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Graphene & 2D Materials: From Research to Applications

Characterisation and understanding of 2D materials is key to developing new applications in sensors, electronics and more

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Introduction

The meeting was held at the National Physical Laboratory, Teddington, UK, on 9th and 10th October 2018. This was the fourth such meeting, with the general aim of bridging the so-called 'valley of death' in translating research on graphene into meaningful products. The speakers were primarily academics and those from companies manufacturing graphene. One or two manufacturers of Raman spectroscopy equipment were also present.

The talks split broadly into two groups in terms of potential applications: electronic properties and semiconductor-type applications plus 'other' applications, largely consisting of adding graphene to existing concepts.

In terms of materials, graphene featured heavily but there was also discussion of transition metal dichalcogenides (TMDC) such as molybdenum disulfide (MoS_2), tungsten diselenide (WSe_2) and tungsten doped molybdenum disulfide ($Mo_xW_{1–x}S_2$). There was also one talk about what may be called two-dimensional (2D) metal-organic frameworks (MOF).

A key point throughout, regarding "graphene" is the uncertainty about what is actually meant by the term – this should be borne in mind whenever reading about the material. Few talks really did discuss a single layer of carbon atoms, the theoretical material.

Applications and Materials

James Hone (Columbia University, USA) gave an interesting talk on 'van der Waals heterostructures' for electronics applications, focusing a little on the problems associated with purity of the materials as made and during transfer of single-layer graphene from one substrate to a device assembly.

A representative of Graphenea, Spain, discussed the company's manufacturing capabilities for graphene and graphene oxide; the concentration is on chemical vapour deposition (CVD) for electronics. The talk mentioned the use of optical microscopy and Raman and terahertz spectroscopies for characterisation. Applications mentioned included a broadband photosensor (infrared (IR) to ultraviolet (UV)).

Rand Elmquist (National Institute of Standards and Technology (NIST), USA) discussed quantum conductance standards and made an interesting comment on adsorbates and their effects on measurement.

Andrew Pollard (National Physical Laboratory (NPL), UK) discussed various aspects of standardisation and measurement of graphene. He highlighted a few standards that have been published or are in progress and gave a description of differential centrifugal sedimentation and its application in particle characterisation.

Raul Arenal (Instituto de Nanociencia de Aragón (INA), Universidad de Zaragoza, Spain) discussed transmission electron microscopy (TEM) and electron energy loss spectroscopy (EELS) of TMDC.

Jonathan Foster (University of Sheffield, UK) discussed metal-organic nanosheets ('2D MOFs'). This was a more chemistry-based talk looking at the tunable nature of chemical functions of MOFs. The possibility of chemical sensing was given (changing UV-visible response on adsorption of imidazole) and some claim of enhancing organic solar cells was made.

A representative of Silson Ltd, UK, discussed a collaboration with Iceni Labs, UK, to develop graphene microphones.

Jonathan Coleman (Trinity College Dublin, Ireland) gave an interesting talk on some possible methods of production and application of dispersions of layered materials (around ten atomic layers) by liquid-phase exfoliation (which in crude terms means using a Silverson laboratory mixer). The most interesting aspect was the discussion of composites. These layered materials are perhaps best considered as additives in mixtures. One particularly interesting idea was a mix of nanotubes and graphene to impart improved electrical and mechanical properties of TMDC layers; the idea is that the one-dimensional (1D) tubes form a carbon fibre-like network imparting physical robustness and the contact of the 1D tubes and 2D graphene affords improved electrical performance. The basic concept of mixing the various aspect ratios and properties to give an overall enhanced performance was noted as being applicable elsewhere. Other applications included printed transistors, strain sensors (graphene-'silly putty' composite able to detect spider and even ant footsteps) and filters for water purification.

Liam Britnell gave a talk on the new Graphene Engineering & Innovation Centre (GEIC), University of Manchester, UK.

Zlatka Stoeva from DZP Technologies Ltd, UK, gave a talk on TMDCs and their use in lithium ion batteries. There was a focus on the company's range of inks (that incorporate MoS_2) for lithium ion battery applications with some claims of good results and a promising future in applications to batteries more generally and supercapacitors.

Cameron Day from William Blythe Ltd, UK, discussed the use of graphene oxide as a performance enhancer in lithium ion batteries. There were slides with units and numbers removed showing how good one energy storage material was compared with 'standard' technology.

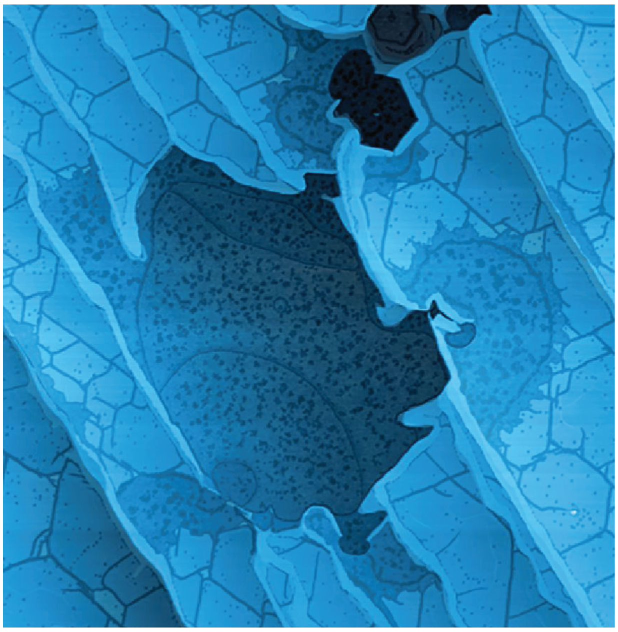

Fig. 1. Scanning Kelvin probe microscopy (SKPM) image of graphene grown on silicon carbide (SiC). Image courtesy of the National Physical Laboratory (NPL), UK

Jong-Hyun Ahn from Yonsei University, South Korea, gave a fascinating talk on wearable devices which showed how far technologies have come, including such items as a glove with multiple touch points that was used as a remote control for a toy car and wearable organic light-emitting diode (OLED) displays (completely transparent, only glowing numbers visible) with the capability using the properties of metal-organic chemical vapour deposition (MOCVD) MoS_2. There was also a discussion on implanted MoS_2 sensors for pressure measurement purposes, possible due to biocompatibility of both elements.

Professor Andrea C. Ferrari (Cambridge Graphene Centre, University of Cambridge, UK) was an entertaining speaker and discussed the meaning of '2D material' and the possibilities of single-photon-emission devices afforded by Cambridge Graphene Centre.

Peter Hansen from Haydale Graphene Industries Plc, UK, gave a discussion on various proof-of-concept 'nano-enhanced' materials, where graphene (for example) was mixed with a standard formulation of a variety of polymer products.

Conclusions

One useful outcome of this meeting was something of a definition. '2D materials' could mean various things: it can mean 2D physics but that is actually rather limited in scope, just idealised graphene and perhaps hexagonal boron nitride. A second class is sheet-like materials where the physics of interest is based on the sheets having limited interactions (van der Waals in nature), molybdenum disulfide is an example. A third is less clear and refers simply to aspect ratio of particles, the 2D MOFs perhaps fit here. In the field of graphene, the need for clarity in what is actually of interest and useful is crucial.

The Reviewer

Dr Richard Smith is a Principal Scientist at Johnson Matthey, Sonning Common, UK. Previously responsible for surface analysis after joining Johnson Matthey in 2006, his current work is the investigation of the potential use of graphene within Johnson Matthey. This follows a long period of developing understanding of carbonaceous materials, starting with a PhD from the Surface Science Research Centre at the University of Liverpool, UK, where the focus was on electron spectroscopy of graphite and ion-irradiated graphite. After postdoctoral work in Vienna, Austria, he returned to the UK to work at Johnson Matthey where among other research and development projects he developed understanding of carbon in Johnson Matthey products and science.

