ConceptGraphene

New Electronics Concept: Wafer-Scale Epitaxial Graphene

Small or medium-scale focused research project

WP5 Dissemination and exploitation

Deliverable 5.2 “Organization of open workshop”

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Deliverable Summary

The 15th to 16th of October 2012 there was a two day conference name "Graphene Conference: From Research to Applications", organized by NPL. The conference reviewed some of the new concepts of graphene electronics and progress in understanding graphene physics, technology and metrology. Participants also had the opportunity to visit various metrology laboratories at NPL.

Talks were given by key international experts from industry and academia, including members of ConceptGraphene as the workshop served as a dissemination event of the project. Invited talks were given by V. Falko (Lancaster), R. Yakimova (Linköping), T. Seyller (Erlangen/Chemnitz), B. van Wees (Groningen), J.T. Janssen (NPL), S. Kubatkin (Chalmers), X. Waintal (CEA), and T. Löfwander (Chalmers).

The conference website address is :

http://www.npl.co.uk/science-technology/quantum-detection/news-events/graphene-conference-2012

On the website, many of the presentations and all abstracts of the talks are available for download in pdf format.

1. Summary of the workshop

Graphene is a material with many unique properties which could lead to numerous exciting applications in many different areas such as ICT, Advanced Materials, Biotechnology, etc. However, so far the commercial exploitation is limited. The National Physical Laboratory (NPL) hosted a conference to explore how the scientific knowledge gained in laboratories and research institutions could potentially be used more effectively to accelerate the use of graphene in applications. The NPL Graphene Conference was held on 15-16 October 2012 attracting over 100 delegates and a long list of internationally renowned speakers.

An important first step when developing an emerging technology is to build a measurement infrastructure. This allows researchers to properly characterise materials and is vital for ensuring that manufactured products fall within necessary tolerances. Measurement, standards, testing, inspection and certification all have a role to play in making products based on novel materials such as graphene a commercial success.

For new technologies to be integrated into production chains and advanced manufacturing processes, we need to understand and agree upon their performance characteristics. The electrical properties of graphene can change, for example, with the number of graphene layers or with impurities present on the surface. Therefore, we need to develop measurements to assess layer thickness and detect impurities, with the necessary level of accuracy to ensure that the graphene will perform as it is expected to.

ConceptGraphene scientists use quantum metrology and nanoanalysis techniques to sustain and extend the performance of graphene based electronic devices and use graphene itself as a quantum resistance standard. This standard is based on the quantised quantum Hall effect, which was discovered by the keynote speaker at the NPL Graphene Conference, Professor Dr Klaus von Klitzing. Von Klitzing's talk on the Quantum Hall Effect was a great start to the conference and introduced a fundamental aspect of transport in graphene.

While graphene is lauded for its exceptional electronic properties, talks by Professor Rositza Yakimova (Linkoping University) and Dr Christos Dimitrakopoulos (IBM) showed how these properties critically depend on growth mechanism, interaction with the substrate and device fabrication.

The potential of graphene was made clear by presentations on the future applications and experimental updates of graphene based spintronics, flexible electronics, and plasmonics. NPL's JT Janssen spoke about graphene based metrology and highlighted the first application of graphene, as a resistance standard. 'The graphene roadmap to applications' by Professor Andrea Ferrari (University of Cambridge) highlighted the potential of the material and its future market. It covered the challenges faced by researchers and led to discussions on carbon nanotubes, which, have failed to live up to expectations. Researchers were urged to look into novel science and applications of graphene rather than replicating the current technologies. Talks on growth by Luigi Columbo (Texas Instruments) and Jong Min Kim (University of Oxford and ex-Samsung) highlighted the differences in approach in industry while showing what can be achieved. The industry-focused talks demonstrated the current capabilities and this combined well with those from researchers that looked at how to push the boundaries forward, both in graphene knowledge and application.

A workshop was held on the second day of the conference to demonstrate some of NPL's current and future work on graphene characterisation. Several University and Research Laboratory groups have since approached NPL to perform measurements on their graphene samples - samples which will, in turn, help the progress of NPL's structural and chemical characterisation research.

There was also a session during the conference on the collaborative ConceptGraphene project, which is funded by the European Union within the 7th Framework Programme.

2. List of invited speakers

- Prof Dr Klaus von Klitzing (Max-Planck-Institut FKFK, Germany)
- **Prof Vladimir I Falko (Lancaster University, UK)**
- **Prof Rositza Yakimova (Linköping University, Sweden)**
- **Prof Thomas Seyller (University of Erlangen, Germany)**
- **Prof Sergey Kubatkin (Chalmers University of Technology, Sweden)**
- Dr Irina Grigorieva (NOWNano DTC, University of Manchester, UK)
- **Prof Bart van Wees (Physics of Nano devices, University of Groningen, Netherlands)**
- Prof Jong Min Kim (Department of Engineering Science, University of Oxford, UK)
- Dr Luigi Colombo (Texas Instruments Incorporated, Texas, USA)
- Prof Andrea Ferrari (Department of Engineering, University of Cambridge, UK)
- **Dr Xavier Waintal (CEA, Grenoble, France)**
- **Dr Tomas Löfwander (Chalmers Institute of Technology, Sweden)**
- Dr Christos Dimitrakopoulos (IBM Research Division, Thomas J Watson Research Centre, New York, USA)
- **Dr JT Janssen / Prof Alexander Tzalenchuk (National Physical Laboratory, UK)**

***Bold face**: ConceptGraphene participant presenting results of the project*

2. Programme

K = Keynote Speaker (40 mins, including discussion time)
I = Invited Speaker (30 mins, including discussion time)
O = Oral Presentation (20 mins, including discussion time)

Monday 15 October 2012			
08.45 - 09.15	Registration		
09.15 - 09.25	Welcome		
09.25 - 09.35	Graphene Conference Opening - Professor John Pethica (Chief Scientific Advisor, National Physical Laboratory)		
Session 1	Chair: JT Janssen		
09.35 - 10.15	Current Distribution in Two-dimensional Electron Systems under QHE Condition (Download abstract)	Klaus von Klitzing (MPI, Germany)	K
10.15 - 10.45	Dirac Fermions beyond Graphene: Silicene and Moiré Minibands in G-BN Heterostructures (Download presentation)	Vladimir I Falko (Lancaster University, UK)	I
10.45 - 11.15	Coffee Break and Poster Session		
Session 2	Chair: Christos Dimitrakopoulos		
11.15 - 11.45	Control of Morphology and Charge Carriers of Epitaxial Graphene in SiC (Download abstract)	Rositza Yakimova (Linköping University, Sweden	I
11.45 - 12.15	Quasi-free Standing Graphene on SiC - Fabrication and Properties (Download abstract)	Thomas Seyller (University of Erlangen, Germany)	I
12.15 - 12.45	Graphene Crystal Growth and Device Integration (Download abstract | presentation)	Luigi Colombo (TI, USA)	I
12.45 - 13.45	Lunch and Poster Session		
Session 3	Chair: Vladimir Falko		
13.45 - 14.15	Making Graphene Magnetic (Download abstract | presentation)	Irina Grigorieva (University of Manchester, UK)	I
14.15 - 14.45	Graphene Spintronics: An Experimental Update (Download abstract)	Bart van Wees (University of Groningen, Netherlands)	I
14.45 - 15.05	Graphene Sensing with IR Plasmonics (Download abstract)	Yan Francescato (Imperial College London, UK)	O
15.05 - 15.25	Bending Rigidity of Graphene Measurements by Electrostatic Actuation of Buckled Membranes (Download abstract)	Oleg Nerushev (Edinburgh University, UK)	O
15.25 - 16.00	Coffee Break and Poster Session		
Session 4	Chair: Luigi Colombo		
16.00 - 16.30	Graphene for the Flexible Electronics (Download abstract)	Jong Min Kim (University of Oxford, UK)	I
16.30 - 16.50	Graphene Hydrogel/Manganese xide/Carbonate Composite as a Novel Electrode for a Supercapacitor (Download abstract)	Susan Libor (Cranfield University, UK)	O
16.50 - 17.10	Graphene- A Market Prospective (Download abstract | presentation)	Khasha Ghaffarzadeh (IDTechEx, Cambridge, UK)	O
17.10 - 17.50	The Graphene Roadmap to Applications (Download abstract)	Andrea Ferrari (University of Cambridge, UK)	I
17.50 - 18.45	Drinks Reception and Poster Session (sponsored by Oxford Instruments NanoScience)		
18.45 - 19.30	Depart for Conference Dinner Venue		
19.30	Graphene Conference Dinner (The Wharf ,Teddington)		

Tuesday 16 October 2012			
Session 5	Chair: Randolph Elmquist		
09.15 - 09.45	Graphene Based Metrology (Download abstract | presentation)	JT Janssen (National Physical Laboratory, UK)	I
09.45 - 10.05	Energy Loss Rates of Hot Dirac Fermions in Epitaxial, Exfoliated and CVD Graphene under High Magnetic Fields (Downloa abstract)	Robin Nicholas (University of Oxford, UK)	O
10.05 - 10.25	Electron Cooling Mechanisms in Graphene (Download abstract)	David Horsell (University of Exeter, UK)	O
10.25 - 10.55	Disordered Fermi Liquid in Epitaxial Graphene from Quantum Transport Measurement (Download abstract)	Sergey Kubatkin (Chalmers University, Sweden)	I
10.55 - 11.15	Coffee Break and Poster Session		
Session 6	Chair: Sergey Kubatkin		
11.15 - 11.35	Diffusion-limited Growth of Epitaxial Graphene on 6H-SiC(0001): Analysis and Characterization (Download abstract | presentation)	Randolph Elmquist (NIST, USA)	O
11.35 - 12.05	Interplay between Quantum Hall and Quantum Spin Hall in Graphene Devices (Download abstract)	Xavier Waintal (Grenoble, France)	I
12.05 - 12.35	Quantum Hall Effect in Graphene with Twisted Bilayer Stripe Defects (Download abstract)	Tomas Löfwander (Chalmers, Sweden)	I
12.35 - 13.05	Wafer-Scale Epitaxial Graphene and Graphene Nanoribbon Arrays on SiC (Download abstract)	Christos Dimitrakopoulos (IBM, USA)	I
13.05 - 13.45	Lunch and Poster Session		
13.45 - 15.15: ConceptGraphene (closed session)			
Session 7	Chair: TBC		
13.45 - 14.05	Fabrication of Graphene-based Micro Strain Gauge (Download abstract | presentation)	Jeff Tsai (National Taiwan Ocean University, Taiwan)	O
14.05 - 14.25	Graphene Biosensors (Download abstract)	Owen Guy (Swansea University, UK)	O
14.25 - 14.45	In-situ Graphene Characterization by Nanoelectromechanical Mass Sensor (Download abstract)	Donats Erts (University of Latvia, Latvia)	O
14.45 - 15.00	Announcement of Poster Winner (sponsored by ConceptGraphene) and Concluding Remarks		
15.00 - 15.15	Coffee Break		
15.15 - 16.30	Lab Tours		
16.30	Conference Close		