CDT Conference 2022

27th-30th June 2022
De Vere Cranage Estate

Sponsored by:

Contents

Welcome Message

The organising committee would like to welcome you back to the first in-person CDT conference since 2019. This year's conference, hosted at the De Vere Cranage Estate, will provide an amazing opportunity to meet peers from across three universities, network, and discuss cutting edge research.

We are also delighted to be welcoming our guest speakers from industry and academia who will be sharing some insight into their work. This is a great opportunity to engage with people from different fields and with varying levels of experience.

If you are in need of assistance at any point, the committee members will be happy help and can be identified by having "ORGANISER" written on their badges. We hope you enjoy the conference!

General Information

Hotel Information

The event hotel will be at De Vere Cranage Estate, Crewe. You will be emailed your room pairing, please go to check in with them on Monday.

Check Out

Check out info will be given at check in.

Attendance at sessions

Attendance at all sessions is expected, unless under extenuating circumstances. Please respect other students and attend all sessions. Additionally, you should arrive at least 5 minutes before the session to get seated.

Information for presenters

Posters should be set up at before before the first session of day. Ie. Before 13:30 Monday, before 9am Tuesday and by 10:15 am Thursday.

Oral presenters should sit at front during the session they will be presenting in. All Oral contributors should email their presentations to andrew.mcellistrim@postgrad.manchester.ac.uk by 12 midday Friday the 24th of June. There will be a laser pointer available for presentations as well as a computer with which your presentation is preloaded on.

General Information

Prizes

There will be £50 Amazon vouchers given as prizes to the best posters and presentations voted by students. For voting a first place vote is worth 3 points, second place is worth 2 points and third place is worth 1 point. The highest points in each category will win the respective prize.

The Royal Society of Chemistry (RSC), one of our sponsors, is also kindly giving two RSC 1-year memberships away; one for a poster presenter and one for an oral presenter. The winners of these will be decided on a nomination basis. You can nominate yourself or someone else to receive this prize.

Voting

Please follow the following links for voting polls.

Student vote for Best-
1st Year Poster: https://forms.gle/XywBJYp4BXvaBG3q7
2nd Year Poster: https://forms.gle/89Ttbh7PSEWGnVZG8
3rd and 4th Year Poster: https://forms.gle/VzuE8Txo7Sy8hBan6
3rd Year Presentation: https://forms.gle/29ToasXCKQU2MSnB9
4th Year Presentation: https://forms.gle/eb5Y2rheYt1yt8DHA

Academics vote for Best-
1st Year Poster: https://forms.gle/eMZ2bq8deSRMu3Pb6
2nd Year Poster: https://forms.gle/ByJQZv7pRrWj9c7X7
3rd and 4th Year Poster: https://forms.gle/Fs2NuSJk4hTJsPPg9
3rd Year Presentation: https://forms.gle/BG7zs3G3SLkQN4UKA
4th Year Presentation: https://forms.gle/U9DAKGpVBww5DAL48

RSC Prize Nominations: https://forms.gle/H2LJhjMksvXg4d1z5

Schedule

Day 1 Schedule (Monday 27th June)

Time	Session
10:00	Bus to venue (Manchester)
11:00	Arrival and check-in
12:30	Lunch
13:30	Opening remarks
14:00	Guest speaker: Dr Anton Guimerà-Brunet
15:00	Break
15:15	4 Student talks: Properties of materials
16:35	Break
16:50	3 Student talks: Properties of materials
17:50	Break
18:30	Dinner
19:30	Poster session 1
21:15	Pub quiz

Day 2 Schedule (Tuesday 28th June)

Time	Session
9:00	Guest speaker: Dr Parth Vashishtha
10:15	Break
10:35	3 Student talks: Energy and sustainability
11:35	Break
11:45	2 Student talks: Energy and sustainability
12:30	Lunch
13:30	5 Student talks: Biology
15:10	Break
15:30	4 Student talks: Theory
17:00	Break
18:30	Dinner
19:30	Poster session 2
21:15	Karaoke

Schedule

Day 3 Schedule (Wednesday 29th June)

Time	Session
9:00	4 Student talks: Fabrication and characterisation
10:20	Break
10:35	4 Student talks: Fabrication and characterisation
12:00	Lunch
13:00	Guest speaker: Prof Cornelia Rodenberg
13:45	Guest speaker: Sam Burrow
14:15	Break
14:30	Guest speaker: Dr I-Ling Tsai
15:00	Break
15:20	Q&A Panel with guest speakers
17:00	Break
18:30	Banquet dinner
20:30	Social

Schedule

Day 4 Schedule (Thursday 30th June)

Time	Session
10:30	Poster session 3
11:40	Break
11:50	Guest speaker: Natalie Warren-Godkin
12:25	Guest speaker: Dr Thanasis Georgiou
13:00	Lunch
14:00	Guest speaker: Dr Sebastian Leaper
14:30	Guest speakers: Dr Mayank Gautam and Dr Pei Yang
15:00	Break
15:15	Guest speaker: Graphene Hackathon
16:00	Closing remarks and prizes
16:40	Depart venue

Invited Speakers

Thank you to all of our fantastic speakers joining us for this event. Your time and contribution is greatly appreciated.

Dr Anton Guimerà-Brunet

IMB-CNM, CSIC. UPC/UAB
Email

Anton Guimerà-Brunet is researcher of IMB-CNM (CSIC) specialized in the development of micro-nanosystems for biomedical applications with a strong background in the development of medical devices and system integration for novel technologies. He is a pioneer in the use of 2D materials, such as graphene for application in bioelectronics and neural interfaces. He participates in several European and National initiatives to develop graphene-based neural implants for bi-directional communication with the nervous system.

Graphene based neural interfaces

Reliable bidirectional neural interfaces are crucial to uncover the fundamental working mechanisms of the brain and for exploiting the full potential of neural prostheses. Despite recent advancements, current microelectrode technologies evidence important shortcomings. Recording capabilities need to be such that they allow the detection of activity from very low frequencies to the signals from individual neurons over large areas and with a high spatial resolution. For stimulation applications, a suitable charge injection capacity is required in order to elicit a response from the tissue being targeted without causing damage. Additionally, these devices must be biocompatible and mechanically compliant with neural tissue. Graphene and graphene-based materials, because their two-dimensional, exhibit a rather unique combination of physicochemical properties which make them an attractive versatile platform for neural technologies.

Dr Parth Vashishtha

Quantum Science
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Dr Parth Vashishtha is a Senior Materials Research Scientist at Quantum Science Ltd, UK. Prior to this, he worked as a Presidential Postdoctoral Fellow at Nanyang Technological University, Singapore. Parth has received his PhD in Physical Chemistry from the Victoria University of Wellington, New Zealand. He is an experimentalist with +6-year experience in semiconductor nanocrystals and optoelectronic devices supported by solid academic credentials. He is the author of more than 32 scientific publications and recognised as ACS Chemistry of Materials top 9 most cited authors in 2019.

Quantum Dots: Synthesis to Application in Devices

Quantum Science Ltd is an award-winning nanotechnology company focusing on innovation, development, and supply of quantum dot materials (small semiconducting nanoparticles with typical size range of 3-10nm) for semiconductor and healthcare applications. It all starts from our unique INFIQ® QDs technology for synthesis, surface functionalisation and ink formulation of colloidal quantum dots with outperforming properties in the infrared range which is beyond the detection limit for human's eyes.

Colloidal QDs are promising candidates for optoelectronic applications such as solar Cells photodiodes, and LEDs due to theirs size tuneable band gap, excellent optoelectronic properties, tuneable surface functional properties, low processing cost, and high efficiency in devices.[1] (Continued on next page)

Dr Parth Vashishtha

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At Quantum Science Ltd, we develop several types of semiconductor nanocrystals including INFIQ® High Performance QDs, INFIQ® Lead-Free QDs, INFIQ® Eco QDs which offers world champion external quantum efficiency in devices with the absorption wavelength ranging from 700 nm to 2,200 nm. INFIQ® QDs are synthesised in a way that their size or quantum confinement can be precisely controlled to tune their infrared optoelectronic properties. These colloidal QDs offer an attractive platform for high performance and low-cost photodetectors for machine vision, consumer electronics, security surveillance, autonomous vehicles and healthcare applications depending on their absorption wavelength.

1) Butkus, J., Vashishtha, P., Chen, K., Gallaher, J. K., Prasad, S. K., Metin, D. Z., & Hodgkiss, J. M. (2017). The evolution of quantum confinement in CsPbBr3 perovskite nanocrystals. Chemistry of Materials, 29(8), 3644- 3652. 2) Hines, M. A., & Scholes, G. D. (2003). Colloidal PbS nanocrystals with size-tunable near-infrared emission: observation of post-synthesis self-narrowing of the particle size distribution. Advanced Materials, 15(21), 1844-1849.

Prof Corneilia Rodenberg

The University of Sheffield
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Professor Rodenburg obtained her first Degree in Engineering in Germany in 1997 and her PhD from Sheffield Hallam University in 2001. She joined the Department of Materials Science & Metallurgy at the University in Cambridge as a postdoctoral researcher before moving to the Department of Materials Science & Engineering at the University of Sheffield. She was awarded a Royal Society Dorothy Hodgkin Fellowship and later held an EPSRC Early Career Fellowship (2016-2021). She was Senior Lecturer in Materials Science & Engineering prior to her appointment as Chair in Nanostructured Materials Technology

There is no doubt that 2D materials can deliver improvements in battery and solar cell technology. There has been much focus on 2D materials discovery but less attention has been paid to questions such as: which structures to incorporate the 2D materials for maximum benefit?; how could such structures be created as part of the manufacturing process?; how to ensure the reliability of the 2D properties prior and after processing?. This talk will give some answers to the above questions using examples from solar cells and lithium ion batteries, using information obtained from scanning electron microscopy and in particular Secondary Electron Hyperspectral Imaging (SEHI). The basics of SEHI will be covered and information encoded in Secondary Electron Spectra will be discussed in the example of graphene and graphite and other carbon based materials. 3D structure formation from 2D materials using electron beams will also be touched upon.

Sam Burrow

Anaphite
Email

Sam Burrow studied Chemistry at the University of Bristol. After this he worked as a Research assistant at several institutions. Following this he Co-Founded Anaphite a Graphene start up. Their mission is to We want to enhance the materials we rely on every day with graphene, to help power the sustainable energy revolution.

Title TBA

Dr I-Ling Tsai

GEIC
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Bio: Dr. I-Ling Tsai is an application specialist in Graphene Engineering Innovation Centre (GEIC). In order to increase the level of commercial exploitation of graphene & 2D materials (2DM), I-Ling currently works alongside commercial collaborative partners who want to see the potential of 2DM in energy storage. She has over seven years of experience working on energy storage devices with graphene-based materials

Energy Storage in Graphene Engineering Innovation Centre (GEIC)

Energy laboratory in the GEIC provides miniature production line for battery and supercapacitor coin and pouch cells. Since 2016 to present, the GEIC energy lab has fabricated, scaled up devices and supported several SME projects. In this talk, the GEIC energy storage capability will be discussed using live project examples.

Natalie Warren-Godkin

Royal Society of Chemistry (RSC)
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Natalie studied her MChem degree at the University of Hull, during which she had a placement year at GSK. Natalie went on to be an Analytical Chemist with 2.5 years of experience within the pharmaceutical and biotechnology sectors, before joining the Membership team at the Royal Society of Chemistry. Her role as Membership Development and Recruitment Executive involves delivering new and enhanced products and services that support the professional development of RSC members.

Starting your journey with the RSC to support your career and professional development

Natalie will be giving an overview of RSC membership for early career researchers. She will also be discussing the key benefits of membership, how the RSC can support early career researchers with their professional recognition and development, funding opportunities to support research and other activities and will also delve into publishing/peer-reviewing with the RSC.

Dr Thanasis Georgiou

Henry Royce Institute
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Thanasis is a business development manager based at the Henry Royce Institute of Advanced Materials, based at The University of Manchester. A graduate of the University of Manchester, upon completion of his NowNano CDT PhD course, he took a position in various start-ups where he worked in developing new products from graphene materials, pitching for funding and setting up manufacturing facilities for production. In 2019 he moved to his current role where he works at the interface of academia and business, working collaboratively with business leaders and academics to develop and commercialise emerging technologies and utilise academic expertise.

How can the Henry Royce Institute help PhD students?

The Henry Royce Institute is the UK's National Institute for Advanced Materials; they combine the expertise of 9 world-leading institutions and unify it under a single front door. In this talk, Thanasis will introduce the Institute's vision and discuss some of the facilities that they have available for use for researchers and industry, their access schemes and will share some of their latest thinking around innovation and commercialisation support for early-stage researchers.

Dr Sebastian Leaper

Watercycle Technologies
Email

Bio: Seb is a CDT alumni and Founder & CEO of University of Manchester spin-out company, Watercycle Technologies. He has spent the majority of his career in Manchester, having been drawn to the city by its music scene, nightlife and an interesting new material that had just brought the city the 2010 Nobel Prize in Physics.

He moved to Manchester in 2011 after hearing about this and enrolled on an MEng in Materials Science & Engineering at the University. He spent his third year working as a packaging technologist for Mars Drinks in Basingstoke and spent his final year making and testing graphene oxide hydrogels. Following this, he was encouraged to stay at Manchester to start a PhD and was later awarded a place on the CDT.

After winning the Eli & Britt Harari Graphene Enterprise Award in his first year, Seb's research direction was steered towards commercialising his graphene-based membranes for applications including desalination, lithium extraction and wastewater treatment.

Now actively raising investment, he is looking to build out a team to work on a collaboration project with Cornish Lithium (UK) aiming to build and install the first carbon neutral lithium extraction system at their R&D facility in Penryn.

Dr Mayank Gautam

Versarien, 2-DTech Ltd.

Dr Mayank Gautam, completed his undergraduate studies in 2012 in Textile Sciences from University of Manchester, followed by a PhD in Material Sciences focussing on the development of subsea flexible composite risers for GE Oil & Gas (UK) that could be operated at greater ocean depths. Following his PhD, Mayank worked as a Postdoctoral researcher at University of Manchester for 3 years working on manufacturing, optimisation, and finite element modelling of bespoke fibre reinforced composite materials for automotive and aerospace applications, before moving to industry and joining Composite Braiding Ltd. (UK) as a Design & Technology Engineer. After a year working on Thermoplastic Composites, he joined the technical team of 2-DTech Ltd. (a subsidiary of Versarien Plc) as a Senior Scientist and entered the world of nanomaterials. His current focus is the application of 2D materials in textiles applications and polymer-composite materials.

(See next page for talk description)

Dr Pei Yang

Versarien, 2-DTech Ltd.

Dr Pei Yang, he is a chemical engineering graduate from Beijing Forestry University in China, which was followed by a Masters degree and PhD in polymer science and materials engineering from the University of Manchester. During his PhD, Pei mainly focussed on 2D materials including graphene, Mxenes and boron nitride thermoset composites with multi-functional properties. Following his PhD, he worked as a research technician at the Graphene Engineering Innovation Centre (GEIC) on manufacturing, characterization, optimisation of graphene polymer composites for structure, automotive and aerospace applications. He joined 2-DTech Ltd. as a Project Scientist in 2021 which took his leap fully from academia to industry. His current focus is application of 2D materials in new generation multi-functional composite materials.

Versarien's Graphene Developments

Versarien will present our experiences moving from PhD positions at University of Manchester to industry, now working within Versarien, a Tier 1 partner of the Graphene Engineering Innovation Centre (GEIC). We will present ongoing innovations, development and scale-up work performed by Versarien’s UK graphene R&D subsidiaries (2-DTech Ltd. and Cambridge Graphene Ltd.). Significant commercial traction has been made following lab and wearer trials of Versarien’s Graphene-Wear formulations - water-based graphene inks that are printed on textiles and other substrates for thermal and moisture management. They will also present recent work in the field of enhanced fibre-reinforced polymer composites for aerospace and automotive applications.

Student Talks

Student talks have been divided into five categories: biology, theory, properties of materials, energy and sustainability, and fabrication and characterisation. The list of students speaking under each topic is below with the page number containing their title and abstract. Talk topic order will run in the order shown below.

Properties of Materials

Student Talks

Energy and Sustainability

Biology

Theory

Student Talks

Fabrication and Characterisation

Ciaran Mullan
Prof. Artem Mishchenko
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Moiré superlattices and Hofstadter's butterfly in graphite aligned to boron nitride

Heterostructures of twisted or closely aligned van der Waals materials have provided the ideal length scale of superlattices to investigate Moiré phenomena in recent years, such as the fractal quantum Hall effect (Hofstadter's butterfly) and Brown-Zak magnetoconductivity oscillations. Graphene has been the material of choice for this so far; either in twisted few layers of graphene alone, or aligned to its insulating counterpart boron nitride. Here we extend this research area into the 3rd dimension by aligning graphite to hexagonal boron nitride. The quantum Hall effect (QHE) is usually forbidden in 3D systems, however it has recently been shown that in graphite the electron dynamics can be reduced to continuous only in the one dimension parallel to applied magnetic field, and in sufficiently thin graphite films standing waves form which quantises this remaining dimension, allowing the observation of QHE [1]. Here we show that in aligned graphite films the QHE in the bulk is surprisingly still modulated by a Moiré potential at the surface, and the observed QHE states show the fractal nature of the Hofstadter butterfly. In addition, there exists distinct states confined to the surfaces of graphite, which also display Hofstadter fractal states if the surface is an aligned interface to boron nitride. The formation of magnetic Bloch states at fields corresponding to integer magnetic flux per superlattice unit cell results in electrons returning to straight trajectories, and this causes oscillations in conductivity as a function of magnetic field, known as Brown-Zak oscillations. At temperatures high enough to smear Landau quantisation, these Brown-Zak oscillations are clearly observed in the aligned graphite-boron nitride systems.

[1] - Yin, J., Slizovskiy, S., Cao, Y., Hu, S., Yang, Y., Lobanova, I., Piot, B. A., Son, S.-K., Ozdemir, S., Taniguchi, T., Watanabe, K., Novoselov, K. S., Guinea, F., Geim, A. K., Fal'ko, V., & Mishchenko, A. (2019). Dimensional reduction, quantum Hall effect and layer parity in graphite films. *Nature Physics*, *15*(5), 437–442. https://doi.org/10.1038/s41567-019-0427-6

David Sanderson
Dr. Andrey Kretinin
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Isotopic Purity Modulation of the Thermal Conductivity of Hexagonal Boron Nitride

For six decades, improvements in microprocessor performance have followed Moore's Law but processor clock speeds plateaued in the 2000s due to the limit of managing heat loads. As microprocessor sizes reach their physical minimum limits, further performance improvements of conventional electronics will require improved thermal management. Hexagonal boron nitride (hBN) has ideal properties for thermal management as its phonon dispersion characteristics make it a very good conductor of heat whereas its very high band gap makes it a very good electrical insulator. Additionally, its highly anisotropic properties make it a good candidate material for lateral heat spreading. Naturally occurring boron contains two isotopes. It has been shown that the conductivity of hBN at large length scales can be improved by modulating the isotopic purity. Isotopically pure hBN is therefore of interest for electronics thermal management. In this talk I will present measurement techniques for determining in-plane and out-of-plane thermal conductivity of hBN at length scales comparable with those seen in modern electronic devices and discuss the results obtained to date.

Hugh Ramsden
Prof. Manish Chhowalla
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Revealing Optoelectronic Processes in Monolayer Transition Metal Dichalcogenides with Nanometre Resolution Cathodoluminescence

Conventionally, luminescence processes in layered materials are probed using a focused laser for excitation, in which the ultimate spatial resolution is diffraction limited to ~1 µm. However, many submicron structures are present in luminescent layered material systems e.g. depletion regions [1], heterostructure interfaces [2] and localised defects [3]. Scanning electron microscopy cathodoluminescence (SEM-CL) can reach < 100 nm resolution [4], whilst still allowing one to probe complex device structures. Here, we use SEM-CL to probe the luminescence properties of a monolayer WSe2 device, encapsulated in 20 and 100 nm hBN. We uncover a submicron region which exhibits a 3x enhancement in luminescence intensity, close to the grounded region of the WSe2 flake. To understand the effect grounding the WSe2 could have on luminescence, we employ Monte-Carlo simulations which give insight into the distribution of carriers in this device under electron bombardment, helping explain the enhancement. This lays foundational understanding of cathodoluminescence processes in layered materials heterostructures.

[1] Frisenda, R., Molina-Mendoza, A. J., Mueller, T., Castellanos-Gomez, A. & Zant, H. S. J. van der. Atomically thin p–n junctions based on two-dimensional materials. Chem. Soc. Rev. 47, 3339–3358 (2018).
[2] Sahoo, P. K., Memaran, S., Xin, Y., Balicas, L. & Gutiérrez, H. R. One-pot growth of two-dimensional lateral heterostructures via sequential edge-epitaxy. Nature 553, 63–67 (2018).
[3] Palacios-Berraquero, C. et al. Large-scale quantum-emitter arrays in atomically thin semiconductors. Nat Commun 8, 1–6 (2017).
[4] Zheng, S. et al. Giant Enhancement of Cathodoluminescence of Monolayer Transitional Metal Dichalcogenides Semiconductors. Nano Lett. 17, 6475–6480 (2017).

Ismail Sami
Prof. Manish Chhowalla
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Semiconducting to metallic phase transition of molybdenum disulfide

Direct bandgap and high charge mobility are useful properties of semiconducting transition metal dichalcogenides (TMDs) for electronic applications [1]. Metallic phases of TMDs have also shown promise for applications from field effect transistors to catalysis [2,3]. In this study, we show the phase transition of molybdenum disulfide for further electronic and electrochemical applications. First, we demonstrate the partial semiconducting-metal phase transition of mechanically exfoliated MoS2 for multiphase TMD devices. Second, we investigate electrochemical actuators based on restacked chemically exfoliated nanosheets of metallic MoS2.

[1] Wang, Q. H., Kalantar-Zadeh, K., Kis, A., Coleman, J. N., & Strano, M. S. (2012). Electronics and optoelectronics of two-dimensional transition metal dichalcogenides. Nature nanotechnology, 7(11), 699-712.
[2] Wang, Y., Kim, J. C., Wu, R. J., Martinez, J., Song, X., Yang, J., ... & Chhowalla, M. (2019). Van der Waals contacts between three-dimensional metals and two-dimensional semiconductors. Nature, 568(7750), 70-74.
[3] Voiry, D., Salehi, M., Silva, R., Fujita, T., Chen, M., Asefa, T., ... & Chhowalla, M. (2013). Conducting MoS2 nanosheets as catalysts for hydrogen evolution reaction. Nano letters, 13(12), 6222-6227.

Max Taylor
Dr. Michael Thompson
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High and low frequency dynamics of superconducting circuits based on graphene Josephson junctions

Josephson junctions are the basis of superconducting electronics. Using graphene to bridge a gap between two superconducting electrodes, where more traditional junctions might use an insulator or normal metal, introduces an active material into the Josephson junction structure. The properties of the junction can then be tuned by electrostatically gating the graphene to control its charge carrier concentration. This affects the critical current of the junction, which can influence the operation of superconducting circuits. Some superconducting circuits use high frequency signals to process information, so a test circuit has been fabricated with Josephson junctions using graphene encapsulated in hBN with the intention of studying the circuit dynamics at high and low frequencies. The presentation will discuss the progress of the circuit characterisation, and the potential avenues that will be explored to progress the understanding of graphene Josephson junction dynamics in high frequency operation.

Michael Pitts
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Fabrication and measurement of monolayer WSe_2 mechanical resonators

Over the last decade considerable research has been done on suspended monolayer material resonators [1-5] for potentially creating quantized states of motion for fundamental tests of quantum theory and for quantum technology applications. However, quality factors of monolayer resonators remain low compared to those made from bulk materials including silicon nitride [6]. The exact cause these low quality factors is unknown and its study is hindered through low device yields and fabrication issues limiting systematic studies [5]. I will present my work towards developing and improving techniques to fabricate monolayer resonators and measure their motion. I will describe using gold exfoliation to suspend large WSe2 (an optically active semiconducting layered material) monolayers. Once suspended I used a highly sensitive interferometer to measure both driven and thermal motion of the monolayer resonators. With this method of fabrication and measurement I have been able to measure over 50 monolayer resonators on a single sample and can do this on multiple substrate types, allowing for statistical comparisons to be made between different resonator samples. This has allowed me to observe correlations between tension and loss rate and resonator radius and loss rate, both of which indicate bending losses at the resonator edges being the primary loss mechanism. These results indicate that bending losses may be the primary cause of mechanical loss for these resonators, similarly to how bulk resonators are affected [6]. My work reveals new ways to increase quality factor and the fabrication and measurement methods I have used provide a means through which they can be explored.

References:

[1] Castellanos-Gomez et al. (2013), Single-Layer MoS2 Mechanical Resonators. Adv. Mater., 25: 6719-6723. https://doi.org/10.1002/adma.201303569
[2] Nicolas Morell et al. Nano Letters 2016 16 (8), 5102-5108 DOI: 10.1021/acs.nanolett.6b02038
[3] Zheng XQ, Lee J, Feng PX. Hexagonal boron nitride nanomechanical resonators with spatially visualized motion. Microsyst Nanoeng. 2017;3:17038. doi:10.1038/micronano.2017.38
[4] Nicolas Morell et al. Nano Letters 2016 16 (8), 5102-5108 DOI: 10.1021/acs.nanolett.6b02038
[5] Robert A. Barton et al. Nano Letters 2011 11 (3), 1232-1236 DOI: 10.1021/nl1042227
[6] S. A. Fedorov et al. Phys. Rev. B 99, 054107 – Published 28 February 2019

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Electrically controlled heat transport in multilayer graphene

The ability to control heat transport with electrical signals has been an outstanding challenge due to the lack of efficient electrothermal materials.

Here, we demonstrate a graphene-based electrothermal switch enabling electrically tuneable heat flow.

The device uses reversible electro-intercalation of ions to modulate the in-plane thermal conductivity of graphene film by over thirteen-fold *via* electrically tuneable phonon scattering.

We anticipate that our results could provide a realistic pathway for adaptive thermal transport, enabling a new class of electrically driven thermal devices which would find a broad spectrum of applications in aerospace and microelectronics.

Alexandra Jones
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Organic Redox Flow Batteries for A Greener Energy Grid

Rising global energy needs coupled with detrimental climate effects of CO2 emissions have fast-tracked demand for carbon-free energy sources. The utilisation of renewable energy resources has increased dramatically over recent years, but their unpredictability and intermittency make inclusion into the current electrical grid a challenge. This can be solved through low cost, high efficiency, scalable large-scale electrical energy storage systems.

Long-lifetimes, scalability and safety make redox flow batteries (RFBs) the most realistic energy storage system for this task. The conventional RFB design comprises two electrolyte-containing half-cells separated by a lifetime limiting ion-exchange membrane and metallic redox active materials which are rare, costly and lack chemical tuneability. These factors hinder major commercialisation.

The present research replaces the metal components with cheap, abundant organic materials and develops a system based on immiscible electrolyte solutions. The aim is to remove the expensive and lifetime limiting components and make RFBs accessible for global integration.

Cassius Clark
Prof. Dominic Wright and Prof. Clare Grey
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Ex-situ Solid-State NMR gives insight into the storage mechanism of lithium and sodium in phosphorus-doped carbon

Cassius Clark 1,2 , Christopher A. O'Keefe 1 , Dominic S. Wright1 , Clare P. Grey1,2
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2Cambridge Graphene Centre, University of Cambridge, Cambridge, UK

The increasing energy demands of the 21st century will require fundamental improvements to existing battery technology. One strategy is the improvement of the specific capacity of currently used carbonaceous anodes in Li- and next-generation Na-ion batteries. Phosphorus shows promise as an alternative anode material, with its ability to reversibly form lithium- or sodium-phosphorus compounds during electrochemical cycling, resulting in a potential capacity 6 times greater than that of standard graphite or hard carbons.1,2 However, the conductivity, stability and safety of elemental P as an anode prevents the technology from reaching real-world applications.3 Whilst previous attempts have been made to utilize carbon-phosphorus composites (i.e., with separate carbon and phosphorus domains), 4,5,6 the incorporation of phosphorus into the graphitic lattice and subsequent use of these materials in electrochemical applications has not been explored. Our single-precursor, single-step pyrolysis synthesis allows the production of stable phosphorus-doped carbon materials. Interstitial incorporation of phosphorus into the turbostratic graphitic lattice gives greater stability than pure phosphorus and improved capacity in Li-ion batteries compared to an undoped graphite. The Na insertion chemistry is similarly explored. Moderate control of the

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phosphorus content, which is also present in a variety of allotropes, provides some control over capacity and stability. Via a thorough structural, compositional and electrochemical analysis, including the use of ex situ solid-state NMR, the insertion mechanisms of these materials may be explored. Identification of the preferential sites used for ion storage within phosphorus-doped graphite gives an improved understanding of the further alterations needed to develop it as a future anode material.

1. Nakhanivej, P. et al. Revealing molecular-level surface redox sites of controllably oxidized black phosphorus nanosheets. Nat. Mater. 18, 156–162 (2019).
2. Mayo, M., Griffith, K. J., Pickard, C. J. & Morris, A. J. Ab Initio Study of Phosphorus Anodes for Lithium- and Sodium-Ion Batteries. Chem. Mater. 28, 2011–2021 (2016).
3. Sun, L. Q. et al. Electrochemical activity of black phosphorus as an anode material for lithium-ion batteries. J. Phys. Chem. C 116, 14772–14779 (2012).
4. Liu, W., Zhi, H. & Yu, X. Recent progress in phosphorus based anode materials for lithium/sodium ion batteries. Energy Storage Mater. 16, 290–322 (2019).
5. Kim, Y. et al. An amorphous red phosphorus/carbon composite as a promising anode material for sodium ion batteries. Adv. Mater. 25, 3045–3049 (2013).
6. Sun, J. et al. Formation of stable phosphorus-carbon bond for enhanced performance in black phosphorus nanoparticle-graphite composite battery anodes. Nano Lett. 14, 4573– 4580 (2014).

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Immobilized 2D sandwich membranes for the advancement of sustainable water technology

Membrane distillation (MD) is an emerging technology that has the potential to outperform conventional water treatment processes. Low-grade heat sources (such as solar power or waste heat streams) can be used to produce water, enabling sustainable water treatment. However, membrane distillation is currently not widely used in industry due to stability challenges including membrane fouling and pore wetting. In this work, GO is explored to overcome these issues, with a particular focus on pore-wetting. Unlike mixed matrix membranes, laminate 2D membranes can have poor adhesion to the substrate. In this work, a successful immobilisation method using anchor molecules was carried out to make sandwich membranes. Overall this work outlines the current progress in the use of GO for developing anti-fouling and pore-wetting resistant membranes for MD.

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Proton and li-ion Permeation through Graphene with Eight-Atom-Ring Defects

Defect-free graphene is impermeable to gases and liquids but highly permeable to thermal protons. Atomic-scale defects such as vacancies, grain boundaries, and Stone–Wales defects are predicted to enhance graphene's proton permeability and may even allow small ions through, whereas larger species such as gas molecules should remain blocked. These expectations have so far remained untested in experiment. Here, we show that atomically thin carbon films with a high density of atomic-scale defects continue blocking all molecular transport, but their proton permeability becomes ~1000 times higher than that of defect-free graphene. Lithium ions can also permeate through such disordered graphene. The enhanced proton and ion permeability is attributed to a high density of eight-carbon-atom rings. The latter pose approximately twice lower energy barriers for incoming protons compared to that of the six-atom rings of graphene and a relatively low barrier of ~0.6 eV for Li ions. Our findings suggest that disordered graphene could be of interest as membranes and protective barriers in various Li-ion and hydrogen technologies.

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Operando Raman mapping of graphene-based lithium-sulfur batteries

Lithium-sulfur batteries have a gravimetric capacity approximately four times greater than conventional lithium-ion batteries [1], however they require host matrices to retain electrical contact with the active material and prevent irreversible capacity loss [1, 2]. In this work, graphene-based sulfur host matrices are synthesised using a novel method (high-pressure co-homogenization [3]), and operando Raman mapping is applied to characterise the spatial distribution of active material as a function of voltage. Co-homogenization results in uniformly distributed, smaller sulfur (S8) particles than conventional melt-infiltrated [4] electrodes (~5µm vs. ~10-50µm). Operando Raman mapping, with insights provided by principal component analysis, shows the spatial variation in the rate of S8 utilisation during discharge and its redistribution during charge, indicating the electrical connectivity of the graphene host matrix. Therefore, operando Raman mapping complements the information obtained from electrochemical characterisation and is a promising tool in future optimisation of candidate battery materials.

[1] J. B. Robinson et al., J. Phys. Energy, 3(3), 031501, (2021)
[2] K. Xi et al., Nanoscale, 6(11), 5746, (2014)
[3] P. Karagiannidis et al., ACS Nano, 11(3), 2742, (2017)
[4] D. Di Lecce, et al., J. Power Sources 472, 228424 (2020).

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Towards building a contact lens based photodetector for ex-situ diagnosis of neurodegenerative diseases

Contact lens based sensors can potentially be used to diagnose a wide range of systemic diseases and ocular conditions. In this talk, I discuss the steps towards fabrication and integration of a photodetector into a contact lens. Such a photodetector can yield valuable information about blinking dynamics, which are correlated with symptoms of neurodegeneration. Moreover, blinking dynamics acquired using a contact lens can also inform manufacturers about the effects of wearing contact lenses such as dry eyes disease or the irritation of the conjunctiva. Enabling such measurements and data communication under the space constraints of a contact lens poses several engineering challenges and some solutions to these challenges are discussed in this talk. Results showing a working photodetector and simulated antennas are also presented and discussed.

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The Impact Graphene Oxide and Hexagonal Boron Nitride Nanosheets on Innate Immune Memory Generation and Inflammation

Engineered 2D nanomaterials like graphene oxide (GO) and hexagonal boron nitride (hBN) are a growing aspect of technology. However, research is still inconclusive on respiratory responses to such materials. Innate immune memory (IMM) is the acquisition of memory like characteristics via epigenetic modifications, potentially inducing altered immune responses to environmental stimuli.

Bone marrow derived macrophages (BMDM) were exposed for 24 h to GO or hBN, and then re-exposed to the same or different stimuli after 5 days. Cytokine secretion, uptake, gene expression and epigenetic markers were measured to investigate inflammation and IIM modifications. Raman mapping and confocal microscopy indicated uptake of both materials; however GO didn’t induce inflammation or IIM. Neither did GO change responses to secondary stimuli such as lipopolysaccharide and β-glucan. Exposure to hBN induced inflammatory responses associated to iNOS pathways. Nevertheless, hBN exposure did not indicate the significant presence of epigenetic markers related to IIM.

For in vitro exposure, GO could be considered ‘inert’ eliciting no response. In contrast, hBN induced inflammation but not IMM epigenetic modifications. The lack of IIM epigenetic responses is a beneficial outcome for safety. It suggests the innate response would not change over repeated low dose exposures, as expected in occupational exposures.

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Graphene oxide complexed with integrin antagonists for targeting of plasma membrane receptors in glioblastoma cells

Graphene oxide (GO) is one of the most promising two-dimensional materials (2DMs), due to outstanding properties that hold potential for various applications, especially in medicine. GO has already been used as a carrier for biomolecules such as proteins, peptides and nucleic acids, to name a few. We have established that GO predominantly interacts with the plasma membrane of cancer cells, rather than being taken up. Therefore, we hypothesize that GO functionalized with therapeutic molecules could target specific signalling pathways emerging from the plasma membrane of cancer cells.

We prepared and characterized GO complexed with either cyclic or linear type of commercially available integrin antagonist (cRGD or lRGD, respectively) using non-covalent approach (GO:RGD) in order to inactivate plasma membrane bound integrin receptors in glioblastoma cells as a model system. RGD concentration needed to obtain biological effects was determined in vitro by studying cellular viability, motility and directionality, as well as the inhibition of phosphorylation of focal adhesion kinase (FAK), which is correlated with metastatic potential of the cells. Subsequently, GO:RGD purification protocols were optimized and RGD release kinetics was studied using trinitrobenzene sulfonic acid assay. Using 50 g/mL of lRGD or 0.6 g/mL of cRGD to complex with GO, we show that 89.1% ± 3.2% of the RGD bounds to GO even after 4 purification cycles. The release of the peptide in water was also studied, obtaining 100% of the release after 24h in water.

Our future research would be focusing on fully characterizing the physicochemical properties of theGO:RGD complexes as well addressing the above mentioned biological endpoints in vitro.

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The 2D graphene oxide biomolecule corona for cancer secretome biomarker discovery

Graphene oxide is a two-dimensional (2D) nanomaterial with distinctive large surface area and high surface reactivity. Upon interaction with biological fluids, the surface of graphene oxide is spontaneously covered by a vast array of biomolecules to form a "biomolecule corona"[1]. This corona forming ability has been shown to enhance the discovery of low abundant biomolecules and has attracted significant interest as a promising technology in cancer biomarker discovery[2].

Interestingly, the current utilization of the graphene oxide corona in biomarker discovery has focused mainly on the blood. The lack of specificity in identified blood biomolecules poses a major challenge to biomarker discovery as the vast array of biomolecules in the blood are not related to the cancer. The cancer cell secretome, on the other hand, consists of biomolecules specifically released by the cancer cell and provides a suitable platform for identifying potential cancer-specific biomarkers.

Therefore, in this study, the biomolecule corona formed around graphene oxide nanosheets is exploited to provide an in-depth analysis of the lung and brain cancer secretome. The cancer cell secretome was obtained by culturing lung adenocarcinoma (A549) cell-lines and brain glioma (GL261) cell-lines both in monolayer cultures and in the in vivo like 3D-environment of a hollow fibre bioreactor. The secretome was incubated with graphene oxide nanosheets and the formed biomolecule corona was isolated using membrane ultrafiltration. Preliminary mass spectrometry analysis of the isolated corona-coated proteins from the secretome has shown the identification of significantly more proteins in the corona than currently utilized conventional techniques.

In the future, we, therefore, plan to utilize the 2D biomolecule corona platform to correlate the proteomic fingerprint from the cancer secretome with patient plasma samples and identify potential cancer biomarkers.

1. Palmieri, V., Perini, G., De Spirito, M., Papi, M., 2019. Graphene oxide touches blood: in vivo interactions of bio-coronated 2D materials. Nanoscale Horizons 4, 273–290.. doi:10.1039/c8nh00318a
2. Di Santo R, Digiacomo L, Quagliarini E, et al. Personalized Graphene Oxide-Protein Corona in the Human Plasma of Pancreatic Cancer Patients. *Frontiers in bioengineering and biotechnology*. 2020;8:491-491. doi:10.3389/fbioe.2020.00491

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Development of bio-mimetic graphene FET sensors for diagnostic applications

My project aims to study, design and develop bio-mimetic sensors based on graphene field effect transistors (FETs), which have novel mechanical, thermal, chemical, and electronic properties. Ion-selective FETs (ISFETs) developed with graphene channels have been reported, where the ion sensing mechanism can be based on both Faradaic and electrostatic interactions. In addition, graphene ISFETs functionalised with bilayer lipid membranes have been demonstrated, and artificial bilayer lipid membranes can be functionalised with transmembrane proteins such as αHaemolysin nano-pores or ion channels. The rationale of this project focuses on the measurement of analytes at the smallest concentrations that are relevant to biological processes, which allows the earliest detection and assessment of diseases. In this context, biological signalling at the cellular level occurs across the cell membrane, a lipid bilayer with embedded transmembrane proteins. Based on a novel bio-mimetic sensing strategy, the complete prototype of a point of care (POC) graphene ISFET-based biosensor gated through an engineered ion-selective membrane will be developed to detect pathogen-specific biomarkers.

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ARPES: A test for modelling gated twistronic graphenes

Motivated by experimental observations, we present a theoretical model for angle-resolved photoemission spectroscopy (ARPES) of Twisted monolayer-bilayer graphene (tMBLG), that is verified alongside experimental results. We hope to present ARPESs potential for furthering the understanding of these novel systems.
Our work begins with a continuum model to describe interlayer coupling in tMBLG [4]. Next, we consider the conventional methods [5] for converting our graphenes systems wave functions into ARPES intensity plots. Following this, we consider the additional effects due to the interaction Hamiltonian for the photoemission process, the polarisation of the light [6,7] and the photon energy used. Next, we present the effect of gating and the subsequent interlayer screening visualised with ARPES intensity plots. We use this information to study the change to the systems electronic structure in the presence of gating. The results demonstrate the importance of considering the field across the layers as well as the change in carrier concentration when a gate voltage is applied. Additionally, we study the interatomic coupling which has not been previously shown at lower angles (θ<5o) where interlayer coupling is highest and there is band hybridization that can lead to the formation of tunable van Hove singularities [8].

[1] Rafi Bistritzer and Allan H. MacDonald, PNAS 108.30, pp. 12233–12237, July 2011
[2] M. Mucha-Kruczyński et al., Phys. Rev. B 77, p. 195403, nMay 2008.
[3] Choongyu Hwang et al., In: Phys. Rev. B 84, p. 125422Sept. 2011.
[4] Jihang Zhu et al., Phys. Rev. B 103, p. 235146, June 2021.
[5] J. J. P. Thompson et al., Nature Communications 11.1, July 2020.

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Eccentric Corbino FET in magnetic field: a highly tunable photodetector

We study gated field effect transistors (FETs) with an eccentric Corbino-disk geometry, such that the drain spans its circumference while the off-center inner ring acts as a source. An AC THz potential difference is applied between source and gate while a static source-drain voltage, rectified by the nonlinearities of FET electrons, is measured. When a magnetic field is applied perpendicular to the device, a strong resonance appears at the cyclotron frequency. The strength of the resonance can be tuned by changing the eccentricity of the disk. We show that there is an optimum value of the eccentricity that maximizes the responsivity of the FET.

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Field-induced pairing transition in a 2D Rashba superconductor

Most quantum computing technologies are so fragile that the majority of their computing power is used to correct errors in the computation arising from decoherence. Emergent excitations known as Majorana modes, could be a platform for decoherence-resistant quantum computing. These Majorana modes are predicted to exist the boundaries of “topological” superconductors: materials with topological surface states and p-wave electron pairing. Layered superconductor β-PdBi2 satisfies the first criterion, with some evidence for p-wave pairing in thin films and at surfaces under certain conditions. Using a self-consistent theoretical framework, we identify a field-induced first order phase transition between s- and effective p-wave states in a spin-helical Fermi surface resembling that of a β-PdBi2 monolayer. We discuss the origin of this effect due to the interplay of spin-orbit coupling and magnetic fields, before extending our analysis to more closely describe surface states in β-PdBi2.

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GFET Lab: An Open Source Software Tool for Simulating Graphene Field-Effect Transistors

We present GFET Lab, a user-friendly, open-source software tool for simulating Graphene field-effect transistors (GFETs). We identify the key criteria for a suitable predictive model for circuit design, and selected a model from the literature to implement in the software. We introduce modifications to improve the predictive properties, namely accounting for saturation velocity and the asymmetry in n- and p-type carrier mobilities. We validate the model by comparing GFETs simulated in our tool against experimentally-obtained GFET characteristics with the same materials and geometries and find good agreement between GFET Lab and experiment. We demonstrate the ability to export SPICE models for use in higher level circuit simulations and compare SPICE simulations of GFETs against GFETs simulated in GFET Lab, again showing good agreement.

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Probing TMD defects with atomic scale probe microscopy

Defects on the atomic scale lead to dramatic local changes in materials that collectively transform the macroscopic properties of the host material. The characterization of defects in 2D materials and an understanding of their formation is therefore important in order to produce consistent material properties and to explore methods of precise tuning. Alternatively, the chaotic formation of defects can be exploited in order to make unclonable keys and security tags [1]. Atomic resolution imaging techniques provide an unparalleled insight into 2D material defects, particularly scanning probe microscopy methods [2,3] which can identify electronic properties unique to specific defect types.

Here, we show that defects can be identified with atomic resolution using conductive atomic force microscopy (cAFM) performed in an ambient environment on monolayer Transition Metal Dichalcogenide (TMD) samples prepared via mechanical exfoliation. We investigate the frequency of these defects on samples of MoS2, WSe2 and WS2 identifying preferences for specific defect types dependant on TMD material. By using AFM feedback for topography scans, whilst simultaneously measuring conductance, it is possible to achieve atomic resolution of defects within the bandgap of 2D material layers, suggesting that atomic resolution imaging of insulators such as hexagonal Boron Nitride may be possible. Through correlation with x-ray photoelectron, and photoluminescence, spectroscopy it is possible to gain further insight into the role of these defects on the optical properties relevant to security devices based on TMD materials.

1. Yameng Cao et al. "Optical identification using imperfections in 2D materials"**.** *2D Mater.* **4,** 4, 045021 (2017).
2. Sara Barja et al. "Identifying substitutional oxygen as a prolific point defect in monolayer transition metal dichalcogenides." *Nat Commun* 10, 3382 (2019).
3. Matthew R. Rosenberger et al. "Electrical Characterization of Discrete Defects and Impact of Defect Density on Photoluminescence in Monolayer WS2." *ACS Nano* **12**, 2, 1793–1800 (2018).

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Engineering Local Doping of 2D Materials

My research is aims to engineer local doping of 2D materials using low energy ion implantation tool P-NAME (Platform for Nanoscale Advanced Materials Engineering) which is a unique tool providing ion doping into precisely defined areas with sub-20 nm resolution. Doping engineering of 2D materials provides an exciting route in controlling the electronic, magnetic, and optic properties of these materials, and to generate new materials with improved performance. We have been testing the capabilities of the unique ion implantation tool P-NAME to implant isolated single metal atoms into graphene, where we successfully implanting Au ions into suspended graphene layers with a range of dopant implantation doses and a variety of graphene layer thicknesses. Low-energy ion implantation of graphene has been established first by B and N substitutions, and then extended to other species such as P, Ge and recently Mn. Fabrication of 2D materials with spatially controlled doping achieved via low energy high precision ion implantation could open possibilities for new quantum technology devices. It would also help make fabrication of 2D material devices compatible with large-scale integrated semiconductor technology.

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Graphene-based Printed Heating Elements for De-icing

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De-icing is a challenge in several industrial sectors, including Aerospace [1], Energy [2], and telecommunications [3]. Failure to de-ice can be most catastrophic in the aerospace sector, such as in the case of helicopter tails leading to the grounding or destruction of the aircraft [4]. The state-of-the-art solutions employ a variety of systems: chemical fluid [7-8], electro-impulsive [9], ultrasonic [8], microwave [9] and electrically triggered [10]. In terms of industrial adaptability and cost, the electro-thermal approach is considered as the most suitable due to its reliability[1]. Electrothermal components typically include the use of carbon fiber reinforced composites [10], carbon black [11], metals [12], carbon nanotubes [13] or other conductive polymer composites [14-15]. For these systems, the electrical and thermal conductivity are the most important properties [16]. Graphene combines electrical and thermal conductivity [18] with manufacturability into inks[19], coatings [20], and sheets/papers [20]. Here we report the production of heating elements for de-icing using graphene-based inks deposited via spray coating, screen printing, bar coating, and brush-painting. Concentrations up to 500g/l are produced via high pressure homogenization in water and IPA. The lateral size of exfoliated flakes are tunable from ~100nm to >10µm with thicknesses down to single layers. Accordingly, the sheet resistance of the printed elements is tuneable between ~0.1-10 W/W with corresponding electrical conductivity from ~5000 S/m to ~150,000 S/m. Fabricated heating elements can reach 100 oC within 10s, corresponding to a temperature efficiency of >150 oC.cm2/W for a 50x3cm device. This performance is >100% improvement over previous joule heating with graphene films [21].

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References:

1. J Palacios et al., J. Aircr., 48, 1020 (2011).
2. O Fakorede Renewable Sustainable Energy Rev., 65, 662 (2016).
3. M Farzaneh et al., in Atmospheric Icing of Power Networks, ed. Farzaneh, M., Springer Netherlands, Dordrecht, 229 (2008)
4. Y Cao et al., J. Aeronaut., 114, 83 (2010).
5. O Parent and A. Ilinca., Cold Reg. Sci. Technol., 65, 88 (2011).
6. Z Goraj, in An Overview of the Deicing and Anti-Icing Technologies with Prospects for the Future, 24th international congress of the aeronautical sciences, 2004
7. J Cole and W Sand, in Statistical Study of Aircraft Icing Accidents, 29th Aerospace Sciences Meeting, 558 (1991).
8. G Zumwalt et al., ELectro-Impulse De-Icing Research (Fatigue and Electromagnetic Interference Tests), Institute for Aviation Research Wichita State University, 1989
9. LE Feher and M Thumm., Proc. SPIE, 99 (2001).
10. GC Botur et al., Development and Demonstration of Low Power Electrothermal De-Icing System, American Institute of Aeronautics and Astronautics, 2005
11. TR Pozegic et al., Sci. Rep., 6, 37334 (2016)
12. E Enríquez et al., Ceramics International 41, 2735 (2015).
13. H Xie et al., Soft Matter, 17, 1901 (2021).
14. G Jiang et al., ACS Appl. Mater. Interfaces, 10, 36505 (2018).
15. D Hull and T. Clyne, An Introduction to Composite Materials, Cambridge university press, 1996
16. M Biercuk et al., Appl. Phys. Lett., 80, 2767 (2002).
17. ME Galvin and GE Wnek, Polymer, 23, 795 (1982).
18. A. C. Ferrari et al., Nanoscale,7, 4598 (2015)
19. P. Karagiannidis et al., ACS Nano, 11, 2742 (2017)
20. K Perepelkin, Fibre Chem., 38, 224 (2006).
21. Y Liu et al., Carbon, 155, 462 (2019).

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Graphene-Polyamide 12 Masterbatches via High Pressure Homogenisation

Masterbatches are composites with high filler loadings (> 10 wt%) used in aerospace [1], transportation [2], electronics [3] industries, among others [4], to make components with lower filler content (< 5 wt%) [5,6]. State-of-the-art processes of producing composites with graphene are based on melt-blending [7] and chemical functionalisation [8]. Using a readymade masterbatch and compounding it with polymers is the preferred method to make composites in industry [10], as this allows to achieve the desired filler loadings and reduces the handling of multiple materials [10]. Due to its low melting temperature (180°C [11]), which makes it easy to process, and its low cost (~£6/kg at 2021 prices [12]), polyamide 12 (PA12) is widely employed for applications ranging from sports equipment [13], to automotive parts [14]. However, it has a low Young's modulus (E=2 GPa [12]). Here we compound graphene and PA12 via high pressure homogenization (HPH) to produce masterbatches with loadings as high as 50 wt%, Fig.1a. HPH serves both to exfoliate graphite and to compound graphene and polymer. Injection-moulded tensile testing specimens demonstrate an increase of Young's modulus of up to 60% (for a 10 wt% graphene loading) compared to pristine PA12, Fig.1b. Such high concentration masterbatches pave way for rapid-prototyping and additive and digital manufacturing, and the increased mechanical strength enables the use of PA12-graphene composites for applications where the mechanical properties of polymers do not suffice.

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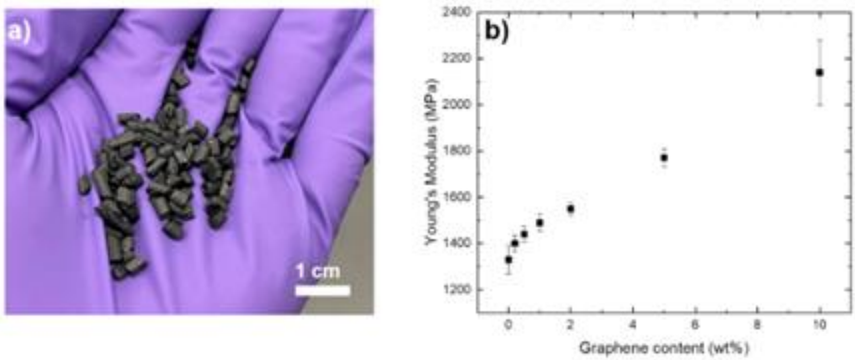

Figure 1: a) PA12 + 50 wt% masterbatch pellets, b) Variations of the Young's modulus PA12 based on its graphene content. At 10 wt% graphene, the Young's modulus has increased by 60%.

[1] J Liu et al., Adv. Mater. 29,1702367 (2017) [2] SR Kwon et al., ACS Nano 11, 6682 (2017) [3] MP Wolf et al., Prog. in Polym. Sci. 83, 97 (2018) [4] DG Papageorgiou et al., Prog. in Mater. Sci. 90, 75 (2017) [5] RK Shah and DR Paul, Polymer. 45, 2991 (2004) [6] J Hou et al., Compos. Part B: Eng. 199, 108220 (2020) [7] C Bao et al., J. of Mater. Chem. 22, 6088 (2012) [8] X Feng et al., ACS App. Mater. & Inter. 8, 25552 (2016)[9] P Pokharel et al., Chem. Engg. J. 253, 356 (2014) [10] M Tolinski, Additives for polyolefins, William Andrew Publishing (2009) [11] G Salmoria et al., Polym. Test. 3, 31 (2012) [12] Granta Design, 2021. CES EduPack Software—Material Level 3. [online] Grantadesign.com [13] Pissa, S., Handbook of Bioplastics and Biocomposites Engineering Applications, John Wiley & Sons (2016) [14] T McNally et al., Polymer 44, 2761 (2003)

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Manipulating ice nucleation and growth during freeze-casting of graphene-based aerogels

Freeze-casting is a facile method for fabricating materials with aligned, porous microstructures. Such materials have potential use in applications such as energy storage and tissue engineering. The method employs unidirectional freezing of aqueous slurries in order to control ice growth. Upon sublimation of the ice, materials with aligned porous architectures are produced. The morphology, size and direction of pores can be influenced by many factors, enabling control over the resulting structure. However, supercooling of the lower region of the slurry during freezing often leads to rapid nucleation and 'explosive' ice growth. Consequently, the material suffers from poor pore alignment in this region. Many proposed solutions can be time consuming or require complex apparatus. The aim of this project is to develop simpler solutions to this issue that could be commercially viable. Work has shown that altering the substrate the slurry is frozen upon can promote ice nucleation, resulting in a higher nucleation temperature and reduced supercooling. This is expected to enable better prediction of freeze-cast microstructures.

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Defect seeded remote epitaxy of GaAs on graphene

Remote epitaxy [1] of materials through 2D layer such as graphene, is an emerging technique that enables the deposition of single crystal films bonded by Van der Waal (vdW) forces to the growth substrate, resulting in the easy exfoliation of epitaxial layer (EL) later. Direct growth of graphene on III-V alloys is fundamentally challenging because these materials are not sufficiently catalytic for low temp growth of graphene but decompose at high temperature. Transfer of graphene to the substrate of interest is therefore essential from its host substrate such as Cu or SiC [2]. However, that results in increased cost and introduction of metal residues, contaminant, or trapped water at graphene and target substrate interface, facilitating the growth of oxide layer and widening the vdW gap at graphene interface [2]. Consequently, the necessary electrostatic potential from remote substrate required for the crystalline growth of EL, cannot propagate through the 2D layer, losing the registry information from underlying graphene coated substrate and restricts the lateral EL growth[3].

We demonstrated that the controlled introduction of pinhole defects in the graphene monolayer provides an accessible way to desorb trapped oxides under graphene sheet prior to EL deposition and nucleation sites for crystalline growth of EL, followed by lateral overgrowth on graphene sheet. We used in-situ Ar-ion beam for defect creation in graphene coated substrate. Sample was exposed to Ar-ion beam for different duration i.e, 109 s, 218 s, 436 s and 872 s, followed by MBE deposition of GaAs EL. This EL was released using Ni stressor layer and thermal release tape. The weak vdW bonding of the graphene monolayer and EL permits exfoliation of EL, leaving behind the graphene coated substrate for reuse, while released EL can be integrated with dissimilar material systems. Single crystal (EL) are grown in the ion beam exposed area on monolayer graphene, while 3D type of growth is visible in multilayer graphene region. Furthermore, unexposed graphene regions also show the 3D type of growth due to trapped oxide layer at graphene interface.

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References:
[1]: Kim, Yunjo, et al. "Remote epitaxy through graphene enables two-dimensional material-based layer transfer." Nature 544.7650 (2017): 340-343.
[2]: Kim Hyunseok, et al. “Impact of 2D–3D Heterointerface on Remote Epitaxial Interaction through Graphene”. ACS Nano. (2021); 15:10587-10596
[3]: Kong, W. et al. Polarity governs atomic interaction through two-dimensional materials.
Nature materials 17, 999 (2018)

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Chemical Vapour Deposition Growth of 3D Porous Graphene Structures

Porous graphene foams have attracted lots of interest due to their high specific surface area combined with high electrical and thermal conductivity of graphene for applications as electrodes in supercapacitors catalyst supports in liquid fuel cells, to increase energy density and reduce cost. Growth of graphene onto commercial copper foams is well established in literature however these commercial foams have large pore sizes and sub-optimal porosity.

Therefore, focus has shifted to the fabrication of porous structures with more favourable properties: high surface area, high porosity, low density & low cost. I present a scalable method for the manufacture of graphene foams by chemical vapour deposition of graphene onto a copper powder substrate. The addition of salt crystal spacers enables tuneable porosity, density and conductivity.

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Morphological Control of MoS_2 during Salt-Assisted Atmospheric Pressure Chemical Vapour Deposition for Catalytic Applications

The energy and environmental problems we face are now common knowledge to us all. However, real, physical solutions can only be realised by those researchers and industrialists of whom have devoted themselves to the renewable energy sector. What we really need is something abundant, high powered, cheap and environmentally friendly to satisfy the ever growing energy demand of humanity. Graphene and other layered 2D materials have been widely investigated for applications in energy conversion and storage due to their unique tuneable electronic structure. Chemical vapour deposition (CVD), an industrial scalable method to produce large area films of these 2D materials in high quality, is investigated to manipulate the morphology of molybdenum disulphide (MoS2). Excellent control, uniformity and reproducibility is demonstrated under atmosphere with the assistance of salt as a seeding promoter. Electrochemical measurement for the hydrogen evolution reaction were performed over different shapes and sizes of isolated domains in order to find an optimised structure for MoS2, without assistance from any other catalytic components. However, stability issues arise in the presence of oxygen and water, causing minor to severe damage. If MoS2 is to become industrially viable, this issue must be overcome. We therefore propose strategies that may mitigate this structural destruction.

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Novel Techniques for Characterising Graphene Nanoplatelets using Raman Spectroscopy and Machine Learning

In this work we develop novel techniques for characterising commercially available graphene nanoplatelets using a big-data approach to Raman Spectroscopy in combination with Machine Learning. We demonstrate techniques for identifying the key Raman peak features most influenced by functionalisation and carrying out accurate rapid quality control using computer vision.

Student Posters

There are three poster sessions of students to present their research. The poster sessions have been split into year groups, with first year posters in session 1, second year posters in session 2, and third and fourth year posters in session 3.

The student names and poster titles for each session can be found on the following pages. The student's year of study is shown in italics next to their name.

Poster Session 1

Alexandra-Daria Dumitriu-Iovanescu *1st*
The interplay between topology, geometry and correlations in novel materials

Chao Wen *1st*
Photodetectors based on TMDs

Darius-Alexandru Deaconu *1st*
Modelling emergent quantum phenomena in cross-correlated materials

Eli Rees *1st*
Dielectric properties of confined liquids

Emma Cusworth *1st*
Topological darkness for ultra-sensitive label-free biosensing

Francisco Selles *1st*
Dynamically twisted 2D materials

Gareth Tainton *1st*
Real time atomic resolution imaging of 2D materials

Hannah Burnett *1st*
Properties of water-in-salt electrolytes for use in redox flow batteries

Hannah Wood *1st*
Molecular simulations of novel aqueous water-in-salt redox flow batteries

Henry De Libero *1st*
Spin-orbit torques in large-scale WS_2/ferromagnet heterostructures

James Faulkner *1st*
Si-Graphene Anode Batteries

Jay Little *1st*
Solving Cryptographic Problems with 2DM

Joshua Swindell *1st*
2D High Entropy Metal Sulfides as Corrosion Resistant Electrocatalysts for the Oxygen Evolution Reaction (OER)

Poster Session 1

Muzi Xu *1st*
Wearable haptic sensor system for silent communications

Sohail Abbas *1st*
Ti_2O_3 Broadband Photodetector

Yuchian Soong *1st*
Field-accelerated interfacial water dissociation across 2D electrodes

Yu-Wei Kang *1st*
2D-Material based plasmonic devices for infrared spectroscopy of biological samples

Poster Session 2

Amy Carl *2nd*
Ultra-high vacuum assembly of van der Waals heterostructures

Ben Teall *2nd*
Harnessing and Investigating Piezoelectricity in Cellulose Nanocrystals

Christopher Hoole *2nd*
Characterisation of twisted bilayer graphene with scanning thermal microscopy

Dafydd Ravenscroft *2nd*
A Wearable Graphene Strain Gauge Sensor with Haptic Feedback for Silent Communications

Ghanshyam Hirani *2nd*
Performance Enhancement of Polymers with Nanoparticles

Guilin Chen *2nd*
Flow-induced voltage generation in hexagonal boron nitride encapsulated monolayer graphene

Guoda Liepuoniute *2nd*
Machine learning for silicon-graphene anodes in lithium-ion battery applications

Hao Chen *2nd*
Efficient coupling of 1L-WSe2 photoluminescence into polymer waveguide

Hugo de Latour *2nd*
Conductive AFM characterisation of twist angle disorder in van der Waals heterostructures assembled in UHV

Jamie Buck *2nd*
Spin-Polarised Graphene Edge-States in Non-Trivial Geometries

Jing Yang *2nd*
Understanding electrical double layer from dilute aqueous solution to ionic liquid and capacitance of ionic liquid on graphene

Kate Hills *2nd*
Characterisation of seizures and spreading depolarisations in rodent models of glioblastoma using graphene microtransistor arrays

Lewis Powell *2nd*
Search for intrinsic topological superconductors and their experimental signatures

Poster Session 2

Lifu Tan *2nd*
Photo Rechargeable Li-Ion Batteries using electroplating Prussian Blue on carbon paper

Lois Smith *2nd*
Multi-scale modelling of polymer composites

Matteo Tiberi *2nd*
Graphene photodetectors on suspended silicon waveguides

Max Rimmer *2nd*
Angstrom scale capillaries as templates for metals

Minghao Zhao *2nd*
Inkjet printable 2D inks beyond traditional 2D materials

Mordjann Souilamas *2nd*
Dielectric properties of liquids confined in atomically thin 2D nanochannels

Oliver Dowinton *2nd*
Modelling interfacial Quantum Phenomena in Two Dimensional Materials

Sam Haskell *2nd*
Unconventional Magnetic Orders in Kitaev Bilayer Systems

Tara Kalsi *2nd*
Three-fold way of entanglement dynamics in monitored quantum circuits

Tasnim Chowdhury *2nd*
Flexible sweat sensors

Tharun Kandukuri *2nd*
Energy Harvesting for Implantable and Wearable Sensors

Thomas Astles *2nd*
Lithium Intercalation in Bilayer Graphene

William Young *2nd*
Investigating the hydrogen evolution reaction with 2D proton permeable membranes

William Thornley *2nd*
Machine Learning for understanding atomic-resolution images of 2D materials

Yong Tao Tan *2nd*
Quantum phenomena in propagation of matter under extreme confinement

Poster Session 3

Benhao Xin *3rd*
Permeability of 2D oxides

Chris Castle *4th*
Hard X-ray study of perovskite/graphene oxide composites made from a single-step vapour deposition process

Emily Gamblen *3rd*
Measuring 2D Materials Using 2D Materials-Based Sensors

Hamideh Ramezani *4th*
A scalable Al_2O_3/SiO_2 dielectric platform for high performance graphene devices

Ismail Sami *4th*
Phase transition of TMDs

Kaiwen Zhang *4th*
Large scale synthesis of blue emitting $CsPbBr_3$ nanoplatelets with tunable emission

Mingwei Chen *3rd*
Capillary condensation in artificial atomic-scale capillaries

Rahma Al Busaidi *3rd*
Graphene oxide membranes for processing pharmaceutical aqueous waste streams

Wendong Wang *3rd*
Inorganic transfer of 2D materials

Yiannis Georgantas *3rd*
"*Accordion-like*" Germanane: An "*in-situ*" HF Synthesis.

Yunze Gao *3rd*
Quantum twistronics

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Contact details: https://www.anaphite.com/#graphene

Graphene Hackathon

Graphene Hackathon is a student lead event born of the Manchester Graphene NowNano CDT.

Contact details: https://www.graphenehackathon.com/

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Contact details: info@versarien.com

Closing Message

We, the committee, have been delighted to be able to host the first in person CDT conference since 2019. We hope the week has given you new insight, new experiences and fun. Thank you to all who have contributed in any large or small way!

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