 Amazon voucher *sponsored by* **The Royal Society of Chemistry**

Poster Sessions

1st and 2nd year students will be presenting their progress in poster sessions on Monday and Wednesday evening. Prizes have been generously sponsored by Keysight Technologies, The Royal Society of Chemistry and IOP Women in Physics group. All the prizes except for the student-choice prize will be judged by a committee of academics.

1st place: Samsung Tablet *sponsored by* **Keysight Technologies**

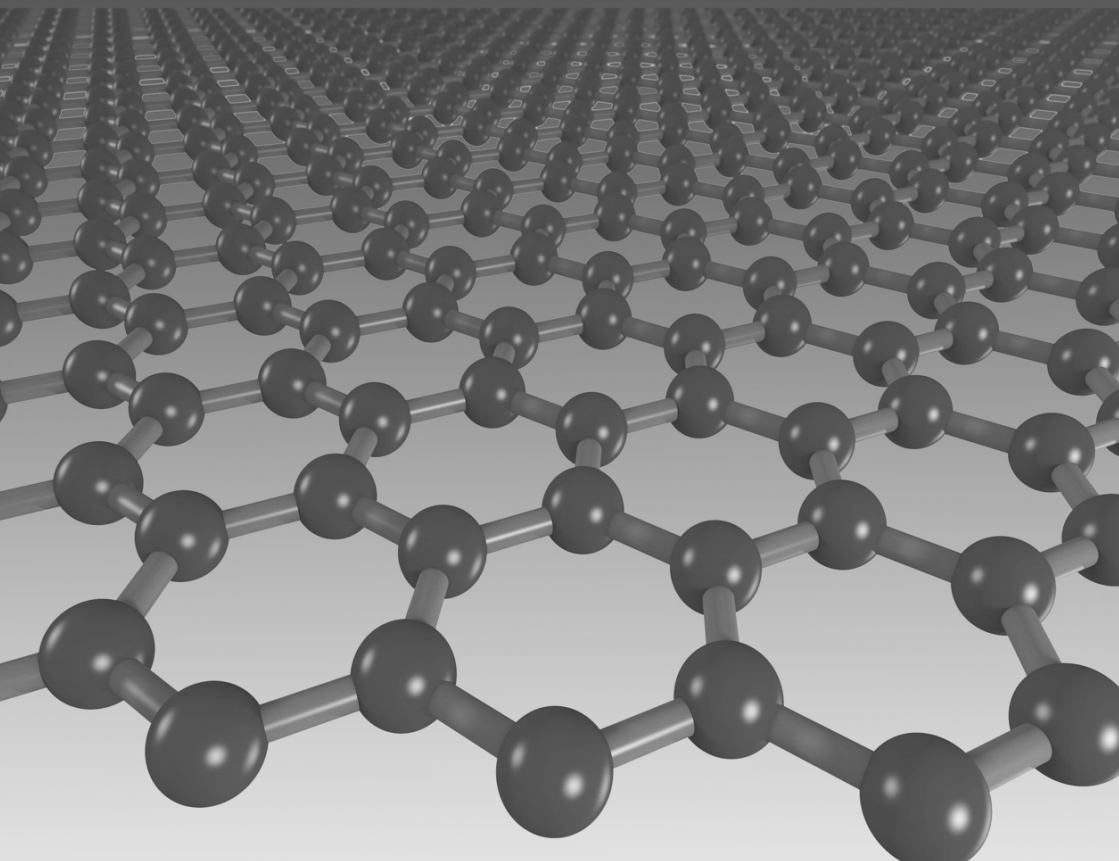
2nd place: £75 Amazon voucher *sponsored by* **The Royal Society of Chemistry**

3rd place: £25 Amazon voucher *sponsored by* **The Royal Society of Chemistry**

Student-choice award: Awarded for the best overall student talk and best overall poster as voted for by the CDT students: £25 Amazon voucher *sponsored by* **The Royal Society of Chemistry**

Women-in-Science award: There will also be two additional prizes (£75 Amazon Voucher) for the best overall student talk and best overall poster amongst females *sponsored by* **IOP Women in Physics**.

INVITED SPEAKERS



Dr. Kirill Bolotin

Dr. Kirill Bolotin received his undergraduate degree from the Moscow Institute of Physics and Technology and his PhD from Cornell University. His thesis work was focused on developing metal-nanoparticle single-electron transistors and studying the quantum analog of anisotropic magnetoresistance. He then became a postdoctoral scientist at Columbia University where he discovered the approaches to fabricate ultrahigh mobility graphene and found the Fractional Quantum Hall effect in graphene. Bolotin was assistant and associate professor of Physics at Vanderbilt University (2009-2015), and is currently professor at Freie Universitat Berlin (2015-). The Bolotin group explores how the quasiparticles in two-dimensional materials are affected by the mechanical stretching of these materials, the environment around them, and by the ultra-strong electrical fields at their surface. Bolotin was awarded the NSF Career, the Sloan foundation, and the ERC starting grant awards.

[IS1] - Bending, pulling, and cutting wrinkled two-dimensional materials

Kirill Bolotin

Department of Physics, Freie Universitat Berlin, Germany

Two-dimensional materials (2DM) such as graphene, monolayer boron nitride, or monolayer molybdenum disulfide are crystalline layers only a few atoms thick. In this talk, we will examine the mechanical properties of these materials using newly developed techniques to pull, bend, twist, and cut them. We will see that the mechanics of 2DMs is drastically different from that of "conventional" bulk matter. It will be shown that inevitable out-of-plane crumpling modifies every mechanical property of 2DMs making their mechanical response more akin to that of biological membranes than of solid objects. For the case of a prototypical 2DM, graphene, it will be shown that out-of-plane crumpling renders the thermal expansion coefficient negative and substrate-dependent, decreases the Young's modulus, increases the bending rigidity by several orders of magnitude, and changes the sign of the Poison's ratio. We will discuss how these unusual mechanical properties can be used in developing new types of nanomechanical devices.

Prof. Francisco Guinea

Prof. Francisco Guinea received his B. Sc from the University of Complutense, Madrid. In 1980 he went on to compete a PhD from the Autonomous University of Madrid (UAM) where he then became an Assistant Professor. He was made a Fullbright scholar at the Institute for Theoretical Physics at the University of California Santa Barbara before heading back to UAM. From 1984 – 2014 he worked first as a researcher then senior researcher at the Spanish National Research Council (CSIC). He now splits his time between the University of Manchester and IMDEA Nanoscience. In 2013 Guinea was awarded the Spanish Physical Society Medal, the highest award given by the society and he was also recently appointed to the National Academy of Sciences as a foreign member. Guinea has an extensive record of scientific contributions in many topics in condensed matter and statistical physics. These include mesoscopic systems and quantum dissipation, materials science with emphasis on highly correlated systems, non equilibrium pattern formation, magnetism, and superconductor and semiconductor physics. He has made seminal contributions in topics such as macroscopic quantum mechanics, pattern formation, magnetism, and the theory of superconductivity and strongly correlated systems. In recent times he has been doing research in graphene and other two dimensional materials, where he is one of the leading theoreticians worldwide.

[IS2] - Novel features of edge channels in two dimensional materials.

Francisco Guinea[1], Rory Brown[2], Phong Tien Vo[2] and Niels R. Wallet[2]

[1]IMDEA Nanociencia, Spain

[2]Department of Physics and Astronomy, University of Manchester, UK

Edge modes have been intensively studied since the discovery of the Quantum Hall Effect. They are relevant in two dimensional materials where the bulk electronic structure imposes their existence, such as graphene, 2D topological insulators and superconductors.

We present results on: i) Edge modes in graphene superlattices. Graphene superlattices arise from the interaction between graphene and very perfect substrates, such as boron nitride. Typically they show a bulk gap in the electronic structure. Our results show the significant influence of edge modes on the transport properties of these superlattices. ii) Edge modes in two dimensional topological superconductors. A significant effort is being carried out to produce “Majorana excitations”, for their use in topological quantum computing. Current emphasis is made on fabricating artificial topological superconductors. We show, using doped Bi_2Se_3 as an example, how natural topological superconductors can become platforms for Majorana modes.

Prof. Ali Khademhosseini

Prof. Ali Khademhosseini is Professor of Medicine at Harvard Medical School and Director of the Biomaterials Innovation Research Center at Brigham and Women's Hospital. He is also a faculty at the Harvard-MIT Division of Health Sciences and Technology as well as an Associate Faculty at the Wyss Institute for Biologically Inspired Engineering. He is recognized as a leader in combining micro- and nano-engineering approaches with advanced biomaterials for regenerative medicine applications. In particular, his laboratory has pioneered numerous technologies and materials for controlling the architecture and function of engineered vascularized tissues. He has authored ~500 journal papers (H-index > 90, >30,000 citations) and 50 books/chapters. In addition, he has delivered 300+ invited/keynote lectures. Dr. Khademhosseini's interdisciplinary research has been recognized by over 40 major national and international awards. He is a recipient of the Presidential Early Career Award for Scientists and Engineers, the highest honor given by the US government for early career investigators. In 2011, he received the Pioneers of Miniaturization Prize from the Royal Society of Chemistry (RSC) for his contribution to microscale tissue engineering and microfluidics. In 2016, he received the Sr. Scientist Award of Tissue Engineering and Regenerative Medicine Society - Americas Chapter (TERMIS-AM) and in 2017 he received the Clemson Award of the Society for Biomaterials. He is also a fellow of the American Institute of Medical and Biological Engineering (AIMBE), Biomedical Engineering Society (BMES), Royal Society of Chemistry (RSC), Fellow of the Biomaterials Sciences and Engineering (FBSE) and American Association for the Advancement of Science (AAAS). Currently he serves on the editorial board of numerous leading journals as well as an Associate Editor for ACS Nano (IF: 13.3) and a member of NIH BTSS study section. He received his Ph.D. in bioengineering from MIT (2005), and MASc (2001) and BASc (1999) degrees from University of Toronto both in chemical engineering.

[IS3] - Nano- and Microfabricated Hydrogels for Regenerative Engineering

Ali Khademhosseini

Department of Medicine, Brigham and Women's Hospital,

Harvard Medical School, Cambridge, MA

Harvard-MIT Division of Health Sciences and Technology, MIT, Cambridge, MA

Wyss Institute for Biologically Inspired Engineering, Harvard University, Boston, MA

Engineered materials that integrate advances in polymer chemistry, nanotechnology, and biological sciences have the potential to create powerful medical therapies. Our group aims to engineer tissue regenerative therapies using water-containing polymer networks, called hydrogels, that can regulate cell behavior. Specifically, we have developed photocrosslinkable hybrid hydrogels that combine natural biomolecules with nanoparticles to regulate the chemical, biological, mechanical and electrical properties of gels. These functional scaffolds induce the differentiation of stem cells to desired cell types and direct the formation of vascularized heart or bone tissues. Since tissue function is highly dependent on architecture, we have also used microfabrication methods, such as microfluidics, photolithography, bioprinting, and molding, to regulate the architecture of these materials. We have employed these strategies to generate miniaturized tissues. To create tissue complexity, we have also developed directed assembly techniques to compile small tissue modules into larger constructs. It is anticipated that such approaches will lead to the development of next-generation regenerative therapeutics and biomedical devices.

Prof. Clare Grey

Clare P. Grey, FRS is the Geoffrey Moorhouse-Gibson Professor of Chemistry at Cambridge University and a Fellow of Pembroke College Cambridge. She received a BA and D. Phil. (1991) in Chemistry from the University of Oxford. After post-doctoral fellowships in the Netherlands and at DuPont CR&D in Wilmington, DE, joined the faculty at Stony Brook University (SBU) as an Assistant (1994), Associate (1997) and then Full Professor (2001-2015). She moved to Cambridge in 2009, maintaining an adjunct position at SBU. She was the director of the Northeastern Chemical Energy Storage Center, a Department of Energy, Energy Frontier Research Center (2009-2010) and Associate director (2011-2014). She is currently the director of the EPSRC Centre for Advanced Materials for Integrated Energy Systems (CAM-IES). Her recent honours and awards include the 2011 Royal Society Kavli Lecture and Medal for work relating to the Environment/Energy, Honorary PhD Degrees from the Universities of Orleans (2012) and Lancaster (2013), the Gunther Laukien Award from the Experimental NMR Conference (2013), the Research Award from the International Battery Association (2013), the Royal Society Davy Award (2014) and the Arfvedson-Schlenk-Preis from the German Chemical Society (2015). Her current research interests include the use of solid state NMR and diffraction-based methods to determine structure-function relationships in materials for energy storage (batteries and supercapacitors), conversion (fuel cells) and carbon capture.

[IS4] - New Characterisation Approaches Applied to Batteries and Supercapacitors

Clare P. Grey

Department of Chemistry, University of Cambridge, Cambridge, UK

The development of light, long-lasting rechargeable batteries has been an integral part of the portable electronics revolution. This revolution has transformed the way in which we communicate and transfer and access data globally. Rechargeable batteries are now poised to play an increasingly important role in transport and grid applications, but the introduction of these devices comes with different sets of challenges. New technologies are being investigated, such as those using sodium and magnesium ions instead of lithium, and the flow of materials in an out of the electrochemical cell (in redox flow batteries). Importantly, fundamental science is key to producing non-incremental advances and to develop new strategies for energy storage and conversion.

This talk will focus on our work developing methods that allow devices to be probed while they are operating (i.e., *in-situ*). I will illustrate how we characterize local structure and determine reaction mechanisms by showing applications to various carbon materials. For example, hard carbons are the most promising materials for use as anodes for sodium ion batteries and yet their structures are poorly understood, hindering attempts to relate capacity to structure and to optimize performance. Our work has used two probes of local structure, ^{23}Na MAS NMR and pair distribution function (PDF) analysis of X-ray total scattering data to monitor structural (and electronic) changes during cycling. For example, PDF studies of hard carbons show that these materials comprise graphene sheets with considerable curvature. The extent of curvature can be determined by analysing the PDF real and reciprocal space data. The electrochemical data observed on reaction with Na comprises two regions, a higher voltage sloping region, and a longer, flatter low voltage region. ^{23}Na NMR data acquired *operando* show that the Na^+ ions occupy sites within the hard carbons that do not interact significantly with the carbon layers in the high voltage region, the ^{23}Na NMR shifts being consistent with ionic environments. The ^{23}Na shifts change dramatically during the low voltage region, shifting to higher frequencies. These Knight shifts are indicative of metallic behaviour and are a measure of the density of states at the Fermi Level, as probed by the Na nuclei. In a second application, I will describe the use of NMR to determine how carbons store charge in supercapacitors, showing how NMR can be used to quantify charge storage mechanisms and to probe aromaticity and anti-aromaticity in sp^2 carbon sheets.

Prof. Cinzia Casiraghi

Prof. Cinzia Casiraghi received her BSc and MSc in Nuclear Engineering from Politecnico di Milano (Italy) and her PhD in Electrical Engineering from the University of Cambridge (UK) in 2006. In 2005 she was awarded with an Oppenheimer Early Career Research Fellowship, followed by the Alexander von Humboldt Research Fellowship (2007) and the prestigious Sofja Kovalevskaja Award, won in 2008. In 2010 she joined the School of Chemistry, at the University of Manchester (UK), where she is currently professor in nanoscience. In 2014 she received the Marlow Award given by The Royal Society of Chemistry in recognition of her contribution towards the understanding and use of Raman spectroscopy to study carbon-based nanomaterials. In 2016 she won a ERC Consolidator Award, followed by the Leverhulme Award in Engineering in 2017. She is member of the EPSRC Early Career Forum in Manufacturing Research since 1014.

[IS5] - Water-based 2D-crystal Inks: from Formulation Engineering to All-printed Devices

Cinzia Casiraghi

Department of Chemistry, University of Manchester, UK

The isolation of various two-dimensional (2D) materials allows for the possibility to combine them into heterostructures. Such a concept can be used to study particular phenomena such as the metal-insulator transition, Coulomb drag, Hofstadter's butterfly, or to make functional devices such as tunnel diodes, tunnelling transistors, photodetectors and light emitters. The range of functionalities and performance are likely to be further improved by increasing the number of components in the heterostructure and by improving their electronic quality. Solution processing of graphene[1] allows simple and low-cost techniques such as inkjet printing[2,3] to be used for fabrication of heterostructure of arbitrary complexity. However, the success of this technology is determined by the nature and quality of the inks used. Available inkjet printable formulations are still far from ideal as they are either based on toxic solvents, have low concentration, or require time-consuming and expensive formulation processing. In addition, none of those formulations are suitable for all inkjet printed heterostructure fabrication due to the re-mixing of different 2D crystals, which gives rise to uncontrolled interfaces, resulting in poor performance and lack of reproducibility.

In this work we show a general formulation engineering approach to achieve highly concentrated, and inkjet printable water-based 2D crystal formulations, which also provide optimal film formation for multi-stack fabrication. Examples of all-inkjet printed heterostructures, such as large area arrays of photosensors on plastic and programmable logic memory devices, will be discussed[4].

References

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3. Finn et al., J. Mat. Chem. C, 2014, **2**, 925.
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Dr. Francesco Bonaccorso

Francesco Bonaccorso gained the PhD from the University of Messina in Italy after working at the Italian National Research Council, the Engineering Department of Cambridge University (UK) and the Department of Physics and Astronomy of Vanderbilt University (USA). In June 2009 he was awarded a Royal Society Newton International Fellowship at Cambridge University, and elected to a Research Fellowship at Hughes Hall, Cambridge, where he also obtained a MA. He is currently leading the processing and prototyping group at the Istituto Italiano di Tecnologia, Graphene Labs. He was responsible in defining the ten years scientific and technological roadmap for the European Graphene Flagship. He was featured as 2016 Emerging Investigator by J. Mater. Chem. A. His research interests encompass both the fundamental understanding and solution processing of novel nanomaterials with on-demand designed structures, their spectroscopic characterization, incorporation into polymer composites and their technological application in solar and photoelectrochemical cells, lithium-ion batteries, light emitting devices and ultrafast lasers. He organized several conferences such as Graphene2015/2016/2017, Graphene Canada, GrapChina 2014/2015/2016, etc., and symposia in MRS, e-MRS. He has several publications in journals such as Science, Nature Nanotechnology, Nature Photonics, Chemical Society Reviews, Advanced Materials, Nano Letters, etc. These have been covered by a number of reports in the technical and general press.

[IS6] - 2D crystals for photonics and optoelectronics

Francesco Bonaccorso

Istituto Italiano di Tecnologia, Genova, Italy.

New materials and processes[1] can improve the performance of existing devices or enable new ones,[1-3] with the added values to be environmentally friendly. In this context, graphene and other inorganic 2D crystals are emerging as promising materials,[1-3] with the opportunity to enable new products/devices.[1] However, a fundamental requirement for the application of 2D crystals in areas such as flexible electronics and energy storage and conversion relies on the development of industrially scalable, reliable, inexpensive production processes.[2] Moreover, the synthesis strategies should provide a balance between ease of fabrication and final material quality with on-demand properties.

Solution-processing[2,4] offers a simple and cost-effective pathway to fabricate various 2D crystal-based (opto)electronic and photonic devices, presenting huge integration flexibility compared to conventional methods. Here, I will present an overview of graphene and other 2D crystals for flexible and printed (opto)electronic and photonic applications, starting from solution processing of the raw bulk materials,[2] the fabrication of large area electrodes[3] and their integration in the final devices.[5-9]

References

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Dr. Amir Gheisi

Dr Amir Gheisi is the Product Manager for Nanoscience and Technology at Springer Nature Heidelberg. He obtained his Ph.D. from Erlangen-Nürnberg University Germany where his thesis focused on stability and transformation of metal oxide nanocomposites. During his research Amir developed a unique synthesis process for production of well-defined metal oxide nanocomposites with controlled composition, structure and size.

[IS7] - Towards a Discovery Solution for Nanotechnology – Challenges & Prospects

Amir Gheisi

Springer Nature, Heidelberg

Nano (nano.nature.com) is a multidisciplinary research solution that gathers data related to nanotechnology from high impact journals and patents. Nano has been designed to be a one-stop solution that will provide detailed information at a glance including synthesis, properties, toxicity and biological effects, characterization methods and application information.

Prof. Jan Stake

Jan Stake received an M.Sc. degree in electrical engineering and a Ph.D. degree in microwave electronics from Chalmers University of Technology, Göteborg, Sweden, in 1994 and 1999, respectively. In 1997, he was a Research Assistant with the University of Virginia, Charlottesville, USA. From 1999 to 2001, he was a Research Fellow with the Millimetre Wave Group at the Rutherford Appleton Laboratory, Didcot, UK. He then joined Saab Combitech Systems AB as a Senior RF/Microwave Engineer, where he remained until 2003. From 2000 to 2006, he held various academic positions with Chalmers University of Technology, and from 2003 to 2006, he was also the Head of the Nanofabrication Laboratory, Department of Microtechnology and Nanoscience (MC2). During 2007, he was a Visiting Professor with the Submillimeter Wave Advanced Technology (SWAT) Group at Caltech/JPL, Pasadena, USA. He is currently Professor and Head of the Terahertz and Millimetre Wave Laboratory at Chalmers University of Technology, Sweden. He is also cofounder of Wasa Millimeter Wave AB, Göteborg, Sweden. His research involves graphene electronics, high-frequency semiconductor devices, THz electronics, submillimeter wave measurement techniques (“THz metrology”), and THz applications in biology and medicine. Prof. Stake serves as Editor-in-Chief for IEEE Transactions on Terahertz Science and Technology.

[IS8] - Graphene terahertz electronics

Jan Stake

Chalmers University of Technology, Göteborg, Sweden

The intrinsically extremely high carrier velocities in graphene open pathways towards high performance transistors and detectors in the millimetre wave and THz frequency regimes. However, the large discrepancy between maximum frequency of oscillation, f_{max} (<0.1 THz), and intrinsic transit frequency, f_t (<0.4 THz), indicate a gap between the promising material properties and applications in active electronics. For instance, the lack of a bandgap in graphene, relative high contact and access resistances, and poor current saturation in Graphene Field Effect Transistors (GFETs) are challenges that must be addressed in order to achieve high f_{max} values. The carrier mobility in GFETs is to a large extent affected by the surrounding oxides, which in part can be solved by sandwiching graphene between hexagonal boron nitride (h-BN). Hence, the device fabrication process and how to minimise contamination and reduce electrical losses are crucial for future graphene electronics.

Today, the low extrinsic maximum frequency of oscillation (f_{max}) for G-FETs only allow active electronics (e.g. amplifiers) at low microwave frequencies, whereas passive devices can be explored across the whole electromagnetic spectrum. The first subharmonic resistive single GFET mixer was proposed at Chalmers, and it has been reported to reach a conversion loss of 19 dB at 24–31 GHz and recently 29 dB at 185-215 GHz. The GFET subharmonic mixer is based on a single transistor without the need for a balanced configuration and a balun, making the circuit topology more compact. The mixers utilise the unique electron-hole conduction symmetry in graphene for subharmonic mixing in a single FET. This talk provides an overview of research on graphene electronics for terahertz and millimetre wave applications. New type of devices for the THz region utilising graphene will be discussed. For instance, results on direct THz detection in G-FETs up to 600 GHz will be presented, integrated heterodyne mixers up to 200 GHz as well as flexible terahertz electronics based on graphene.

Prof. Roland Kawakami

Prof. Roland Kawakami received a B.A. in physics and B.S in Electrical Engineering from the University of Pennsylvania. He then received an M.A and PhD in Physics and the University of California, Berkeley. His early research focused on spin and magnetism specifically, studies on ferromagnetic metal and semiconductor heterostructures grown by MBE. His current research interests are spintronics, valleytronics, and looking at novel magnetic and topological phenomena. His team has worked to develop a unique laboratory with advanced MBE, device, optics, and spin-polarized STM capabilities to create materials and devices with atomic-scale precision and to explore their properties by transport and microscopies with high spatial and temporal resolution. Some aspects of their work are connected to future computers and electronics that operate faster while using less energy.

[IS9] – Spins, Valleys, and Magnetism in 2D Materials

Roland Kawakami

Department of Physics, The Ohio State University, USA

Two dimensional (2D) materials provide a unique platform for investigating the properties of spin and valley degrees of freedom, which can be probed by optical methods and electrical transport methods. Graphene provides an excellent medium for spin transport within a low spin orbit coupling (SOC) environment for long spin diffusion lengths at room temperature. Monolayer transition metal dichalcogenides (TMD) provide optical coupling to the spin and valley degrees of freedom within a high SOC environment. Ferromagnetic metals and insulators provide a means for electrical injection, detection, and manipulation of spin and valley degrees of freedom. One distinguishing characteristic of 2D materials is the ability to produce vertical heterostructures that combine vastly different functionalities at the length scale of a few atoms or less. Taking advantage of such an opportunity requires the use and development of advanced synthesis, fabrication, and characterization techniques for creating systems with atomic-scale precision and performing spin/valley-sensitive measurements with high fidelity. In this talk, I will present recent work on some of the first steps toward multifunctional 2D spintronics. This includes modulation of spin currents in graphene by proximity to ferromagnetic insulators [1], optical spin injection into graphene via optical excitation in MoS2/graphene heterostrucures [2], spin/valley dynamics in monolayer TMDs [3], and room temperature ferromagnetism in van der Waals magnetic layers grown by molecular beam epitaxy.

References

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Dr. Petr Stepanov

Petr Stepanov received B.S. and M.S. degrees in applied physics and mathematics from Moscow Institute of Physics and Technology (MIPT) in 2010 and 2012, respectively. During this time he worked on nanostructured thermoelectric materials at the Technological Institute for Superhard and Novel Carbon Materials (Troitsk, Russia). He moved to UC Riverside to pursue his PhD at Prof. Chun Ning Lau's laboratory where he worked on quantum Hall effect in multi-band 2D electron gases such as trilayer graphene and long-distance spin transport through graphene anti-ferromagnet insulators. In January 2017 Prof. Lau's laboratory moved to OSU where this work has been continued.

[IS10] - Long-Distance Spin Transport Through a Graphene Quantum Hall Antiferromagnet

Petr Stepanov[1, 2], Shi Che[1, 2], Dmitry Shcherbakov[1, 2], Jiawei Yang[1, 2], Kevin Thilahar[1], Greyson Voigt[1], Marc W. Bockrath[1, 2], Dmitry Smirnov[3], Kenji Watanabe[4], Takashi Taniguchi[4], Roger Lake[5], Yafis Barlas[1, 5], Allan H. MacDonald[6], Chun Ning Lau[1, 2]

[1]Department of Physics and Astronomy, The Ohio State University, USA

[2]Department of Physics and Astronomy, University of California, USA

[3]National High Magnetic Field Laboratory, Tallahassee, USA

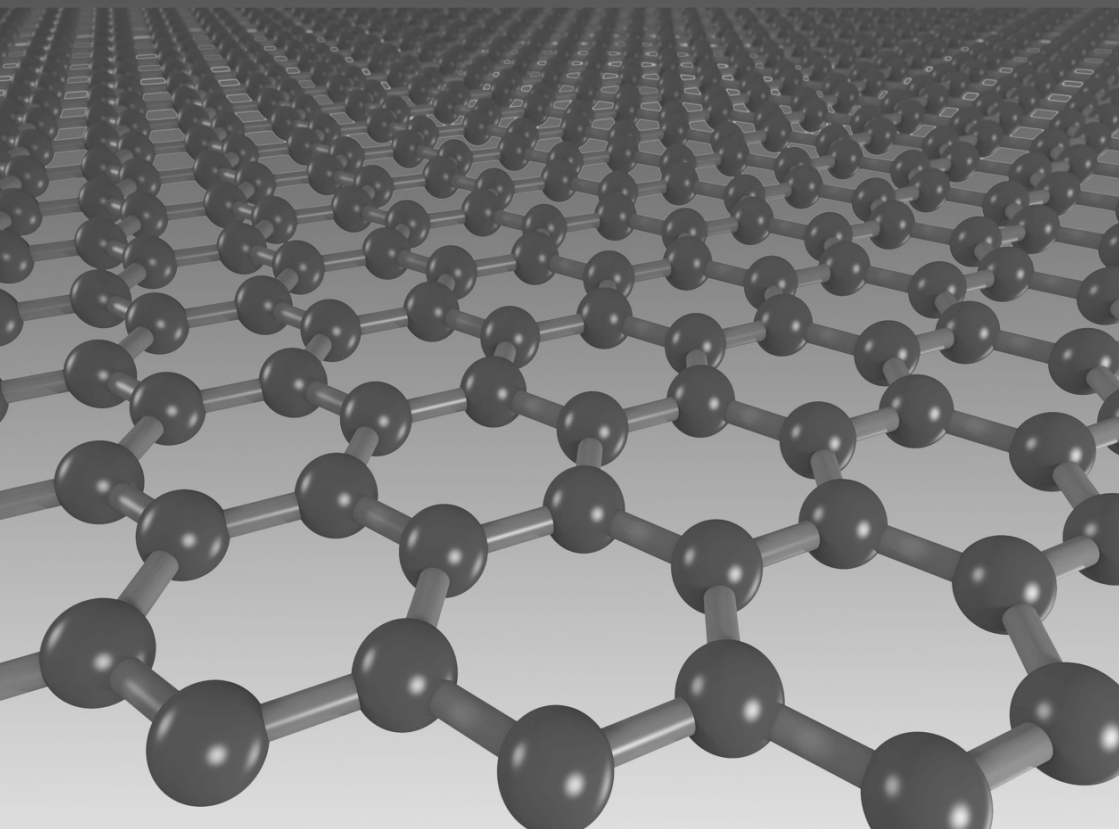
[4]National Institute for Materials Science, Japan

[5]Department of Electrical and Computer Engineering, University of California, USA

[6]Department of Physics, University of Texas at Austin, USA

An important goal in spintronics is to establish mechanisms that minimize dissipation in the devices that are to exhibit the action of spin currents. In magnetic insulators the easy plane ordered spin currents could be carried dissipationless in the form of spin-supercurrents. Spin superfluidity transport has been theoretically predicted in a graphene quantum Hall insulator[1]. Here we report on the first experimental demonstration of the robust spin-current transport through graphene anti-ferromagnet insulator (AFMI) in the quantum Hall regime. The charge neutrality point (CNP) forms canted anti-ferromagnet (CAF) in the ground state that effectively serves as AFMI for spin currents propagation. By utilizing quantum Hall (QH) edge modes as injector, filters and detector we find large non-local signal across 5-μm long graphene CAF region. Our work demonstrates a long-distance spin transport through AFMI in graphene and shows that QH states can serve as a powerful tool for fundamental studies of ferromagnet and anti-ferromagnet spintronics. In this talk I will also make a short introduction to graphene quantum Hall physics and graphene spintronics advances, which are crucial in understanding of the above-mentioned results. In addition, I will discuss the electronic structure of the lowest Landau level in charge neutral monolayer graphene that serves as a spin supercurrent propagation media.

STUDENT TALKS – 4th YEARS



[ST4.1] - Water-based and biocompatible 2D crystal inks for all-inkjet-printed heterostructures

Daryl McManus[1], Sandra Vranic[2], Freddie Withers[3], Veronica Sanchez-Romaguera[1], Khaled Parvez[1], Kostas Kostarelos[2], Cinzia Casiraghi[1]

[1] School of Chemistry, University of Manchester, UK

[2] Faculty of Biology, Medicine and Health, University of Manchester, UK

[3] School of Physics and Astronomy, University of Manchester, UK

daryl.mcmanus@manchester.ac.uk

Inkjet printing is an attractive fabrication technique as it allows for production of large-area, low-cost and flexible electronics on a wide range of substrates.[1, 2]

Here we show a simple method to produce highly concentrated (up to 8 mg/mL), stable and inkjet printable graphene dispersions in water.[3] The method has also been successfully extended to other 2D materials. The inks can be inkjet printed on a wide range of substrates (glass, plastic, paper, silicon, etc.) and are suitable for fabrication of both planar and vertical devices. In particular, we show for the first time an array of 100 heterostructure-based devices entirely made by inkjet printing.[3]

Preliminary in vitro dose-escalation cytotoxicity tests also demonstrated the biocompatibility of the inks, extending their possible use to biomedical applications.[3]

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[ST4.2] - Structural and magnetic properties of MnAl thin films on MgO substrates

David Huskisson[1,2], Ernie Hill[1], Sarah Haigh[2] and Tom Thomson[1]

[1]School of Computer Science, The University of Manchester, UK

[2]School of Materials, The University of Manchester, UK

david.huskisson@postgrad.manchester.ac.uk

Materials with perpendicular magneto-crystalline anisotropy, specifically L10 ordered alloys, offer improved magnetic properties over conventional in-plane materials. They give potential benefits to many applications, including magnetic tunnel junctions and spin torque oscillators. L10 ordered MnAl has a high anisotropy and moderate saturation magnetization [1] and only contains light elements, so has weak spin-orbit coupling [2]. These properties make it the ideal ferromagnetic material for efficient spintronics.

However, the ferromagnetic phase is metastable at room temperature, with a narrow range of atomic ratios from 49–59 Mnat%. Deposition temperature and annealing temperature are crucial factors. This work thoroughly explores the fabrication parameter space and presents the latest results in this ongoing study.

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[ST4.3] - Structural Graphene Composites for Aerospace

Edward Pullicino

edward.pullicino@postgrad.manchester.ac.uk

Carbon fibre composite materials now make up just over 50% by weight of the Boeing Dreamliner and Airbus XWB. Their high strength and low weight have enabled greater fuel efficiency, lower emissions and shorter flight times. In spite of this, composite materials have pitfalls which have prevented their use in more load bearing parts of an aeroplane such as landing gear. Their biggest flaw is their poor resistance to impact damage. Subsurface cracks can form easily in the thermosetting resin holding the fibres together. These cracks can spread easily causing failure of parts. This is a costly issue for Airplane companies and composites with better impact resistance are required. This project will examine ways of improving the resistance of materials to crack growth by modifying the resin with nano materials in an attempt to block or divert moving cracks.

[ST4.4] - Fine-tuning molecular interactions between peptide nano-fibres and graphene for engineering functional hybrid hydrogels

Jacek K. Wychowaniec[1,2], Maria Iliuta[3], Mi Zhou[4], Jonathan Moffat[5], Wagner Pinheiro[1,6], Judith A. Hoyland[4], Aravind Vijayaraghavan[1,3] and Alberto Saiani[1]

[1]School of Materials, University of Manchester, UK

[2]Manchester Institute of Biotechnology, University of Manchester, UK

[3]National Graphene Institute, University of Manchester, UK

[4]Faculty of Biology, Medicine and Health, University of Manchester, UK

[5]Asylum Research an Oxford Instruments company, UK

[6]Military Institute of Engineering, Rio de Janeiro, Brazil

jacek.wychowaniec@postgrad.manchester.ac.uk

Hybrid hydrogels have attracted wide interests due to their potentials in biomedical applications as 3-dimensional (3D) functional scaffolds for engineering tissues[1]. The incorporation of graphene-based nano-fillers offers potentials to tailor properties of materials[2]. The relationship between molecular structures of nano-fibres forming the 3D network and the nano-filler is critical to understand in order to design tunable and functional biomaterials. The interplay of various molecular interactions between nano-fibres formed from three rationally designed β-sheet self-assembling peptides: FEFKFEFK (F8), FEFEFKFE (FE) and VEVKVEVK (V8) and five graphene-based materials was used to obtained range of biocompatible 3D scaffolds with tunable properties. We endeavor to use this versatile platform for further biomedical and tissue engineering research.

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[ST4.5] - Graphene Polarization by Ions

J. Dix[1], C. D. Williams[1], P. Carbone[1]

[1]School of Chemical Engineering and Analytical Sciences, University of Manchester, UK

james.dix@postgrad.manchester.ac.uk

Earlier this year the work of J. Abrahams, *et al.*[1] showed that graphene oxide membranes could prevent the transport of ions while allowing the transport of water, which is ideal for desalination purposes. Although the experiments were very successful it is difficult to understand from them alone the exclusion mechanism for these membranes. To aid in our attempts to further understand this process we employed molecular dynamics simulations [1]. They provide a vital insight in the dehydration process of ions, but they are still some discrepancies between experiment observations and the simulations results (like spontaneous ion uptake in GO membranes). To improve the accuracy of our models, we present here recent work that we have done to include the effects of graphene polarization on ion-graphene interactions[2].

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[ST4.6] - Significant effect of semiconductor thickness on the reverse current of Schottky diodes.

Joshua Wilson, Jiawei Zhang and Aimin Song

School of Electrical and Electronic Engineering, The university of Manchester, UK

joshua.wilson@postgrad.machester.ac.uk

Recently, indium-gallium-zinc-oxide (IGZO) Schottky diodes have demonstrated GHz operation – further confirming their suitability for future thin-film electronics[1]. While the scalability of TFTs has been well documented – particularly the short-channel effect – there has been very little discussion of the effects of device scalability in Schottky diodes. In published literature on IGZO Schottky diodes there is a noticeable dependence of the current on the thickness of the semiconductor layer[2]. This phenomenon remains largely undiscussed even though it can cause the reverse current to vary over orders of magnitude. A combination of simulations and experiments has been carried out to demonstrate such an effect. Our work indicates the important role of non-uniform Schottky interface properties and may have implications for the fabrication of large scale thin-film electronics.

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[ST4.7] - Phase-sensitive detection of HT-2 mycotoxin using graphene-protected copper plasmonics

Philip A. Thomas[1], Fan Wu[1], Henri Arola[2], Miika Soikkeli[2], Vasyl G. Kravets[1] and Alexander N. Grigorenko[1]

[1] School of Physics and Astronomy, University of Manchester, United Kingdom

[2]VTT Technical Research Centre of Finland Ltd., Espoo, Finland

philip.thomas-2@manchester.ac.uk

Surface plasmon resonance (SPR) is an established technique for label-free detection of trace amounts of adsorbents at a metal-dielectric interface. We have recently shown that copper thin films protected by graphene can provide a stable platform for SPR with high-quality plasmon resonances[1]. These plasmon resonances give points of zero reflection, allowing for phase-sensitive SPR measurements which could give a fundamental detection limit 10^4 times higher than the limit of currently-available commercial systems[2].

Here we use graphene-protected copper thin films to detect HT-2 mycotoxin, important in food safety applications. Our assay is capable of detecting concentrations of HT-2 mycotoxin as low as 1 pg/ml, 10^3 times more sensitive than in previous studies[3]. Our results provide a practical demonstration of ultra-sensitive biosensing using phase-based detection methods.

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[ST4.8] - High temperature quantum oscillations caused by recurring Bloch states in graphene superlattices

R. Krishna Kumar[1,2,3], X. Chen[2], G. H. Auton[2], A. Mishchenko[1], D. A. Bandurin[1] S. V. Morozov[4,5], Y. Cao[2], E. Khestanova[1], M. Ben Shalom[1], A. V. Kretinin[2], K. S. Novoselov[2], L. Eaves[2,6], I. V. Grigorieva[1], L. A. Ponomarenko[3], V. I. Fal'ko[1,2], A. K. Geim[1,2]

[1]School of Physics & Astronomy, University of Manchester, UK

[2]National Graphene Institute, University of Manchester, UK

[3]Department of Physics, University of Lancaster, UK

[4]Institute of Microelectronics Technology and High Purity Materials, Chernogolovka, Russia

[5]National University of Science and Technology 'MISiS', Moscow, Russia

[6]School of Physics and Astronomy, University of Nottingham, UK

Cyclotron motion of charge carriers in metals and semiconductors leads to Landau quantization and magneto-oscillatory behavior in their properties. Cryogenic temperatures are usually required to observe these oscillations. We show that graphene superlattices support a different set of quantum oscillations that do not rely on Landau quantization. The oscillations are extremely robust and persist well above room temperature in magnetic fields of only a few T. We attribute this phenomenon to repetitive changes in the electronic structure of superlattices such that charge carriers experience effectively no magnetic field at simple fractions of the flux quantum per superlattice unit cell. Our work points at unexplored physics in Hofstadter butterfly systems[1] at high temperatures.

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[ST4.9] - Multimodal Magnetic and Luminescent Nanomaterials for Biomedical and Data Storage Applications

Simon McAdams,[1] David Lewis,[2] Paul O'Brien,[1,2,3] and Floriana Tuna [1,3]

[1]School of Chemistry, University of Manchester, UK

[2]School of Materials, The University of Manchester, UK

[3]Photon Science Institute, The University of Manchester, UK

simon.mcadams@postgrad.manchester.ac.uk

Multimodal nanomaterials are a growing class of nanocomposites that integrate various functionalities into a single entity, and in turn demonstrate applicability in a broad range of fields. We have functionalised colloidal quantum dot nanocrystals and MoS_2 nanosheets with paramagnetic species to create novel luminescent and paramagnetic hybrid materials. Specifically, liquid-exfoliated *2H-MoS_2* nanosheets were covalently functionalised simultaneously with preformed luminescent and magnetic lanthanide complexes as a potential multimodal imagining platform.[1] Furthermore, monofunctionalised molecular nanomagnet {Cr_7Ni} rings were attached to CdSe/ZnS quantum dots, with the resulting hybrid nano-objects retaining both the bright optical emission of the quantum dots, and the molecular qubit properties of the {Cr_7Ni} rings with a $S = ½$ ground state.[2]

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[ST4.10] - Silicon Based Nanophotonic Sensors for Healthcare

Thomas Catherall[1] and Matthew Halsall[1]

[1]School of Electrical and Electronic Engineering, The University of Manchester, United Kingdom

thomas.catherall@postgrad.manchester.ac.uk

Silicon photonic waveguide devices are compact, CMOS compatible and have a range of applications. Ring resonators were originally designed as optical filters and signal modulators; they allow controlled selection of specific wavelengths down silicon optical waveguides. This feature is highly desirable in next generation applications such as ON/OFF switching in tera-scale optical computing. Ring resonators have also emerged as highly sensitive refractive index sensors, demonstrating capabilities in temperature sensing and biosensing.[1] This presentation will introduce the field of ring resonator technologies, offer an overview of improvements made to device sensitivity and progress made in biosensing.

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[ST4.11] - Magnetic Nanoparticles for Theranostics and Magnetophoresis

T. W. Fallows[1], J. E. Gough[2] and S. J. Webb[1]

[1]Manchester Institute of Biotechnology and School of Chemistry, University of Manchester, UK

[2]School of Materials, University of Manchester, UK

thomas.fallows-3@postgrad.manchester.ac.uk

Magnetic nanoparticles (MNPs) are incredibly versatile for a wide range of biomedical applications. This is especially true when they are functionalised with ligands[1,2] which can actively target certain cells.

One example is coated MNPs being used for dual-purpose therapy and diagnostics (theranostics). Iron oxide MNPs are promising T_2 contrast agents for magnetic resonance imaging (MRI), and can also be used to locally induce hyperthermia to kill cancer cells.

Another use of MNPs is to separate cells across a magnetic gradient by magnetophoresis. By targeting MNPs to specific cell types, those cells will preferentially take up the MNPs and magnetically label them. They can then be separated from non-labelled cells. This has applications in cell separation, sepsis treatment and even 3D-bioprinting.

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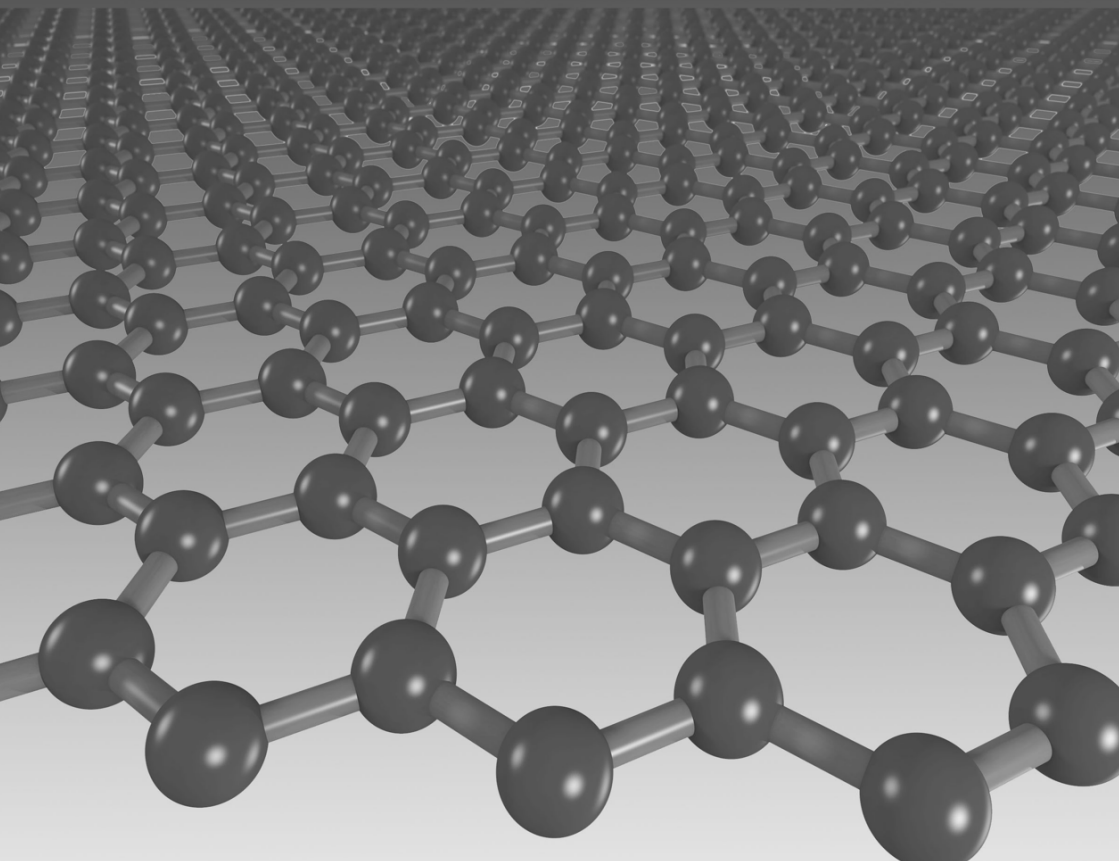
STUDENT TALKS – 3rd YEARS



[ST3.1] - Naturally Occurring van der Waal Heterostructures

Alexander Rakowski[1], Roman Gorbachev[2] and Sarah Haigh[1]

[1]School of Materials, University of Manchester, UK

[2]School of Physics, University of Manchester, UK

alexander.rakowski@manchester.ac.uk

Since the discovery of Graphene in 2004[1], numerous other 2D crystals have been isolated. Soon after the explosion in 2D research it was realised that one could layer these 2D crystals and thus create van der Waal Heterostructures. These heterostructures have exhibited a vast array on unique properties, and offer a route for applications such as transistors[2]. Yet the synthesis of these heterostructures is non-trivial and currently not scaleable. The existence of naturally occurring heterostructures would offer a route to the top down production of van der Waal heterostructures, new materials for the 2D library and possibly new physics. Here we present the characterisation of naturally occurring heterostructures using cross-sectional scanning transmission electron microscopy.[3]

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[ST3.2] - Protein Coating Determines the Cellular Responses in the Abdominal Cavity after Graphene Oxide Administration

Artur Filipe Rodrigues[1], Leon Newman[1], Dhifaf Jasim[1], Kostas Kostarelos[1] and Cyrill Bussy[1]

[1]Nanomedicine Lab, Faculty of Biology, Medicine and Health & National Graphene Institute, The University of Manchester, United Kingdom,

artur.rodrigues@postgrad.manchester.ac.uk

The implementation of graphene oxide (GO) in commercial products demands a thorough understanding of its potential health effects[1]. Our group has shown that small GO flakes (s-GO, < 1 μm) do not trigger significant inflammation after intraperitoneal (i.p.) injection[2], however the *in vivo* impact of large GO flakes (l-GO, 1 to 20 μm) was still not clear[3]. Here, we revealed that l-GO had similar impact to s-GO on the abdominal mesothelium after i.p. injection. In addition, we demonstrated that a bio-corona can modulate the surface reactivity of GO flakes towards biological systems by showing that s-GO elicited greater recruitment of monocytic immune cells when pre-dispersed in 5% dextrose compared to 0.5% BSA/saline. These results highlight the importance of physicochemical features including absorbed molecules when assessing the biological impact of GO flakes.

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[ST3.3] - Scalable Methods for the Encapsulation of Graphene in Hexagonal Boron Nitride

D. G. Purdie[1], D. De Fazio[1], A. K. Ott[1], P. Braeuninger[2], D. Johnstone[3], P. Midgley[3]. S. Hofmann[2], A. C. Ferrari[1], I. Goykhman[1], A. Lombardo[1]

[1]Cambridge Graphene Centre, University of Cambridge, UK

[2] Department of Engineering, University of Cambridge, UK

[3] Department of Materials Science and Metallurgy, UK

dp421@cam.ac.uk

Single Layer Graphene (SLG) encapsulated in h-BN is a widely investigated van der Waals heterostructure both for fundamental physics and applications due to its exceptional electronic properties[1]. Several challenges remain before encapsulated graphene can be achieved over large areas, including the move towards scalable material synthesis techniques such as chemical-vapour deposition (CVD)[2], as well as the development of methods to achieve atomically clean interfaces over large areas[3]. Here we report high mobility in CVD-grown SLG deposited on SiO_2 by wet transfer, and subsequently encapsulated in exfoliated h-BN, with values up to 60,000 $cm^2V^{-1}s^{-1}$ achieved at room temperature. In addition, methods that enable the complete removal of contamination blisters over the entire dimensions of encapsulated samples will be reported. These results represent significant steps towards the goal of scalable synthesis of ultra-high mobility graphene.

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[ST3.4] - Graphene Aerogels by Room Temperature Freeze Casting

Gabriel Casano[1], Mark Bissett[1], Suelen Barg[1], Ian Kinloch[1] and Brian Derby[1]

[1]School of Materials, University of Manchester, UK

gabriel.casanocarnicer@postgrad.manchester.ac.uk

Aerogels are low density, solid, porous 3D structures with numerous possible applications. They can be used to leverage graphene's exceptional properties in areas such as sensing, environmental remediation or energy storage[1]. Freeze casting is a versatile technique for aerogel production, allowing good morphology control. Traditional freeze casting relies on water as the solvent, limiting it to graphene oxide (GO) as the source material, which carries some inherent disadvantages in terms crystalline quality and processing conditions available[2]. Last year we reported a new freeze casting method which allows for the use of pristine graphene sheets as well as sublimation at room temperature by using suitable solvents[3]. We will now present recent progress in expanding the range of solvents available for this technique.

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[ST3.5] - Optical properties of MoS_2 quantum discs for highly efficient tuneable emitters

Georgia Kime[1], Nigel Pickett[2], Ombretta Masala[2], Steven Daniels[2], Paul O'Brien[3] and David Binks[1]

[1] Photon Science Institute, School of Physics and Astrophysics, University of Manchester, UK

[2] Nanoco Technologies Ltd, Nanoco Group PLC, UK

[3] School of Chemistry & School of Materials, University of Manchester, UK

georgia.kime@manchester.ac.uk

MoS_2 'quantum discs' are atomically thin and a few nanometers in diameter, and are candidates as stable, non-toxic emitters for use in displays and biological imaging[1]. Hydrothermal synthesis allows for scalable fabrication and acid treatment of these discs, producing large quantities of material[2] with quantum yields up to 90%. Quantum confinement modifies the optical properties of these quantum discs relative to those of larger sheets, which are explored here using steady-state and time-resolved absorption and photoluminescence studies. In particular, strong blue emission is observed in contrast to the weak red emission typically seen for larger MoS_2 monolayers.

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[ST3.6] - Towards substrate engineering of graphene-silicon Schottky diode photodetectors

H. Selvi[1], N. Unsuree[1], M.P. Halsall[1,3], E.W. Hill[2], P. Parkinson[3,4] and T.J. Echtermeyer[1,2,3]

[1]School of Electrical & Electronic Engineering, University of Manchester, Manchester, UK

[2]National Graphene Institute, University of Manchester, Manchester, UK

[3]Photon Science Institute, University of Manchester, Manchester, UK

hakan.selvi@manchester.ac.uk

Graphene-silicon (GS) junctions provide highly promising platforms for photodetection applications due to their broadband operating regime[1], high responsivity[2] and fast response time[3]. In this work, we investigated the effect of an intentionally present or inadvertent interfacial native oxide layer on the optoelectronic characteristics of the diode. Further, we show the importance of diffusion currents in the bulk of the substrate. The combined effect of drift and diffusion currents causes a strong saturation of the photoresponse with increasing reverse bias, leading to a constant responsivity. Obtained results demonstrate the effect of the substrate on the opto-electronic properties and performance of GS photodetectors and contribute to paving the way for engineering the GS Schottky platforms for customized photodetection applications.

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[ST3.7] - Topological Tight-Binding Models from Non-Trivial Square Roots

Jake Arkinstall[1] and Henning Schomerus[1]

[1]Physics Department, Lancaster University, United Kingdom

jake.arkinstall1@lancaster.ac.uk

We describe a versatile, algebraic mechanism that provides tight-binding models with an enriched, topologically nontrivial band structure. This mechanism illustrates hidden connections between different quantum systems, and allows us to ask strange questions such as "*What is the square root of a quantum system?*" and "*How do the properties of a lattice translate to properties of its square root?*". This provides a condensed matter analogy to the passage from a Klein-Gordon equation to a Dirac equation,[1] and reveals a new approach to finding, and designing, quantum systems with bespoke band-structures and topological properties. Alongside the theoretical framework,[2] we present an example lattice with topological characteristics and its experimental realisation in a photonic setting.[3]

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[ST3.8] - Superconductivity in Atomically Thin $NbSe_2$

John Birkbeck[1], I.V. Grigorieva[1] and A. Geim[1]

[1]School of Physics and Astronomy, University of Manchester, United Kingdom

john.birkbeck@postgrad.manchester.ac.uk

Superconductivity in two dimensions (2D) has been a topic of interest and debate for many decades. Previously, the study of superconductivity in this regime was limited to either evaporated or epitaxially grown thin films. Evaporated samples are typically highly disordered amorphous or granular films, while epitaxial layers are strongly coupled to the substrate, influencing their 2D behaviour[1]. Recently, mechanical exfoliation has provided a new pathway to obtain highly crystalline, defect-free superconductors down to monolayer thickness[2]. In addition to the relative ease of fabrication it is possible to isolate single layers on any desired substrate, therefore minimising its effect. Here we focus on $NbSe_2$ which has been exfoliated and encapsulated in an inert atmosphere. We study the evolution of the superconducting energy gap (Δ) with number of layers by fabricating planar tunnel junctions using hexagonal boron nitride as a thin insulating barrier.

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[ST3.9] - Electrochemical and QCM analyses of biocatalysts adsorbed on carbon nanomaterials

Joseph Butcher[1] and Christopher F. Blanford[2]

[1]Manchester Institute of Biotechnology and School of Chemistry, University of Manchester, UK

[2]Manchester Institute of Biotechnology and School of Materials, University of Manchester, UK

joseph.butcher@postgrad.manchester.ac.uk

The stable activity of proteins interfaced with nanomaterials is vital to the development of biofuel cells, biosensors and theranostic devices. The electrochemical quartz crystal microbalance is a tool to simultaneously observe mass, stiffness and catalytic activity of adsorbed protein films in real time. Here we used graphene oxide-coated QCM sensors to monitor the effects of adsorption and potential cycling on adlayers of bilirubin oxidase, a model oxygen-reducing bioelectrocatalyst, and also the production of heme-loaded recombinant honeybee silk films for oxygen reduction.[1,2] This work feeds into the overall project goal of interfacing proteins with graphene for combined sensing and drug release.

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[ST3.10] - Comparison of Graphene Materials for Supercapacitor Electrodes

Lewis Le Fevre[1,2]

[1]School of Chemistry, University of Manchester, UK

[2]School of Electrical and Electronic Engineering, University of Manchester, UK

lewis.lefevre@postgrad.manchester.ac.uk

Research into graphene supercapacitors is undergoing a large increase in growth due to its properties. Reports on ‘graphene’ supercapacitors use materials produced through various methods. Currently, the effect the production method has upon the capacitance hasn’t been compared meaning comparison of literature is not possible. In this work we compared several graphenes. These include “pure” graphenes which are liquid phase exfoliated graphene, graphene nanoribbons, anodic and cathodic electrochemical exfoliated graphene. Also included were “modified” graphenes which include graphene oxide and reduced graphene oxide. It was observed that graphene oxide exhibited the highest specific capacitance due to the oxygen groups giving a pseudocapacitive response. However, its intrinsically high resistance means a conductive additive is required for high rate capability.

[ST3.11] - Graphene Micro-Electrodes to Study the Effect of Amyloid Proteins on Neuronal Function

Philippa Hooper[1,2], Pranoti Kshirsagar[3], Claus Burkhardt[3], Antonio Lombardo[2] and Gabriele Kaminski Schierle[1]

[1] Department of Chemical Engineering and Biotechnology, University of Cambridge, Philippa Fawcett Drive, Cambridge, UK

[2] Cambridge Graphene Centre, University of Cambridge, 9 JJ Thomson Avenue, Cambridge, UK

[3] Natural and Medical Sciences Institute, 55 72770 Reutlingen, Germany

pjh200@cam.ac.uk

The ~10 nm protein aggregates that occur in neurodegenerative diseases like Alzheimer's disease can be imaged using super-resolution microscopy [1]. To understand the effects of protein aggregation and propagation on neuronal firing, it is desirable to combine the super-resolution imaging with electrical recordings made using microelectrode arrays (MEAs) [2]. The microelectrodes should be transparent for use on the inverted microscopes. Graphene, combines excellent optical transparency, good electrical conductivity and bio-compatibility and is therefore ideal for transparent MEAs [3]. Here, we report on graphene-based MEAs, fabricated from large area graphene grown by chemical vapour deposition. The graphene MEAs are used to record action potentials from cultured iPSC cardiomyocytes. This work paves the way to understanding the physiological effects of protein aggregates on neurodegenerative diseases.

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[ST3.12] - Two-band tight-binding model of indium selenide laminates

Samuel Magorrian[1], Viktor Zólyomi[1], and Vladimir Fal'ko[1]

[1]National Graphene Institute, University of Manchester, United Kingdom

samuel.magorrian@manchester.ac.uk

We present a two-band tight-binding model of InSe[1,2] laminates based on the band-edge states of the monolayer and interlayer hoppings between them. The model is parameterised from the dispersion of bulk-InSe, calculated using density functional theory, where the band gap is corrected with reference to the underlying monolayer states. The model represents the different possible stacking orders and interlayer distances in terms of the values of the hopping parameters. We predict a larger gap for arbitrarily rotated heterostructure interfaces than for an equivalent single crystal with the same number of layers. The model can easily be extended to consider the other hexagonal III-VI materials and interfaces between them, and we discuss the properties of InSe/GaSe heterostructures.

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[ST3.13] - Vertically oriented electrode structures with $LiCoO_2$

Simon Engelke[123], Michael de Volder[1] and Clare Grey[2]

[1]NanoManufacturing, Institute for Manufacturing, University of Cambridge, UK

[2]Department of Chemistry, University of Cambridge, UK

[3]Graphene Centre, University of Cambridge, UK

se357@cam.ac.uk

For future batteries an increase of capacity and rate are desired to enable for instance electric cars with greater range and faster charging. One way to increase the capacity are thicker electrodes, but simply increasing the electrode thickness is inadequate for lithium-ion batteries as diffusion of Li through the battery electrode then becomes rate limiting. This is especially the case for thin and 2D materials, which preferentially stack parallel to the current collector and essentially form diffusion barriers. Here, we present our work on synthesizing hexagonal platelet building blocks made of the cathode material $LiCoO_2$. In the future, we aim to functionalize and coat (e.g. thin layer of carbon), and self-assemble them vertically. To enable higher throughput, individual building blocks are to be pre-assembled into stacks and then assembled further into macroscopic structures, ideally with Roll-to-Roll (R2R) coating processes currently used in industry. Also other layered 2D materials will be considered as building blocks in future. Diffusion can be measured with PFG NMR

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[ST3.14] - Inkjet Printing of Black Phosphorus for Photonics and Optoelectronics

Tom Albrow-Owen, Guohua Hu, Richard C. T. Howe, Zongyin Yang, Tien-Chun Wu and Tawfique Hasan

Cambridge Graphene Centre, University of Cambridge, Cambridge, CB3 0FA, UK.

ta374@cam.ac.uk

Black Phosphorus (BP) has recently emerged as an interesting two-dimensional material with respect to photonic and optoelectronic applications, due to its high carrier mobility and thickness dependent bandgap encompassing telecommunications wavelengths[1,2]. Options for depositing BP, however, are limited, due to its instability under ambient conditions[3]. Here, we demonstrate a stable, liquid-phase exfoliated BP ink that can be reliably printed, enabling scalable, low-cost device production. Our ink dries rapidly, minimizing ambient exposure, and affords deposition with excellent consistency (<2% variation) and spatial uniformity (<3.4% variation) onto a range of untreated substrates. Furthermore, encapsulation in parylene-C provides long-term (>30 days) stability against photo-oxidation. We integrate our printed BP thin-films into a visible to near-infrared photodetector, exhibiting high responsivities, and an ultrafast laser, as a saturable absorber, demonstrating long-term stability under intense irradiation. Our work demonstrates the viability of BP as a functional ink platform with significant potential for printed devices.

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[ST3.15] - Spray coating transparent conductors on 3-dimensional surfaces for a graphene based capacitive touch device

Tian Carey[1], Chris Jones[2], Felice Torrisi[1]

[1]Cambridge Graphene Centre, University of Cambridge, United Kingdom.

[2]Novalia Ltd, Impington, Cambridge, CB24 9N, UK

tc419@cam.ac.uk

Electronics on three dimensional (3D) curved surfaces is a rapidly emerging field with applications in communication and automotive industries. Electronic devices can be printed or coated on 3D surfaces, enabling fully conformable electronics. Spray coating is highly suited to the large scale production of conductive films while graphene inks are highly promising for applications in printed electronics such as in large area transparent conductive films (TCFs)[1]. In this work a graphene ink was produced by liquid phase exfoliation[2] of graphite in ethanol/PEDOT:PSS solutions. Fundamental spray parameters such as temperature, surface tension and boiling point were investigated in order to optimise the production of morphologically uniform films on polyethylene terephthalate (PET) substrates[3]. We then demonstrated spray coating of electrically and optically uniform graphene electrodes on a Perspex sphere enabling a capacitive touch-sensitive and transparent 3D device.

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[ST3.16] - High Moblity Graphene Devices on Yttrium Iron Garnet Thin Films

Y. Li[1,2], M. Amado[2], A. Lombardo[1], A. C. Ferrari[1] and J. W. A. Robinson[2]

[1]Cambridge Graphene Centre, University of Cambridge, UK

[2]Department of Materials Science and Metallurgy, University of Cambridge, UK

yl539@cam.ac.uk

Utilizing magnetic two-dimensional (2D) materials for spintronic applications can potentially lead to low power consumption and high performance electronic devices for spin-electronics[1]. Hints of inhomogeneous proximity-induced magnetism in single layer graphene (SLG) on the ferromagetic insulators yttrium iron garnet (YIG)[2] and europium sulphide (EuS)[3] have been reported[3] albeit with a reduced mobility of less than 10,000 cm^2V^{-1} at 2 K. Here we report a systematic investigation of the electronic properties of exfoliated SLG on epitaxial thin films of YIG with mobilities that exceed 40,000 cm^2V^{-1} at 9 K and 20,000 cm^2V^{-1} at 300 K.

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[ST3.17] - Protecting CVD Graphene By ALD Encapsulation; The Effect Of Graphene Grain Boundaries, Atmospheric Doping And Polymer Residues

Zenas Van Veldhoven[1,2], Jack Alexander-Webber[1], Abhay A. Sagade[1], Philipp Braeuninger[1] and Stephan Hofmann[1]

[1] Department of Engineering, University of Cambridge, UK

[2] Cambridge Graphene Centre, University of Cambridge, UK

zav20@cam.ac.uk.

Chemical vapour deposited (CVD) graphene is typically polycrystalline and unintentionally doped by polymer residues and atmospheric dopants[1]; all of which is unfavorable for the control of electronic properties over large areas. Encapsulating CVD graphene by atomic layer deposition (ALD) of Al_2O_3 is a promising approach to integrated manufacturing of graphene-based devices, protecting it from the environment and improving long term stability[2]. We investigate the electronic properties of two types of CVD graphene where the grain size differs by an order of magnitude, before and after encapsulation with ALD Al_2O_3. This decouples the electronic effects of atmospheric and substrate doping from those of grain boundaries and polymer residues. We find that additional grain boundaries not only reduce carrier mobility but also significantly reduce the effectiveness of the ALD encapsulation[3], thus highlighting the manifold advantages of microstructure control in large area CVD graphene.

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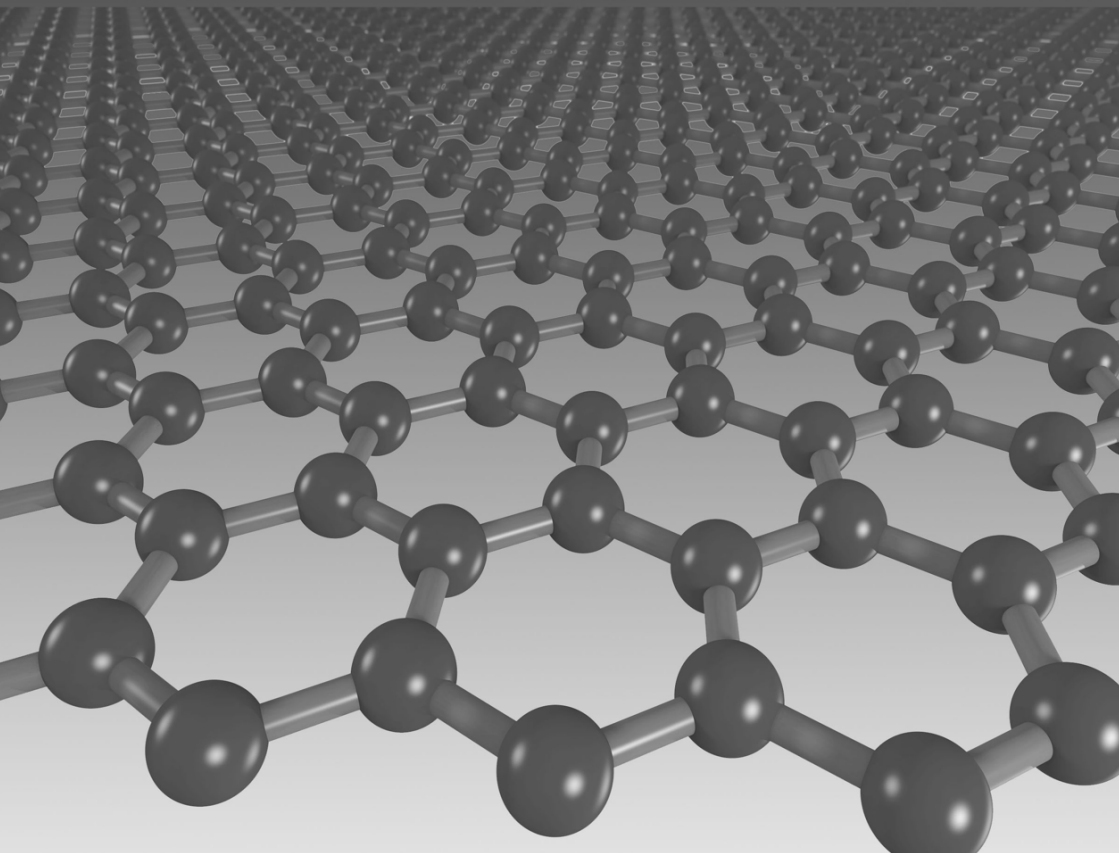
STUDENT POSTERS – 2nd YEARS



[SP2.1] - Characterisation of Multilayer Graphene in the Terahertz Spectral Region

Adam Shorrock[1], Alex Jones[2], and Darren Graham[1]

[1]School of Physics and Astronomy & Photon Science Institute, The University of Manchester, United Kingdom,

[2]School of Chemistry, Manchester Institute of Biotechnology & Photon Science Institute, The University of Manchester, United Kingdom

adam.shorrock@postgrad.manchester.ac.uk

Since its initial isolation in 2004, graphene has become of increasing interest in the scientific community due to its unique optical and electronic properties. Furthermore, the observation of a unique electronic spectrum and quasi-relativistic charge carrier transport make graphene a promising material for use in optoelectronic applications.[1] With the commercial viability of graphene becoming ever more apparent, terahertz time-domain spectroscopy (THz-TDS) has proved to be a reliable method of finding important figures of merit of a material, with distinct advantages over traditional contact methods.[2] We report initial results of the characterisation of chemical vapour deposition (CVD)-grown graphene on sapphire in the terahertz spectral region, including absorption coefficients, refractive indices and conductivities as a function of the number of layers.

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[SP2.2] - Coupling to Layered Heterostructures with Extreme Nano-Plasmonic Cavities

Alex Casalis de Pury[1,2], Marie-Elena Kleemann[1], Ruizhi Wang[3], Dean Koos[1], Christoph Grosse[1], Jeremy J. Baumberg[1]

[1] Cavendish Laboratory, University of Cambridge, UK

[2] Cambridge Graphene Centre, University of Cambridge, UK

[3] Department of Engineering, University of Cambridge, UK

alc99@cam.ac.uk

The extreme optical confinement in nanoparticle-on-mirror (NPoM) plasmonic geometries has proven enormously productive in exploring light-matter interactions of nanoscale emitters. Recently we showed that strong coupling is achievable at room temperature with several layers of WSe_2, the result of plasmons interacting with strongly-bound excitons.[6] However a full description of these extreme nanocavities seems to depend on atomic-scale details of their morphology. We thus build a robust NPoM system using hBN monolayer spacers, which allows us to explore in detail the confinement of light in 2D heterostructures, for use in myriad optoelectronic devices.

As a foundation, we use CVD-deposited monolayer hBN and compare our findings with current understanding of NPoM plasmonics, including a full circuit model. Reliable identification of dark field scattering resonances due to NP faceting[3], spacer thickness, and mirror/spacer morphology is seen.

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[SP2.3] – Synergy of cellulose nanocrystals and graphene

Cyan Williams[1], Giulia Guidetti[2], Guohua Hu[3], Tawfique Hasan[3] and Silvia Vignolini[2]

[1]Department of Chemistry, University of Cambridge, UK, caw74@cam.ac.uk

[2] Department of Chemistry, University of Cambridge, UK

[3] Cambridge Graphene Centre, Department of Engineering, University of Cambridge, UK

Green, environmentally friendly materials are greatly increasing in importance. Graphite and cellulose are organic natural materials; cellulose is the most abundant bio-polymer on the planet and crystalline graphite is produced by the pressure and temperature of the earth's crust. Acid hydrolysis of cellulose isolates crystalline nanorods called cellulose nanocrystals (CNC). These rods self-assemble into a chiral nematic structure producing structural colour. Graphene can be produced via liquid phase exfoliation of graphite in water with the use of an exfoliant/dispersant. Combination of graphene and CNCs can be achieved in many different ways. CNCs can be used to exfoliate graphite and disperse graphene. Graphene can be used to produce a black background to emphasise the colour of the transparent CNC composites. Based on these promising results and compatibility, I am investigating how these two materials can enhance each other's advantageous properties.

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[SP2.4] - High-resolution EDX Spectral Imaging in Liquids

Daniel J. Kelly[1], Mingwei Zhou[2,3], Nick Clark[3], Edward A. Lewis[1], Sarah J. Haigh[1,3] and Roman V. Gorbachev[2,3]

[1]School of Materials, University of Manchester, U.K.

[2]School of Physics and Astronomy, University of Manchester, U.K.

[3]National Graphene Institute, University of Manchester, U.K.

daniel.kelly-5@postgrad.manchester.ac.uk

The ability to study samples in liquid using scanning transmission electron microscopy (STEM) and energy dispersive X-ray spectroscopy (EDX) has been enabled by the development of *in situ* liquid cells (LC). A liquid cell consists of a solution encapsulated by electron beam transparent windows, conventionally silicon nitride is the material of choice, which hermetically seal the liquid from the high vacuum of the STEM and causes minimal scattering of the beam[1]. Graphene has been looked to as the ultimate window material due to its atomic thickness and high mechanical strength[2]. Here we present a new form of graphene-based liquid with engineered dimensions and its ability to achieve higher resolution EDX spectral imaging than has previously been shown for liquid STEM[3].

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[SP2.5] - New Semiconducting Chalcogenides for Electronic and Optoelectronic Applications

Daniel. J. Terry and Roman Gorbachev[1]

[1]National Graphene Institute, University of Manchester, UK,

daniel.terry-3@postgrad.manchester.ac.uk

With the isolation of graphene in 2004 has come the discovery of a multitude of other 2D materials with a wide range of properties. However, many 2D materials are unstable in ambient conditions, degrading due to reactions with oxygen and water[1]. The aim of this project is to solve the aforementioned problems by using a new fabrication technique in which 2D materials can be isolated and processed in an inert atmosphere. The aim of this is to search for new semiconducting materials with unique properties, novel devices with better characteristics and new physical phenomena that are likely to emerge along the way. Initially, the optical properties of atomically thin GaSe layers encapsulated in BN have been studied, providing foundation for the investigation of their optoelectronic properties.

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[SP2.6] - Development of the next-generation graphene-based electronic materials

Dian Yi[1], Konstantin Novoselov[1] and Andrey Kretinin[2]

[1]School of Physics and Astronomy, University of Manchester, United Kingdom

[2]School of Materials and Physics and Astronomy, University of Manchester, United Kingdom

dian.yi@postgrad.manchester.ac.uk

Increasing circuit density and miniaturization of the modern electronics make the highly efficient heat removal and dissipation ever more critical for reliable operation of the electronic devices and systems[1,2]. As the first 2D material discovered, Graphene has been realised that it possesses an extremely high thermal conductivity virtually unmatched by any other material[3]. Due to this remarkable enhancement in thermal conductivity the graphene-based polymer composites are being considered as the next generation thermal interface materials, thermal pads, heat spreading coatings, packaging and phase-change materials. Within this project, characterization techniques for 2D materials of various degrees of functionalization and formulated 2D material-based composites are developed and their mechanical thermal and electrical properties are studied.

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[SP2.7] - A“QSAR” Approach Leading To The Identification Of Enhanced Novel Graphene Exfoliants

Fiona Porter[1], Kane W. J. Heard[1], Cian Bartlem[2], Junru Zhang[1], Adam Parry[1], Christopher D. Williams[3], Mark S. Little[1], Flor R. Siperstein[3], Peter Quayle[1], Aravind Vijayaraghavan[2] and Stephen G. Yeates[1].

[1]School of Chemistry, the University of Manchester, UK

[2]School of Materials and National Graphene Institute, the University of Manchester, UK

[3]School of Chemical Engineering and Analytical Science, the University of Manchester, UK

fiona.porter@manchester.ac.uk

Commercially available, functionalised, polycyclic aromatic hydrocarbons have been used as graphene exfoliants and dispersants in aqueous conditions, however such systems have not been optimised in terms of their exfoliation efficiency.[1] Despite instances in the literature where pyrene derivatives have been bought for use, either as direct exfoliants or as building blocks to synthesise novel stabilisers, their structures, and the experimental conditions used for exfoliation, are so different that a comparison of their performance based on structural characteristics would not be relevant.[2,3] Herein we describe a “quantitative structure-activity relationship” approach leading to the identification of modified exfoliants for the stabilisation of aqueous rGO dispersions. Our results provide an insight into how structural features within an exfoliant affect its interaction with the graphene surface and aqueous environment.

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[SP2.8] - Multiplexing 2D Devices.

Jack Oliver Batey[1,2] and Charles Smith[1]

[1]Cavendish Laboratory, University of Cambridge, United Kingdom

[2]Cambridge Graphene Centre, University of Cambridge, United Kingdom

job28@cam.ac.uk

Investigating quantum behaviour of carriers often requires cryogenic conditions achieved by a dilution refrigerator. Achieving a base temperature in the tens of milikelvin limits the number of electrical contacts which can be used in the fridge, which in turn limits the number of devices which can be tested. In addition, changing samples can take several days. Building upon existing work[1,2], a GaAs multiplexer is used to address up to 256 devices made form 2D materials at cryogenic temperatures. A proof of principle experiment uses the multiplexer to operate 256 GFET devices at 4.2K and obtain statistical variation of carrier concentrations and mobilities. Any anomalous results are subject to Raman mapping to identify scattering mechanisms in the graphene sheet. Future work will use graphene as electrodes to contact nanoparticles, in order to perform a statistical study of graphene-nanoparticle interactions and quantum transport in molecular scale devices.

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[SP2.9] - Electroluminescence of Interlayer Excitons in van der Waals Heterostructures

James Howarth[1], Aleksey Kozikov[1], Johannes Binder[2,3], Maciej Molas[2], Marek Potemski[2], Konstantin Novoselov[1]

[1]School of Physics and Astronomy, University of Manchester, Manchester, UK

[2]Laboratoire National des Champs Magnetiques Intenses, Grenoble, France

[3]Faculty of Physics, University of Warsaw, Warsaw, Poland

james.howarth-3@postgrad.manchester.ac.uk

We present experimental results of electroluminescence measurements of spatially indirect excitons [1] formed in MoS_2/WSe_2 and MoS2/BN/WSe_2 based light emitting, van der Waals heterostructures. The studied light emitting diodes [2] are fabricated by vertically stacking graphene, few layer hBN and monolayer transition metal dichalcogenides.

We observe electrically induced photon emission of interlayer excitons and investigate thoroughly the dependence of these excitons on bias voltage, thickness of hBN between MoS_2 and WSe_2 and temperature. We find the mechanism of charge carrier injection differs depending on bias voltage and on thickness of the hBN spacer, leading to interesting effects in electroluminescence.

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[SP2.10] - Interactions between supramolecular metal-organic capsules and 2d graphene and the effect of guest encapsulation for sensory applications.

Jason Deacon[1,2], Shouhu Liu[2], Tawfique Hasan[1] Antonio Lombardo[1] and Jonathan Nitschke[2]

[1]Cambridge Graphene Centre, Cambridge University, UK

[2]Chemistry Department, Cambridge University, UK

jtd27@cam.ac.uk

Metal-organic capsules[1] participate in host-guest interactions through two mechanisms, in a dynamic environment the ligand is displaced and the guest enters the capsule and becomes trapped when the ligand is regained, this leads to an affinity difference where the guest may interact strongly with the forces in the capsule and thus be retained, or weakly and can be ejected out in the same manner.

The second mechanism is the guest being small enough to enter the pores, interact and leave. The latter has the advantage of working in the solid state, which should be able to be used as a sensing device via interfacial charge transfer which can be heavily investigated through CVD graphene interactions with a pyrene cage or inkjet printed graphene[2] based on the surfactants used[3].

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[SP2.11] - Microfluidic approach to optimize liposome drug encapsulation

Leonidas Gkionis[1], Harmesh Aojula[1], Lynda Harris[1], and Annalisa Tirella[1,2]

[1] Division of Pharmacy and Optometry, School of Health Sciences, University of Manchester, United Kingdom

[2] NorthWest Centre of Advanced Drug Delivery (NoWCADD), School of Health Sciences, Medicine and Health, University of Manchester, UK

leonidas.gkionis@postgrad.manchester.ac.uk

Amphiphilic macromolecules (such as natural lipids), when in presence of water or other selective solvents and above a critical concentration, tend to self-assemble in highly ordered structures. In the case of natural phospholipids, usually associated with cholesterol, a vesicular hollow structures is formed, and these structures are called liposomes[1]. Over the last 30 years liposomes have been used in a wide range of pharmaceutical and biomedical applications e.g. drug delivery, diagnostic, theranostic[2]. In this study, different preparative methods will be evaluated to prepare liposomes encapsulating hydrophilic drug(s), controlling their size and its distribution. We here present the results of the 'standard' steps of thin-film hydration[3]. A microfluidic system will be further used as an alternative method to prepare such liposomes; with the advantage of a fine-tuning of manufacturing parameters (e.g. temperature, flow rate) this method will allow a better control over liposome size, drug encapsulation efficiency and optimisation of the manufacturing steps e.g. sterile preparation, easy scale-up.

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[SP2.12] - Graphene/MoS_2 junctions for applications in high frequency electronics

Muraleetharan Boopathi[1], David G. Purdie[1], Andrea C. Ferrari[1] and Antonio Lombardo[1]

[1]Cambridge Graphene Centre, University of Cambridge, Cambridge CB3 0FA, UK

mb2058@cam.ac.uk

The deterministic stacking of two-dimensional crystals with atomically-clean interfaces allows assembling novel electronic devices with tailored functionalities resulting from the interaction between the layers[1]. This is particularly interesting for high frequency electronics and devices such as resonant tunneling diodes have been demonstrated[2]. Here we report on graphene-MoS_2 junctions assembled by a dry transfer method where multilayer MoS_2 crystals are deposited onto single layer graphene. In-plane and vertical transport is investigated at room and low temperature. Such results pave the way for the demonstration of more complex devices such as heterojunction transistors[3].

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[SP2.13] - Ionic Transport Across Graphene Membranes

Mustafa Caglar[1], Michael Walker[1], Robert S. Weatherup[2], Stephan Hofmann[2], and Ulrich F. Keyser[1]

[1]Cavendish Laboratory, University of Cambridge, J.J. Thomson Avenue, Cambridge, UK.

[2]Department of Engineering, University of Cambridge, Cambridge, UK.

mc934@cam.ac.uk

By studying the concentration driven diffusion of positive and negative ions across porous 2D membranes of graphene and hexagonal Boron Nitride (h-BN) we demonstrate cation selectivity. Using the current-voltage characteristics of graphene and h-BN monolayers separating reservoirs of different salt concentrations we use the reversal potential to determine selectivity. We demonstrate that negative surface charge gives rise to cation selectivity by tuning the Debye screening length. Surprisingly, h-BN and graphene membranes show similar characteristics strongly suggesting a common origin of selectivity in aqueous solvents. We also demonstrate that the cation flux can be increased by using ozone to create additional pores in graphene whilst maintaining excellent selectivity and we show how the selectivity can be tuned to work towards anion selectivity. We discuss opportunities to exploit our 2D membranes for applications including osmotic power conversion.

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[SP2.14] - Pillared MXenes for high capacitance supercapacitors

Phil Maughan[1] Harry Hoster[2], Sarah Haigh[3] and Nuno Bimbo[1]

[1] Department of Engineering, Lancaster University, UK

[2] Department of Chemistry, Lancaster University, UK

[3] School of Materials, University of Manchester, UK

p.maughan@lancaster.ac.uk

Two dimensional transition metal carbides, MXenes, are a family of materials which have shown promise as supercapacitor electrodes. Unlike carbon electrodes, which rely on electric double layer capacitance to store charge, MXenes show pseudocapacitive charge storage, which has led to some of the largest volumetric capacitance values ever reported[1]. However, the performance can be further improved by increasing the spacing between the MXene nanosheets[2]. Pillaring is a technique used to introduce pores between sheets of layered clays to substantially increase surface areas, and allows fine control of the size of the pores created, down to the angstrom level[3]. By using these pillaring techniques, this project aims to not only improve the performance of MXenes as electrode materials, but also allow the interplay between the pore size, electrolyte ion size and electrochemical characteristics to be studied.

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[SP2.15] - Mechanochemical Synthesis of 2D Materials

Richard Stevenson[1], Steve Edmondson[2] and Guillaume De Bo[1]

[1]School of Chemistry, University of Manchester, Oxford Road, Manchester, UK, M13 9PL,

[2]School of Materials, University of Manchester, Oxford Road, Manchester, UK, M13 9PL

richard.stevenson@postgrad.manchester.ac.uk

Since the discovery of graphene just over ten years ago 2D materials have received a large amount of attention. However, unlike their 1D and 3D counterparts, the chemical synthesis of 2D materials remains a challenge[1]. Mechanical force is a largely untapped method of chemical activation despite its ability to distort, bend and stretch chemical bonds[2]. By synthesising a mechanoresponsive molecule (a 'mechanophore') and embedding it in a polymer, precise control of bond activation can be achieved. Polymer brushes are prepared by the dense grafting of polymers onto a surface which produce extended chains and a steric strain on the polymer resulting in a large force on the chemical bonds at the bottom of the chain[3]. This project aims to use this localised force to trigger mechanochemistry at the surface resulting in the fabrication of 2D materials.

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[SP2.16] - Inkjet Printing of 2D Crystal Inks on Different Substrates

Robyn Worsley[1], Jarrid Wittkopf[2], Robert Cri Ionescu[2], Roberto Silveira[2], Ning Ge[2], Helen Holder[2] and Cinzia Casiraghi[1]

[1]School of Chemistry, University of Manchester, United Kingdom,

[2]HP, Palo Alto, United States of America

robyn.worsley@postgrad.manchester.ac.uk

Biocompatible, inkjet-printable, water-based 2D crystal inks have been recently developed[1]. These inks can be used for several applications, for example in smart packaging, where thinner, lighter, cheaper and easy-to-integrate components are needed. This requires the printability and properties of the inks to be tested on a wide range of substrates used for such applications.

This project investigates the deposition of the inks onto different technologically significant substrates. In particular, three substrates have been investigated: silicon, paper for printed electronics (Nano P60) and a specialised paper provided by HP. These substrates were found to vary dramatically in both surface roughness and wettability, affecting the continuity and electrical properties of the printed structures.

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[SP2.17] - Edge Modes in Graphene Superlattices

Rory Brown[1], Niels Walet[1] and Francisco Guinea[1,2]

[1] School of Physics and Astronomy, University of Manchester, Manchester, M13 9PY, UK

[2] Imdea Nanoscience, Faraday 9, 28015 Madrid, Spain

rory.brown-3@postgrad.manchester.ac.uk

It has long been established that for certain geometries a honeycomb lattice supports electronic states localised at the edges. We analyse the stability of such edge modes in a graphene superlattice, following recent experimental work on gapped graphene systems [1]. Existing models of the superlattice produce dispersive bands but cannot explain why the system is a good conductor [2]. We show that the electronic sub-bands possess non-trivial integer Chern numbers, effectively turning each valley in monolayer graphene into a topological insulator. Supported by numerical calculations of the electronic structure of graphene nanoribbons, we show that edge states are a generic feature of lattices with zigzag edges. For realistic superlattice sizes the electronic spectrum becomes gapless even in the presence of a large bulk gap, allowing significant transport in superlattice devices.

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[SP2.18] - Diffusion Monte Carlo studies of semiconducting energy gaps

Ryan J. Hunt[1], M. Szyniszewski[1], N. D. Drummond[1] and R. Maezono[2]

[1]Department of Physics, Lancaster University, United Kingdom

[2] Japan Advanced Institute of Science and Technology (*JAIST*), University at Nomi, Japan

r.hunt4@lancaster.ac.uk

Accurate determination of the excited-state properties of atoms, molecules and solids is an important goal for modern theoretical and computational physics. We have shown that quantum Monte Carlo (QMC) methods[1] are capable of addressing this goal in a wide array of circumstances. We will present the results of studies on model systems, atomic and molecular systems, two-dimensional materials, and bulk solids. Particular emphasis has been placed on determining best-practices in carrying out excited-state QMC calculations – care is needed here, as one loses the crutch of any general variational principle[2]. Finite size effects currently limit the applicability of QMC, these are significant in excited state calculations, and we will discuss the physics behind these effects (and their corrections) in 2D systems.

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[SP2.19] - Graphene-based Membranes for Sustainable Desalination

Sebastian Leaper[1], Bilal Faki[2] and Patricia Gorgojo[2]

[1]School of Chemical Engineering and Analytical Science, University of Manchester, UK

sebastian.leaper@postgrad.manchester.ac.uk

Graphene oxide (GO) was functionalised with (3-Aminopropyl)-triethoxysilane (APTS) and was added in varying quantities to PVDF/DMF solutions. These were then cast into membranes using non-solvent-induced phase inversion. The membranes were tested for seawater desalination *via* air-gap membrane distillation (AGMD). In all cases, the addition of GO or f-GO resulted in increased permeate flux compared to nascent PVDF. Up to a 16 % increase was achieved with 1 wt% GO loading, reaching a value of 10.5 ± 0.3 LMH with complete salt rejection. Such results reveal the potential of graphene oxide materials to enhance the performance of low cost desalination technology.

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[SP2.20] - The Use of Adipose Stem Cells and Graphene-Derived Substrates for Peripheral Nerve Regeneration.

Steffan Llewellyn [1,2], Alessandro Faroni [1], Andrea Francesco Verre [2], Aravind Vijayaraghavan [2], Adam Reid [1]

[1] Blond McIndoe Research Laboratories, Centre for Tissue Injury and Repair, Institute of Inflammation & Repair, Faculty of Biology, Medicine and Health, University of Manchester, UK.

[2] Nanofunctional Materials Group, School of Materials, National Graphene Institute, Faculty of Engineering and Physical Sciences, University of Manchester, UK

Peripheral nerve injuries cause debilitating damage, with surgical procedures failing to regain full functional recovery. Adipose stem cells are abundant, harvestable and secrete neurotrophins, promoting neural regeneration. Neurotrophin production is upregulated through chemical stimulation to a regenerative, differentiated phenotype, but this phenotype is unstable [1]. Graphene and its derived materials may promote stability through physicochemical properties, accelerating cell colonization, differentiation and protein adhesion [2]. We developed an *in vitro* platform to assess graphene oxide substrate effect on cell viability/differentiation. No viability changes were observed over 7 day incubation. Cell-material interaction indicates changes in gene expression of neurotrophin targets. With this platform, we are assessing cell interaction with functionalized graphene oxide.

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[SP2.21] - Graphene-metal oxide nanocomposite electron transport layers for BiOI based solar cells

Tahmida N. Huq[1,2], Dr Robert Hoye[3] and Professor Judith Driscoll[1]

[1]Department of Materials and Metallurgy, University of Cambridge, UK

[2]Cambridge Graphene Centre, University of Cambridge, UK

[3]Department of Physics, The Cavendish Laboratory, University of Cambridge, UK

tnh25@cam.ac.uk

BiOI is an ns^2 compound with a spectroscopically limited maximum efficiency exceeding 20% at room temperature. Electron transport layers (ETLs) with optimal band alignment are crucial for realizing this potential. ZnO and TiO_2 are two of most common metal oxide based ETLs investigated in solar cells due to their minimal parasitic light absorption and controllable properties. However, interface recombination and defects in ZnO limit the V_{OC} and efficiency of our BiOI cells. Graphene-ZnO and graphene-TiO_2 nancomposite ETLs have shown to improve device efficiency for dye-sensitized, perovskite and organic solar cells due to improved electron transport and extraction [1][2]. In this work, we investigate graphene-metal oxide nanocomposites to reduce recombination using low-temperature processing to improve BiOI device performance.

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[SP2.22] - Valley-Polarised Interface Modes in a Delaminated Graphene Bilayer

Thomas Lane[1] John Wallbank[1] and Vladimir Fal'ko[1]

[1]National Graphene Institute, Manchester University, UK

thomas.lane-3@postgrad.macnhester.ac.uk

We study the ballistic transport of electrons across a sheet of bilayer graphene (BLG), with interlayer coupling γ_1 broken for a finite range $0<y<W$ such that this central region behaves as two distinct monolayers (2ML). We demonstrate that at a single interface there exist topological valley polarised modes propagating within the bilayer energy gap that have a directional dependency on both the valley and layer stacking. For identical bilayer stacking either side of the double boundary system (AB/AB) these modes vanish, whilst reversing the stacking convention on one side (AB/BA) allows them to coexist. A high probability of reflection at the 2ML/BLG interfaces leads to bouncing modes within the 2ML region, with the number of available states being highly dependent upon both width, W, and the various electrostatic parameters.

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[SP2.23] - Raman Spectroscopy of Graphene-based Formulations

Vaiva Nagyte[1], YuYoung Shin[1], Adriana Alieva[1], Khaled Parvez[1], Sarah Haigh[2], Antonios Oikonomou[3], Andrew Pollard[4], Cinzia Casiraghi[1]

[1]School of Chemistry, University of Manchester, United Kingdom

[2]School of Materials, University of Manchester, United Kingdom

[3]National Graphene Institute, University of Manchester, United Kingdom

[4]National Physical Laboratory, United Kingdom

vaiva.nagyte@postgrad.manchester.ac.uk

Graphene has attracted a lot of research interest due to its outstanding properties since 2004.[1] Despite this, a large-scale and low-cost production method of graphene is still unavailable. The most promising solution to this is chemical exfoliation.[2,3] However, chemically exfoliated graphene dispersions contain crystals of varying size and thickness. In addition, characterization of graphene dispersions is challenging due to re-stacking and folding of the flakes. The goal of this project is to improve Raman spectroscopy characterization of graphene-based formulations in order to provide quantitative information about graphene quality and thickness distribution. Raman spectroscopy results will be compared with transmission electron microscopy data of the same flakes. It is hoped that this method could improve standardization and manufacturing of graphene formulations.

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[SP2.24] - Spintronics in high-quality graphene heterostructures via 1D contacts

Victor H. Guarochico Moreira[1,2], Irina Grigorieva[1] and Ivan J. Vera-Marun[1]

[1]School of Physics and Astronomy, University of Manchester, United Kingdom

[2]Departmento de Física, Escuela Superior Politécnica del Litoral, Ecuador,

victor.guarochico@postgrad.manchester.ac.uk

We report the first observation of nonlocal pure spin currents in high-quality graphene channels that are fully encapsulated by hexagonal boron nitride (hBN) layers. Our heterostructure devices prevent residual contamination from the fabrication process, routinely allowing high-quality channels with mobilities up to 100000 cm^2/Vs. This architecture is enabled by creating spin injectors based on edge one-dimensional (1D) contacts[1], which avoid any significant charge doping from the contacts in the center of the channel. We present evidence for spin transport both at room and low temperatures. Spin injection through 1D contacts into uniform high-quality graphene gives us access to explore spintronics in the quantum transport regime, where we exploit quantum interference to enhance the nonlocal spin signals.

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[SP2.25] - Moiré pattern in encapsulated 2D materials

Yibo Wang[1]

[1]School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK

Yibo.wang-2@postgrad.manchester.ac.uk

Recent studies in 2D atomic crystal heterostructures reveal that hexagonal moiré pattern can form relying on the lattice constant and rotation angle.[1,2] The relative rotation angle between the crystals leads to the change of moiré period. With AFM studies and Raman spectroscopy investigation, the domain walls and tensile strain distribution are observed. [1,2]

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[SP2.26] - In-Operando NMR Study of Charging Behaviour of Activated rGO and Activated Carbon Supercapacitor Electrodes

Yuning Zhou[1], Josh Stratford[1], Clare Grey[1]

[1]Department of Chemistry, University of Cambridge, United Kingdom

yz489@cam.ac.uk

Supercapacitors have the potential to play a crucial role in high-power energy storage solutions for future energy systems based on renewable sources. One of the principal strategies for improving performance is to increase the specific surface area of the electrodes. However, this simplistic approach overlooks the intricate relationships between electrode structure, charging mechanism and performance, which are not well understood. Recently, in-situ NMR techniques have been used to provide unique insights into the charging mechanisms, but have focused on measurements at equilibrium.[1] In this work, we present progress made on in-operando NMR techniques to investigate the dynamic charging behaviour of high surface area electrodes based on activated carbons and activated reduced graphene oxides.

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[SP2.27] - Atomically thin 2D and quasi-2D organic-inorganic perovskite emitters

Ziyue Yi[1] and Robert Hoye[1]

[1] Cavendish Laboratory, Department of Physics, University of Cambridge, United Kingdom

zy263@cam.ac.uk

Methylammonium lead halide perovskites have recently risen to prominence as an exceptional photovoltaic material, with rapid increases in efficiency to over 20% already demonstrated. High photoluminescence quantum efficiencies (PLQEs) have also been measured from these materials,[1] and this paved the way for the demonstration of room-temperature electroluminescence.[2] The efficiencies of these light emitting diodes (LEDs) have risen rapidly, increasing from <1% to 8.5% external quantum efficiency after a year of development.[3] To achieve efficient electroluminescence, architectures that confine electron-hole pairs in the perovskite emitter are needed. One structure is through confinement in 2D or quasi-2D perovskites, with the general formula $(RNH_3)_2(CH_3NH_3)_{m-1}A_mX_{3m+1}$. R is an alkyl group, A the inorganic cation (Pb^{2+}) and X the halide (Cl^-, Br^- or I^-).[4] These atomically-thin perovskite emitters have the potential to have important applications for low-cost, flexible displays.

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STUDENT POSTERS – 1st YEARS

[SP1.1] - Polysiloxane based graphene composites for stretchable electronics

Adrees Arbab[1], Tian Carey[1], Sia Shivareddy[1], Siva Bohm[1] and Felice Torrisi[1].

[1]Cambridge Graphene Centre, University of Cambridge, United Kingdom

aa969@cam.ac.uk

There is strong demand for stretchable electronics which can be incorporated in to strain sensors and other electronics, such as stretchable cameras requiring a maximum degree of freedom[1,2]. Many novel stretchable devices have been reported in the literature such as field effect transistor (FET) with a mobility of 10000 $cm^2 V^{-1} s^{-1}$ and batteries with initial discharge capacity of 600 mAh g^{-1} [4]. However, there is still a lack of inks which are stretchable and shows little change in electrical conductivity when deformed. Graphene has shown a lot of potential for excelling in the field of stretchable electronics due to its remarkable properties such as high surface area (1654 $m^2 g^{-1}$), high thermal conductivity (2000 to 5300 $W m^{-1} K^{-1}$) and low young's modulus (ca. 1 TPa)[3,4]. In this work we functionalize graphene using (3-Aminopropyl) trimethoxysilane and polydimethylsiloxane which is used to tether the graphene flakes together[1]. This allows us to achieve a stretchability of 4 % while retaining much of its conductivity of 2 S m^{-1}, thus creating stretchable inks with unprecedented performances.

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[SP1.2] - Semiclassical approach to quantum oscillations in conductivity in a ballistic regime.

Adrian Ceferino[1]

[1] National Graphene Institute, The University of Manchester, UK

adrian.ceferino@postgrad.manchester.ac.uk

Oscillations in conductivity with B-field can be observed in a simple semiclassical model in which electrons injected at a given point and form caustics as they propagate due to cyclotron orbit. Such caustics are in most situations continuous, however, under special geometries, such continuity can be broken. The parametric equations of such caustics were calculated and its matching properties when it encounters geometric perturbations were studied as well as the quantum oscillations of current flow in a p-n junction in graphene.

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[SP1.3] - Transport properties of MoS_2 and Bi_2Se_3.

Alexey Berdyugin[1], Shuigang Xu[2], Renyan Zhang[1], John Birbeck[1], Denis Bandurin[1], Irina Grigorieva[1] and Andre Geim[1, 2]

[1]School of Physics and Astronomy, University of Manchester, UK

[2]National Graphene Institute, University of Manchester, UK

alexey.berdyugin@postgrad.manchester.ac.uk

MoS2 samples with different number of layers were measured. The field effect mobility and Hall mobility were obtained as high as 10 000 cm^2/Vs. At magnetic field Shubnikov de Haas oscillations were observed, using these, the degeneracy of MoS2 was extracted as 12 for samples with even number of layers and 6 for samples with odd number of layers. These observations agree with the previous work[1].

Bi2Se3 intercalated and pristine bulk samples were characterized through transport measurements. Shubnikov de Haas oscillations were observed in bulk samples. Thin Bi2Se3 sample was characterized with transport and quantum capacitance measurements. The Dirac point of surface fermions was observed.

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[SP1.4] - Perovskites for Advanced Solar Cells

D. G. Hopkinson[1], D. J. Lewis[1], S. J. Haigh[1]

[1]School of Materials, University of Manchester, UK, M13 9PL

david.hopkinson@postgrad.manchester.ac.uk

In recent years, hybrid organic-inorganic photovoltaic perovskites have emerged at the forefront of various optoelectronic technologies, as both a high efficiency solar absorbers and tuneable photoluminescent nanocrystals[1]. In the realm of solar cells, hybrid perovskites have achieved peak power conversion efficiencies (PCEs) of >22%, with an incident photon-to-electron conversion efficiency of >35%, overtaking traditional, single junction Si technologies (PCE ~21%)[1,2]. Most current hybrid perovskite designs feature 3D networks of methylammonium lead iodide (MAPI), formed from the conversion of the 2D layered MXene, PbI_2, with CH_3NH_3. This poster seeks to introduce and highlight the development and function of MAPI solar cells, and future research directions for this promising class of materials.

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[SP1.5] - Gold Nanoparticle Coated Carbon Fibres for a Non-enzymatic Anode in a Glucose Biofuel Cell

D. Maxwell[1] T. Zhao[2] H. K. Kim[2] R. V. Kumar[2]

[1]Cambridge Graphene Centre, University of Cambridge, UK

[2]Department of Engineering, University of Cambridge, UK

A free-standing, high surface area carbon fibre mat, sputtered with gold nanoparticles, was prepared for use as an anode in a glucose biofuel cell. The anodes were prepared via an electrospinning technique whereby a PAN precursor, dissolved in DMF, was dispensed from a needle under a high electric field before being carbonised and sputtered with gold nanoparticles. Cyclic voltammetry measurements confirmed that nanoparticles of width 5 - 25 nm and thickness ≤ 3 nm were the optimum size to oxidise glucose to gluconic acid in a 0.1 M NaOH solution. The maximum current at the oxidation peak (0.4 V) increased exponentially with glucose concentrations reaching 12.9 mA AT 80 mM, this was expected to be diffusion limited at higher concentrations. It was shown that if incorporated into a full glucose biofuel cell that a power of 0.3 mW/cm^2 could be produced meaning it could power an artificial urinary sphincter.[1,2]

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[SP1.6] - Graphene Inks for Paper Electronics

F.K. Mangwanya[1], X Zhu[1], L Ng W.T.[1], C Jones[2], T Hasan[1]

[1]Cambridge Graphene Centre, University of Cambridge, Cambridge, CB3 0FA, UK,

[2] Novalia, Impington, CB24 9NP, UK

fkm26@cam.ac.uk

Screen printed graphene electrodes circumvent the challenges associated with conductive metallic inks. However, formulation of stable graphene inks with consistent ink characteristics remains a challenge. We investigate the formulation of graphene inks from commercially available, high specific surface area, -OH functionalised graphene powder. A surfactant-free binary solvent for pre-dispersion is used and ethyl cellulose binder is used for the formulation of a screen printable ink. Furthermore, we demonstrate that uncoated paper gives a lower sheet resistance and higher printing resolution for screen printing than higher surface energy polymer coated papers typically used for inkjet printing. The doping effect of ascorbic acid (Vitamin C) on -OH functionalised graphene is investigated using Raman spectroscopy. A -7.12 cm^{-1} shift in the position of the 2D peak and decrease of 12.2% in I(2D)/ I(G)is observed.

[SP1.7] - Waveguide Integrated Double Layer Graphene-Si Modulators for On-chip Optical Interconnect

Hannah Watson[1], Jakob E. Muench[1], Junjia Wang[1], Dengke Zhang[1], Andrea C. Ferrari[1], and Ilya Goykhman[1]

[1]Cambridge Graphene Centre, University of Cambridge, Cambridge CB3 0FA, United Kingdom

hfyw2@cam.ac.uk

Optical modulators are an essential component of optoelectronic links[1]. Si photonics is an emerging technology for short-reach optical interconnect[1]. On-chip integrated Si electro-refractive (phase) and Si-Ge electro-absorption (amplitude) modulators are currently employed to encode information into guided light[1]. However, Si-based optical modulators are unlikely to meet future requirements of power consumption, insertion loss, and device scaling[1]. Graphene integration with Si photonics provides a unique opportunity to reduce insertion losses by tuning the Fermi level of graphene[2], miniaturize the device footprint by exploiting the strong electro-refractive modulation in graphene[3], and achieve <1 pJ/bit energy cost for optical modulation[3]. Here, we design power efficient Si-graphene amplitude and phase modulators operating at telecom wavelengths with 10dB extinction ratio and <1 dB insertion loss at 1V driving voltage. This is an important part of the development of hybrid graphene-Si photonics technology for on-chip integrated optical interconnects.

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[SP1.8] - Towards THz dynamics of 2D spintronic materials and devices

Harry James Waring[1], Professer Tom Thomson[2] and Dr Ivan J. Vera-Marun[3]

[1]School of Computer Science, University of Manchester, United Kingdom,

[2] Head of Nano Enginering and Storage Technology group, School of Computer Science, University of Manchester, United Kingdom.

[3]Dr Ivan J. Vera-Marun, School of Physics and Astronomy, University of Manchester, United Kingdom.

harry.waring@postgrad.manchester.ac.uk

Spintronics, where device functionality relies on the spin of electrons, offers the potential for improved and crucially more energy efficient devices including quantum technologies in practical devices. One of the most exciting areas that has recently emerged is the use of spintronics in near THz frequency devices[1]. 2D magnetic thin films, where materials are deposited one atomic layer at a time, have significant potential in high frequency and high efficiency spintronic devices such as spin torque oscillators, where a DC input produces an rf output in the 10s-100s of GHz[2]. Indeed, perpendicular anisotropy can generate high frequencies with possible extensions including the addition of in-plane layers[3]. In this project, the understanding needed to create these devices utilizing new combinations of 2D materials will be developed.

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[SP1.9] - Plasmonic enhanced waveguide integrated graphene p-n junction photodetectors for telecom wavelengths

J. E. Muench[1], H. Watson[1], D. Zhang[1], J. Wang[1], A. C. Ferrari[1], I. Goykhman[1]

[1]Cambridge Graphene Centre, University of Cambridge, Cambridge CB3 0FA, UK

jem227@cam.ac.uk

Waveguide integrated photodetectors (PDs) are the basic components of on-chip optical interconnects[1]. Currently, Si photonics technology relies on Si-Ge PDs[2], where Ge is used as the active absorber at telecom wavelengths[2]. However, these devices suffer from an increased dark current due to defects at the Ge-Si interface[2], and show a reduced thermal budget[2]. Graphene integration with Si photonics may lead to power efficient and high-responsivity PDs[3,4]. Utilizing the photo-thermoelectric effect[4] in a graphene p-n junction to generate a photovoltage, the PD may operate with zero dark current and without trans-impedance amplifiers. Here, we design a plasmonic-enhanced waveguide integrated graphene PD with a responsivity of up to 120V/W at 1550 nm. This could lead to high responsivity integrated graphene PDs for optoelectronic links.

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[SP1.10] - Modeling of Electrowetting and Other Interfacial Properties of Liquids on Graphene

Jezabel Boni[1], Paola Carbone[2], Robert Dryfe[3] and Anne Juel[4]

[1]School of Chemical Engineering and Analytical Sciences, University of Manchester, UK

[2]School of Chemical Engineering and Analytical Sciences, University of Manchester, UK

[3]School of Chemistry, University of Manchester, UK

[4]School of Physics and Astronomy, University of Manchester, UK

jezebel.boni@postgrad.manchester.ac.uk

The project focus is on using molecular simulations to analyse interfacial properties of electrolyte solutions in contact with graphene flakes. In particular it is of interest the variation of contact angle of droplets with the application of an electric field, a phenomenon called electrowetting. The initial stages will involve the study of water droplets, followed by the analysis of electrolyte droplets to study the wetting properties of graphene as a function of ion valency and applied electric field[1]. During the project the simulation results[2] will be compared with concurrent experiments[3] to provide the opportunity to confirm the validity of the models created.

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[SP1.11] - Novel High-Performance Devices

Joseph Brownless[1], Aimin Song[1] and Ernie Hill[2]

[1]School of Electrical and Electronic Engineering, University of Manchester, M13 9PL, UK

[2]Manchester Centre for Mesoscience and Nanotechnology, University of Manchester, M13 9PL, UK

joseph.brownless@postgrad.manchester.ac.uk

This project aims to develop the design, fabrication, and testing of novel high-performance electronic and optoelectronic devices. In particular, graphene-based 'ballistic rectifiers', combined with high-speed antennas, will be studied. These devices use the extremely long mean free path in graphene alongside an asymmetric geometry to achieve current rectification[1]. Looking towards the THz range, these devices will be tested using black-body sources. Additionally, investigations will be made into methods of increasing device efficiency/sensitivity. This may involve plasmonics, possibly involving the simulation thereof.

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[SP1.12] - Investigating the role of graphene plasmons in an integrated THz quantum cascade laser (QCL) system

Joshua Spence[1] and Subhasish Chakraborty[2]

[1]School of Electrical and Electronic Engineering, The University of Manchester, United Kingdom

[2] School of Electrical and Electronic Engineering, The University of Manchester, United Kingdom

Joshua.spence@postgrad.manchester.ac.uk

Graphene has exciting plasmonic properties (such as plasmon tunability). Recently the inclusion of a graphene layer in a QCL has shown promise for laser modulation[1]. There has also been interest in the development of a surface plasmon polariton (SPP) laser, a laser which uses the amplification of surface plasmons to cause an increase in electromagnetic field intensity. A SPP laser (SPASER) would allow tight confinement of an electromagnetic field and sub-wavelength lasing. Issues have been encountered with SPASERS due to large losses in the metallic waveguide. However this loss can be reduced by incorporating a graphene sheet into the system, as graphene has relatively low losses compared to noble metals. In this work we simulate the THz plasmons in the graphene layer (generated by the THz QCL) in order to determine their role. This allows quantitative data to be collected about the intensity of the electromagnetic field around the graphene sheet.

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[SP1.13] - Sustainable Carbon Material from Cellulose Nanocrystals

L. Lai[1], G. Guidetti[2], C. Grey[2], S. Vignolini[2]

[1]Cambridge Graphene Centre, University of Cambridge, Cambridge, CB3 0FA, UK

[2] Department of Chemistry, University of Cambridge, Cambridge CB2 1EW, UK

The ability to produce cheap conductive porous materials with desired porosity and precise chemical composition is vital for energy applications.[1] Here, we produced a mesoporous carbon material with high conductivity and surface area by carbonisation of cellulose nanocrystals (CNCs) films with chiral nematic morphology. By studying the thermal properties of CNC films, we showed that the films can retain their chiral nematic structure at up to 250 ℃ by either adding $KHCO_3$ into CNC water-suspensions or by impregnation of dry CNC films in alkaline solutions. After KOH activation at 900 ℃**,** the carbon material obtained from CNC-$KHCO_3$ composite exhibited a surface area of 363 m^2/g, a narrow pore width distribution centred at 2.7 nm and a conductivity of 208 S/m. This cheap, conductive, sustainable and highly mesoporous carbon material shows a potential for energy applications.

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[SP1.14] - Investigating the protein corona formation on graphene oxide

Livia-Elena Crica and Kostas Kostarelos

Nanomedicine Lab, Faculty of Biology, Medicine & Health, University of Manchester, UK

livia.crica@postgrad.manchester.ac.uk

Protein adsorption onto surfaces occurs in the early phase of the contact between materials and protein-rich fluids such as saliva, blood, interstitial fluid, *etc*[1]. Often referred to as the protein corona, this layer of proteins has a dynamic evolution in time, spanning from minutes to several hours. Within the very first seconds (<0.5 minutes), proteins adsorbed with high affinity build the so called "hard corona", a strongly adsorbed layer of proteins[2]. The "soft corona" is formed within minutes/hours *via* weak interactions and has a more dynamic character[2,3]. We hypothesize that disease-specific proteins can be part of the protein corona, that could potentially offer insights on the origin, stage and prognosis of numerous pathologies. Our studies will explore the unique properties of graphene oxide (surface area, curvature, amphipathic surface character) and other 2D materials in an effort to decipher the mechanisms of the *in vitro* and *in vivo* protein adsorption and the molecular signatures of the protein corona formed in mouse and human blood plasma.

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[SP1.15] - One-atom-thick crystals with subatomic selectivity

Lucas Mogg[1], Dr. Marcelo Lozada-Hidalgo[1], Prof. Irina Grigorieva[1] and Prof. Andre Geim[1]

[1]School of Physics and Astronomy, The University of Manchester, UK

lucas.mogg@postgrad.manchester.ac.uk

Unlike conventional membranes used for sieving atomic and molecular species, monolayers of graphene and hexagonal boron nitride exhibit subatomic selectivity[1-3]. They are impermeable to all atoms and molecules at ambient conditions but thermal protons and deuterons (nuclei of hydrogen isotopes) can permeate through these crystals[1-2]. 'Thermal' in this context refers to protons with energies of the order of several kT at 300K. In follow-up experiments we found that deuterons permeate ≈10 times slower than protons; allowing for efficient sieving of hydrogen[2]. The project hopes to extend these results to investigate transport of other atomic species and explore the separation factor of tritons compared with that of deuterons and protons.

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[SP1.16] - Molecular Separation with Atomically Precise Nanocapillaries

Dr. Radha Boya[1, 2] and Madeleine L. B. Howe[1, 2]

[1]School of Physics and Astronomy, University of Manchester, United Kingdom

[2] The National Graphene Institute, University of Manchester, United Kingdom

madeleine.howe@postgrad.manchester.ac.uk

Nanoscale pores and capillaries have been studied intensively because of their importance in many natural phenomena and use in numerous applications. Significant progress has been achieved in the fabrication of such artificial capillaries leading to the emergence of new research areas including nanofluidics. It remains extremely challenging to control capillary sizes at this spatial scale. However, through novel techniques, nanocapillaries with tuneable atomic-scale dimensions and atomically smooth walls have been achieved via van der Waals assembly of two-dimensional materials. The aim of this project is to fabricate and study mass transport through these structures with a focus on volatile hydrocarbon separation. Building upon previous work on water transport[1], we hope to advance the fundamental understanding of molecular transport through these novel architectures.

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[SP1.17] - Inkjet Printable Formulations of Novel 2D-based Materials

Marco Zarattini[1], Daniele Rizzo[1], Adriana Alieva[1], Jarrid Wittkopf[2], Robert Cri Ionescu[2], Roberto Silveira[2], Ning Ge[2], Helen Holder[2] and Cinzia Casiraghi[1]

[1]School of Chemistry, University of Manchester, United Kingdom

[2]HP, Palo Alto, United States of America

marco.zarattini@postgrad.manchester.ac.uk

The research and preparation methods applied to graphene, the most famous two-dimensional (2D) crystal exhibiting unique properties, have paved the way for exploring other 2D materials[1,2]. There is an entire periodic table of solid state crystalline materials, each with different optical, mechanical, electronic and transport properties, which have only been investigated in recent years[3].

The aim of this project is to investigate the ability to produce chemically, via bottom-up reactions, or by exfoliation such 2D materials that show attractive proprieties when they are reduced to single or few layers. The colloidal synthesis and characterization of Titanium disulphide (TiS_2) and Bismuth Tungstate perovskite (Bi_2WO_6) will be presented in this poster.

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[SP1.18] - Graphene-biopolymer hydrogels for biomedical applications

Natalie Parsons[1]

[1]School of Materials, University of Manchester, UK

natalie.parsons-2@postgrad.manchester.acuk

Biopolymer hydrogels are promising materials for a wide range of biomedical applications but are limited by their poor mechanical properties. The incorporation of graphene in such systems has the potential to improve the mechanical properties in addition to the electrical and thermal properties.[1] The objectives of this work are to develop and test a range of novel graphene-reinforced biopolymer hydrogel materials, which will then be exploited for applications in scaffolds for tissue engineering, chemical- and bio-sensors, and drug-delivery. Gelatin is the first biopolymer that is being investigated and the preliminary mechanical data of this initial work is presented.

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[SP1.19] - Production of red/black phosphorus hybrids using liquid-phase processing

N. Jay[1], S. Hodge[1], G. Guidetti[1], D. Akinwande[1,2], A. C. Ferrari[1]

[1]Cambridge Graphene Centre, University of Cambridge, Cambridge, UK

[2]Department of Electrical and Computer Engineering, The University of Texas at Austin, USA

nvj21@cam.ac.uk

Black phosphorus is an interesting material for electronics and optoelectronics due to its large, direct band gap.[1] However, the cost of production remains a challenge.[2] Here we investigate the scalable conversion of red to black phosphorus using microfluidization,[3] and the limitations of previously reported phase conversion using ultrasonication.[4] Microfluidized and ultrasonicated materials are characterized by a combination of Raman, scanning electron microscopy, thermogravimetric analysis, surface area, and dye sensitized UV-Vis spectroscopy. Thermogravimetric analysis of the microfluidized red phosphorous indicate that the resulting material is a red/black phosphorus mixture. The microfluidized red phosphorus has 8-times higher visible-light-driven photocatalytic activity compared to unprocessed or ultrasonicated red phosphorus, making it a promising candidate for photocatalytic applications.

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[SP1.20] - Towards Circularly Polarised Perovskite LED's

S. Bourelle[1], R. Di Pietro[2], J. Alexander-Webber[3], S. Hofmann[3], H. Sirringhaus[2]

[1]Cambridge Graphene Centre, University of Cambridge, UK

[2]Hitachi Cambridge Laboratory, University of Cambridge, UK

[3]Department of Engineering, University of Cambridge, UK

[4]Department of Physics, University of Cambridge, UK

sab229@cam.ac.uk

Organometal halide perovskites have recently demonstrated bright green electroluminescence and strong spin orbit coupling[1,2]. However, the suitability of ferromagnetic contacts for efficient spin injection into these materials is not well understood. As such, this project aimed to fabricate $CH_3NH_3PbBr_3$ perovskite LED's with additional control over the polarisation state of the emitted light. A graphene passivated nickel electrode was fabricated using chemical vapour deposition, and characterised using AFM and Raman spectroscopy[3]. This structure was then used as a magnetic electrode within the perovskite LED architecture. Additionally, a bright green LED utilising a ferromagnetic permalloy electrode is demonstrated, with an output radiance of 5.5 mW Sr^{-1} m^{-2} at a current density of 21.7 mA cm^{-2}. Future work will analyse the polarisation state of the emitted light to determine spin diffusion within $CH_3NH_3PbBr_3$.

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[SP1.21] - Coulomb Diamonds in hBN converted Graphene Quantum Islands

Servet Ozdemir[1], Davit Ghazaryan[1], Abhishek Mishra[1,2], Artem Mischenko[1,2] and Konstantin Novoselov[1,2]

[1]School of Physics and Astronomy, The University of Manchester, UK

[2]National Graphene Institute, The University of Manchester, UK

servet.ozdemir@postgrad.manchester.ac.uk

Graphene and hBN have been used to create tunneling transistors of van der Waals heterostructures[1]. It has also recently been demonstrated that CVD grown hBN can be converted to graphene following a reaction catalysed by a Pt substrate[2]. This work reports transport measurements of graphene quantum dots produced by catalytic conversion of a CVD grown hBN substrate in a tunneling transistor heterostructure. Various sizes of quantum dots produced manifest themselves as varying sizes of Coulomb diamonds in the tunneling spectroscopy measurements.

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[SP1.22] - Hybrid graphene-photochromic molecules photodetectors for high gain and responsivity

S. Akhavan[1], G. Guidetti[1,2], M. Montali[2], F. Mancin[3], A. C. Ferrari[1], I. Goykhman[1],

[1]Cambridge Graphene Centre, University of Cambridge, Cambridge CB3 0FA, UK

[2]Department of Chemistry, University of Bologna, Bologna, 40126, Italy

[3]Dipartimento di Scienze Chimiche, Università di Padova, via Marzolo 1, 35131 Padova, Italy

sa766@cam.ac.uk

Graphene is a promising material for photodetectors (PDs) offering multi-spectral absorption[1] and fast response time.[2,3] However, a single layer graphene absorbs only 2.3%[4], which limits PD responsivity. One way to overcome this obstacle is employing hybrid graphene PDs with enhanced optical absorption and photoconductive gain[5] using plasmonic nanostructures[6] or semiconductors quantum dots[7]. Here, we integrate photochromic molecules (PCM) with a graphene phototransistor and show charge transfer of photoexcited carriers at the PCM-graphene interface, resulting in photogating (photoconductive gain) and enhanced device responsivity.

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[SP1.23] - Black phosphorus/PEDOT:PSS: Towards Flexible and Transparent Chemiresistive Gas Sensors

V. S. Malhotra[1], D. Beesley[2], S. A. Hodge[1], A. C. Ferrari[1], M. de Volder[2]

[1]Cambridge Graphene Centre, University of Cambridge, CB3 0FA, UK

[2]Institute for Manufacturing, University of Cambridge, CB3 0FS

vsm28@cam.ac.uk

Chemiresistive gas sensors are typically based on semiconductors, organic or polymeric composites[1]. The primary disadvantage of these sensors is the lack of selectivity towards different gases. Black phosphorus (BP) has shown good selectivity for NO_2 sensing[2]. We combine multi-layer BP flakes with a conductive polymer (PEDOT:PSS, P:P) to investigate the potential for flexible and transparent gas sensors that could be integrated into various smart wearable electronics and display devices[3]. At room temperature, P:P shows a resistance response of <10% for CO_2, NH_3 and NO_2. However, P:P responds to a change in relative humidity (RH) by 600% at 60% RH. The addition of BP inhibits this response to 150% while enhancing the response for NO_2 by 22% at 20 ppm. If these responses can be decoupled, P:P could provide a promising flexible gas sensor platform; the selective interactions of NO_2 with BP will certainly lead to further investigation of other conductive polymer based sensor platforms.

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[SP1.24] - Superconductivity in intercalated layered materials

Wenjun Kuang, Andre Geim, and Irina Grigorieva[1]

[1]Condensed Matter Physics Group, School of Physics and Astronomy, University of Manchester, UK

wenjun.kuang@postgrad.manchester.ac.uk

Intercalation of layered materials offers an effective approach for enhancement of conductivity and electron-phonon coupling, which are two critical prerequisites for superconductivity in BCS theory. Intercalation of graphite[1], MoS_2[2] and black phosphorus[3] by alkali metals or alkaline earth metals have been demonstrated to be superconducting successfully, and large enhancement of superconducting transition temperature were observed by intercalating Li into FeSe host. My work focuses on the intercalation of dopants like alkali metals or alkaline earth metals into layered materials, the interlayer interaction of which is mainly attributed to weak van-der waals force. By intercalation, structure characterisation, and magnetic measurements, we aim to explore the possibility of superconductivity in intercalated layered compounds.

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[SP1.25] - Chemical Modification on TMDs for Supercapacitors

Yuling Zhuo[1] Mark Bissett[1] and Ian Kinloch[1]

[1]Graphene Institute, University of Manchester, UK

yuling.zhuo@postgrad.manchester.ac.uk

Supercapacitors have become increasingly attractive due to it fast charging and discharging rate, long life cycle and potentials to replace batteries. However the problem that supercapacitors have nowadays is low energy density. This means the specific capacitances will need to be increased, which are mostly dependent on the materials of the electrodes. Thus in recent year scientists have put effort into the development of new materials and improvements of these materials. 2D materials, especially graphene have been investigated for the supercapacitors as electrodes due to its unique physical, chemical and mechanical properties[1], which has also inspired the development of other 2D materials. Among these 2D materials, transition metal dichalcogenides (TMDs) have attracted scientists' interests since they are sizable in bandgap and abundant in nature[1].

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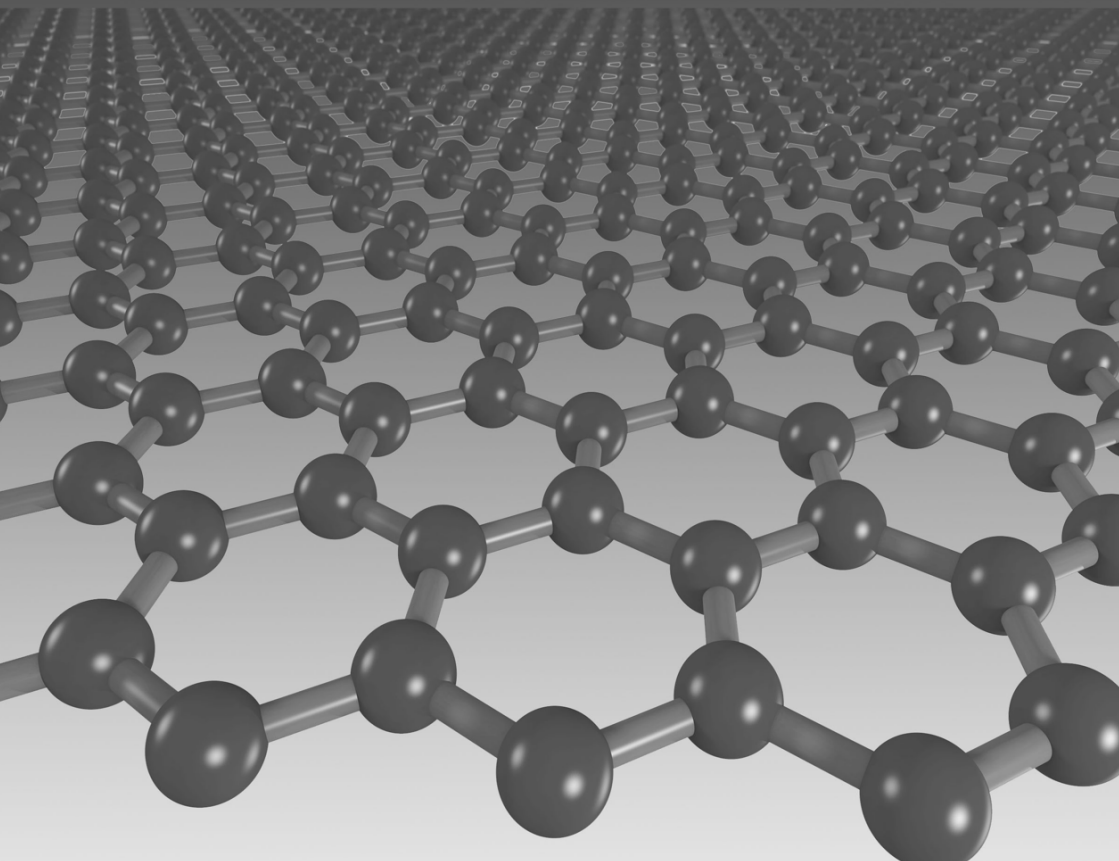
SPINOGRAPH TALKS/POSTERS



[STS.1] - h-BN-based Magnetic Tunnel Junctions

Regina Galceran[1], Maëlis Piquemal-Banci[1], Sabina Caneva[2], Marie-Blandine Martin[2], Rob S. Weatherup[2], Piran R. Kidambi[2], Karim Bouzehouane[1], Stéphane Xavier[3], Abdelmadjid Anane[1], Frédérick Petroff[1], Albert Fert[1], John Robertson[2], Stephan Hofmann[2], Bruno Dlubak[1] and Pierre Seneor[1]

[1]Unité Mixte de Physique, CNRS-Thales, Université Paris-Sud, Université Paris-Saclay, 91767 Palaiseau, France

[2]Department of Engineering, University of Cambridge, Cambridge CB21PZ, United Kingdom

[3]Thales Research and Technology, 1 avenue Augustin Fresnel, 91767 Palaiseau, France

regina.galceran@cnrs-thales.fr

The potential for 2D materials in magnetic tunnel junctions (MTJs) relies not only on their reduced thickness, but also on the new functionalities these may provide [1]. The largest number of studies focus on graphene, but atomically-thin 2D insulating hexagonal boron nitride (h-BN) is also an effective tunnel barrier [2]. In our latest study [3], we integrate h-BN as tunnel barrier in Co/h-BN/Co and Co/h-BN/Fe magnetic tunnel junctions. Grown by chemical vapor deposition (CVD) directly on Co and Fe, vertical transport across it exhibits typical tunneling behavior. We report on the Tunnel Magnetoresistances (TMR) measured for these heterostructures and comment on the spin polarizations of Co-hBN and Fe-hBN interfaces, for which the extracted values are in-line with theoretical predictions.

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[STS.2] - Experimental Evidence to the Hydrodynamic Electron Flow in Graphene

D. A. Bandurin[1], R. Krishna Kumar[1,4], I. Torre[2,3], M. Ben Shalom[1,5], L. A. Ponomarenko[1,4], I. V. Grigorieva[1], M. Polini[3,6], A. K. Geim[1]

[1]School of Physics & Astronomy, University of Manchester, UK

[2]National Enterprise for nanoScience and nanoTechnology, Pisa, Italy

[3]Istituto Italiano di Tecnologia, Graphene labs, Genova, Italy

[4]Physics Department, Lancaster University, Lancaster LA14YB, UK

[5]National Graphene Institute, University of Manchester, UK

[6]National Enterprise for nanoScience and nanoTechnology, Pisa, Italy

denis.bandurin@manchester.ac.uk

Transport in systems where particles undergo frequent collisions is described by hydrodynamic theory. It has been argued for a long time that collective behavior of charge carriers in solids can be also treated by hydrodynamic approach. However, there has been almost no direct evidence to electron hydrodynamic so far. This is because the condition at which the hydrodynamic effects become observable are very strict: the electron-electron scattering length should provide the shortest spatial scale in the problem.

Due to weak electron-phonon coupling graphene offers an ideal system to study electron hydrodynamics. In this talk hydrodynamic effects of electron liquid in graphene, such as negative local resistance[1] and super-ballisticflow[2], will be discussed.

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[STS.3] - Graphene Based Nuclear Spin Quantum Bits

N. A. García-Martínez[1], J. L. Lado[1], Manuel Melle-Franco[2], J. Fernández-Rossier[1,3]

[1] International Iberian Nanotechnology Laboratory (INL), 4715-330 Braga, Portugal

[2] DCICECO - Aveiro Institute of Materials, Department of Chemistry, University of Aveiro, 3810-193 Aveiro, Portugal

[2] Departamento de Física Aplicada, Universidad de Alicante, 03690 San Vicente del Raspeig, Spain

noel.garcia@inl.int

In this work we study the possibility of hydrogenated graphene based Qubits. The chemisorption of hydrogen in graphene provides a nuclear spin 1/2 as well as the localization of an electron in the vecinity of the adatom, very much like in the Qubits based on P donors in Si[1,2].

The possibility to cotrol with atomic precision the chemisorption of hydrogen[3], along with the high tunability of the electronic properties of graphene (and graphene nano-structures), offers a great tool to control the interactions in the system allowing to perform single and two qubit operations.

We use a 4 orbital tight-binding model in the Slater-Koster approximation, validated with DFT calculations, to explore the tunability of the interactions and the feasability of these ideas.

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[STS.4] - Quantum Spin Hall Effect in Twisted Bilayer Graphene

Francesca Finocchiaro[1,2], Francisco Guinea[1,3] and Pablo San-Jose[2]

[1] *IMDEA Nanociencia*, Calle de Faraday 9, 28049 Madrid, Spain

[2] *ICMM-CSIC*, Sor Juana Ines de La Cruz 3, 28049 Madrid, Spain

[3] Department of Physics and Astronomy, *University of Manchester*, Manchester M13 9PL, UK

francesca.finocchiaro86@gmail.com

Motivated by a recent experiment[1] reporting evidence of helical spin-polarized edge states in layer-biased twisted bilayer graphene under a magnetic flux, we study the possibility of stabilising a quantum spin Hall (QSH) phase in such a system, with a bulk gap induced by electronic interactions. We analyse how magnetic flux, electric field, interlayer rotation angle and interactions combine to produce a pseudo-QSH with broken time-reversal symmetry, and spin-polarized helical edge states. The effect is a consequence of a robust interaction-induced ferrimagnetic ordering of the quantum Hall ground state under an interlayer bias, provided the two rotated layers are effectively decoupled. We find, in particular, that purely local electronic interactions are not sufficient to account for the experimental observations, which demand at least nearest-neighbour interactions to be included.

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[STS.5] - On the origin of magnetic anisotropy in two dimensional CrI_3

J. L. Lado[1] and J. Fernández-Rossier[1,2]

[1]QuantaLab, International Iberian Nanotechnology Laboratory (INL), Av. Mestre José Veiga, 4715-330 Braga, Portugal

[1]Departamento de Fisica Aplicada, Universidad de Alicante, 03690 Spain

jose.lado@inl.int

The observation of ferromagnetic order in a monolayer of CrI_3 has been recently reported [1], with a Curie temperature of 45 Kelvin and off-plane easy axis. Here we study the origin of magnetic anisotropy, a necessary ingredient to have magnetic order in two dimensions. We find two contribution to the magnetic anisotropy of the material. First, ferromagnetic super-exchange is anisotropic, due to the spin orbit interaction of the ligand I atoms. Second, a much smaller contribution that comes from the single ion anisotropy of the S = 3/2 Cr atom. Our results [2] permit to establish the XXZ Hamiltonian, with a very small single ion easy axis anisotropy, as the adequate spin model for this system. Using spin wave theory we estimate the Curie temperature and we highlight the essential role played by the gap that magnetic anisotropy induces on the magnon spectrum.

References

1. Huang, Bevin, et al. "Layer-dependent Ferromagnetism in a van der Waals Crystal down to the Monolayer Limit." arXiv preprint arXiv:1703.05892 (2017).
2. J. L. Lado, and J. Fernández-Rossier. "On the origin of magnetic anisotropy in two dimensional CrI_3." arXiv preprint arXiv:1704.03849 (2017).

[STS.6] - Magnetoresistance of 2D materials in vertical structures

Jose Luis Sambricio and Pablo Asshoff

School of Physics and Astronomy, The University of Manchester, UK

joseluis.sambriciogarcia@manchester.ac.uk

One promising application of graphene is its use as a spacer separating ferromagnetic metals in vertical magnetoresistance devices[1]. In this talk we will show the role of doping and the magnetic proximity effect in the emergence of magnetoresistance in these devices.

We will base this new model on Co/Graphene/NiFe junctions with single and few layer graphene devices, as well as on Co/Graphene/hBN/NiFe structures and their comprehensive characterization.

References

1. Karpan, V. M. *et al.* Graphite and graphene as perfect spin filters. *Phys. Rev. Lett.* 2007*,* **99**, 176602.

[SPS.1] - Directional control of spin currents and long spin relaxation lengths in hexagonal Boron Nitride encapsulated bilayer graphene

Josep Ingla-Aynés and Bart J. van Wees

Physics of Nanodevices, Zernike Institute for Advanced Materials, University of Groningen, The Netherlands

J.Ingla.Aynes@rug.nl

Long distance spin transport and its efficient modulation are major requirements to achieve new functionalities in spintronic devices[1]. Both of them can be realized using graphene-hexagonal Boron Nitride heterostructures. These devices have shown that spin signals can be measured over unprecedentedly long distances[2]. When applying a DC current in the channel we measure a strong modulation of the spin signal. This indicates that the spin current injected in the channel is guided by the drift field. Our results, together with a model, show that 88% of the spins can be directed to follow the drift. Moreover, the spin relaxation length increases up to 90 μm when the drift current is 90 μA, a record value for high quality graphene-based spintronic devices[3].

References

1. S. Datta, B. Das, *Appl. Phys. Lett.* 1990, **56**, 665
2. J. Ingla-Aynés et al. *Phys. Rev. B* 2015, **92**, 201410(R)
3. J. Ingla-Aynés et al. *Nano Lett.* 2016*,* **16**(8), pp 4825-4830

[SPS.2] - Proximity induced ferromagnetism and spin orbit interaction in the Graphene/YIG heterostructure

J.C. Leutenantsmeyer, A.A. Kaverzin, and B.J. van Wees

Physics of Nanodevices, University of Groningen, Groningen, The Netherlands

j.c.leutenantsmeyer@rug.nl

The two dimensionality of graphene makes it an optimal material for the study of proximity induced effects. Recently, it has been shown that the spin orbit coupling in graphene can be tuned via proximity and, when deposited on a magnetic insulator, graphene can exhibit the characteristics of ferromagnetism.[1,2] We present the spin transport properties of ferromagnetic graphene arising from proximity coupling to the ferrimagnetic insulator Yttrium Iron Garnet (YIG),which induces an exchange field to graphene. Compared to pristine graphene, the spin precession in ferromagnetic graphene is affected by the presence of the exchange field, which we use to modulate the spin transport. We show further that YIG, when brought into ferromagnetic resonance, injects spin into graphene. Despite the low spin orbit coupling in graphene, the spin accumulation can which can be detected as a voltage.

References

1. S. Roche et al., 2D Mater., 2015, **2**, 030202.
2. J.C. Leutenantsmeyer et al., 2D Mater., 2017, **4**, 14001.

[SPS.3] - Ballistic Transport in Graphene Nanoconstrictions

S. Somanchi[1], B. Terrés[1,2], L. A. Chizhova[3], F. Libisch[3], J. Peiro[1], D. Jörger[1], S. Engels[1,2], A. Girschik[3], K. Watanabe[4], T. Taniguchi[4], S. V. Rotkin[1,5,6], J. Burgdörfer[3,7], and C. Stampfer[1,2]

[1] JARA-FIT and 2nd Institute of Physics, RWTH Aachen University, Germany

[2] Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany

[3] Institute for Theoretical Physics, Vienna University of Technology, Austria

[4] National Institute for Materials Science, Japan

[5] Department of Physics, Lehigh University, USA

[6] Center for Advanced Materials and Nanotechnology, Lehigh University

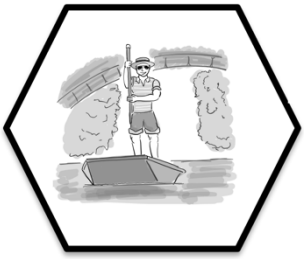
[7] Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), Hungary

somanchi@physik.rwth-aachen.de

We show ballistic transport and quantized conductance in high quality encapsulated graphene nano-constrictions [1]. At higher charge carrier densities, the observed conductance agrees well with the Landauer theory of ballistic transport. Interestingly, there is a discrepancy around the charge neutrality point which can be explained by the presence of trap states i.e. localized states along the edges. To further investigate the role of trap states, we have fabricated constrictions with top gates. We observe a non-constant relative gate lever arm which can be attributed to the edge modification of the constriction due to Fluorine based etching during fabrication. We also observe that the top gate tunes the transmission through the constriction which might be due to the gate dependent screening of the scattering at the edges. Thus, using multiple gates can be highly useful to understand how the trap states can be tuned.

References

1. B. Terrés, *et al,. Nature Communications*, 2015, **7**, 11528



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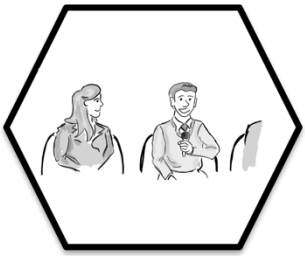

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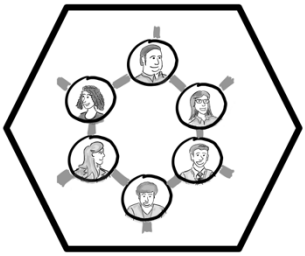
Finally, thank-you to the staff at Wyboston lakes and to all delegates for helping to make the conference a success.



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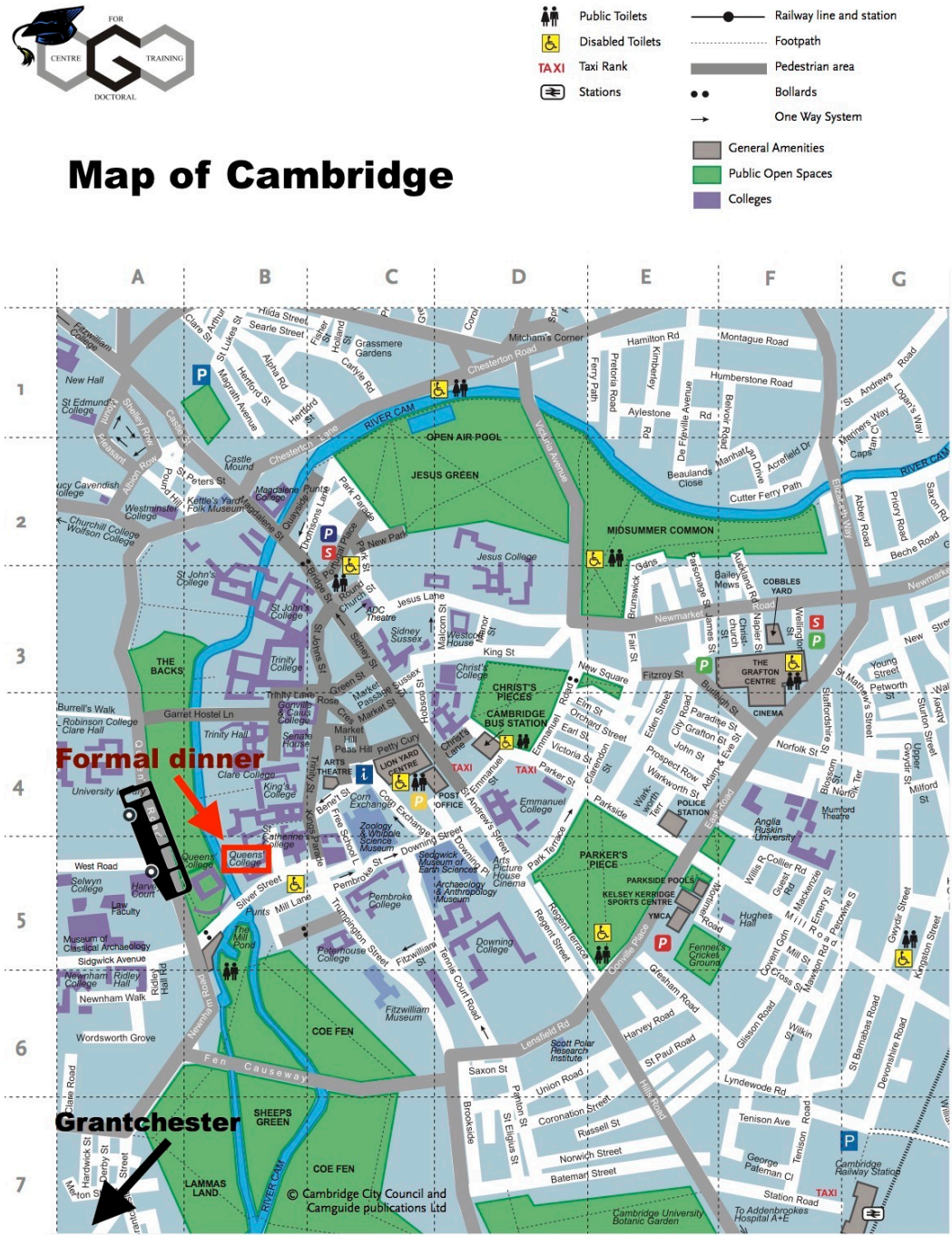

Wyboston Lakes

Monday 12th

11:15-13:00 Arrival

12:00-13:00 Registration and Lunch at Wyboston Lakes

13:45-14:00 Opening remarks

14:00-15:50 ***SESSION 1***
Invited Speaker: Kirill Bolotin

Student Talks: Zenas Van Veldhoven [ST3.17], David Purdie [ST3.3], John Birkbeck [ST3.8], James Dix [ST4.5]

15:50-16:10 Break

16:10-18:00 ***SESSION 2***
Invited Speaker: Francisco Guinea

Student Talks: Jake Arkinstall [ST3.7], Samuel Magorrian [ST3.12], Alex Rakowski [ST3.1], Roshan Krishna Kumar [ST4.8]

18:00-18:30 Break

18:30-19:30 Dinner

19:45-21:15 **1st Year Students Poster Session** - *sponsored by* IOP Semiconductor group

21:30-Late Pub Quiz

Tuesday 13th

07:00-09:00	Breakfast
09:00-10:50	***SESSION 1*** **Invited Speaker: Ali Khademhosseini** **Student Talks:** Artur Filipe Rodrigues [ST3.2], Philippa Hooper [ST3.11], Thomas Fallows [ST4.11], Philip Thomas [ST4.7]
10:50-11:10	Break
11:10-12:30	***SESSION 2*** **Invited Speaker: Clare Grey** **Student Talks:** Simon Engelke [ST3.13], Lewis le Fevre [ST3.10]
12:30-13:30	Lunch
13:45	**Coach to Cambridge**
14:30-17:00	Punting, walks, and museum tours in Cambridge - *sponsored by* APL Materials
17:00-18:15	Free time in Cambridge
18:15-19:00	Meet at Queens' College to get changed
19:00-21:45	**Formal dinner at Queens' College** - drinks reception *sponsored by* Materials Chemistry Today
21:45-23:00	Guests invited to Queens' College bar
23:30	Coach collection from Queens lane

Wednesday 14th

07:00-09:00	Breakfast
09:00-10:50	***SESSION 1*** **Invited Speaker: Cinzia Casiraghi** **Student Talks:** Tian Carey [ST3.15], Daryl McManus [ST4.1], Tom Albrow-Owen [ST3.14], Gabriel Casano [ST3.4]
10:50-11:10	Break
11:10-13:00	***SESSION 2*** **Invited Speaker: Francesco Bonaccorso** ***Women in Science: Panel Discussion sponsored by IOP Women in Physics***
13:00-14:00	Lunch
14:00-15:50	***SESSION 3*** ***Talk by Royal Society of Chemistry*** **Invited Speaker: Amir Gheisi** **Student Talks:** Georgia Kime [ST3.5], Thomas Catherall [ST4.10], Hakan Selvi [ST3.6]
15:50-16:10	Break
16:10-18:00	***SESSION 4*** **Invited Speaker: Jan Stake** **Student Talks:** Edward Pullicino [ST4.3], Simon McAdams [ST4.9], Joesph Butcher [ST3.9], Jacek Wychowaniec [ST4.4]
18:00-18:30	Break
18:30-19:30	Dinner
19:45-21:15	**2nd Year Students Poster Session** - *sponsored by* IOP
21:30-Late	Film night

Thursday 15th

07:00-09:00 Breakfast **(Designated check-out time)**

09:00-10:50 ***SESSION 1***
Invited Speaker: Roland Kawakami

Student Talks: Regina Galceran [STS.1], Denis Bandurin [STS.2], Noel Garcia-Martinez [STS.3], Yang Li [ST3.16]

10:50-11:10 Break

11:10-13:00 ***SESSION 2***
Invited Speaker: Petr Stepanov

Student Talks: Francesco Finocchiaro [STS.4], Jose Lado [STS.5], David Huskisson [ST4.2], Jose Luis Sambricio [STS.6]

13:00-13:45 Lunch

13:45-14:15 ***Publishing Workshop***

14:15-15:15 ***Industrial Partners: Panel Discussion***

15:15-15:30 Break

15:30-16:00 **Prize ceremony** - *sponsored by* Keysight Technologies, RSC and IOP Women in Physics

16:00 Closing remarks: Andrea Ferrari

17:00 Departure / Conference end