Report from the conference

Graphene Week 2019, Helsinki

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Content:

Introduction

Every year, the Graphene Flagship organizes the Graphene Week conference, as part of one of the largest European conference series with a focus on graphene. The other is the Graphene 2019 series, on which we reported earlier this year. Both series are based on the academic/researcher's point of view. In the morning, more general, plenary presentations were given. In the afternoons, up to six parallel sessions focused on various topics were offered. There was other so called "fringe sessions" where different topics were presented and discussed, such as the place of graphene in space exploration as well as an overview of the patent landscape.

The Graphene Week also included the Graphene Innovation Forum which spread over three days focusing on Wearables, Datacom & 5G and Energy. It aimed at strengthening ties between Graphene Flagship researchers and industry stakeholders to enable the increase of graphene's technology readiness level. Each session started with a presentation of the latest results from the Technology and Innovation Roadmap, which was created by the Graphene Flagship to see more clearly the path of graphene to commercial success and was focused on the session's application area. Following this, the latest results from the Graphene Flagship's application orientated spearhead projects were presented. Spearheads are market-motivated actions targeting specific applications and demonstrators. The projects presented during this year's edition of the Graphene Innovation Forum were started in April 2018 and will conclude in March 2020. The bulk of the presentations in each session was given by top level industrial representatives who provided an interesting and unique mix of viewpoints on the business relevance of graphene for their application area and for their company.

Graphene Week Exhibition showcased approximately 15 companies and organizations which presented their products and prototypes.

The conference was held at the Scandic Marina Congress Center in Helsinki, Finland September 23 to 27, 2019. It had roughly 550 participants from over 40 countries.

The comments and information below are not totally comprehensive but represent the sessions that were attended.

Growth, Integration and Heterostructures

Dean (Columbia University) gave an overview of the possibilities of using layered materials, such as graphene, boron nitride (hBN) and transition metal dichalcogenides (TMDs) to create heterostructures with a wide range of electrical properties. More than the material themselves, the layered materials have several other degrees of freedom when assembling heterostructures, such as the relative alignment of the layers, layer separation and patterning, which gives almost endless opportunities to create new materials with tailored properties. **Rubio Verdú (Columbia University)** discussed about the possibility of engineering new band structures in bilayer van der Waals materials by controlling the angle between the two layers and the material used. **Geim (University of Manchester)** showed Hofstadter butterfly patterns when applying magnetic fields to vdW heterostructures and talked about electron hydrodynamics and '2D nothing' (properties of 2D empty space).

Brems (IMEC) and **Hoffman (The University of Cambridge)** both discussed on the importance and challenges of perfecting the growth and transfer process of graphene and other 2D layers. **Beton (University of Nottingham)** discussed about the possibility to grow graphene and hBN using molecular beam epitaxy at temperatures higher than 1200°C. By controlling the growth temperature, the degree of epitaxy and hence the strain of the film can also be controlled, giving rise to novel electronic properties.

Van Wees (Zernike Institute for Advanced Materials) presented results on heterostructures spin devices based on graphene and other 2D materials. Graphene has low spin orbit coupling and is therefore a good material for spin transport. Other layered materials, such as TMDs, have high spin orbit coupling, which makes them prime candidates to inject, detect and control spin. Heterostructures combining both types of materials are new types of spin devices that could potentially be one day used in a low power computer.

Figure 1. Vincent Bouchiat from Grapheal presented their work on CVD graphene-on-polymer

Biotechnologies and Wearables

Most of the participants giving presentations on these topics tied their applications to energy concerns. Some used graphene to design low power alternatives, others said it could be used for energy harvesting in self-powered devices. These are very real concerns and this observation seems to confirm that research is generally taking a turn toward applications. There is also some diversification, as more and more work done and presented on other 2D materials, such as transition metal dichalcogenide (TMD), such as MoS_2 and WSe_2.

Palacio (MIT) discussed how he believes graphene and other 2D materials can offer real engineering possibilities. He talked about ubiquitous electronics, where the production of large-scale CVD graphene would enable electronics integrated on a variety of substrate, such as 3D objects and textiles. He also showed results from his research group on the development of small (<100µm) sensing heterostructures based on MoS_2 that could eventually be used in the body as synthetic cells (syncells). Another material was functional fibres with a conductive core coated with a graphite layer that could harvest Wi-fi energy to power small devices.

Yida (National University of Singapore) talked about the possible use of graphene and other 2D materials to develop a new type of memory (Resistive RAMs) and other types of devices for new computing architecture. **Garrido (ICN2)** showed how graphene could be used in a brain computer interface for brain mapping, monitoring and recording. He also showed data of graphene-based devices which were fabricated with high yield, stable over time and biocompatible (mouse models). **Anh (Yinsei University, Korea)** showed bioelectronics that could diagnose epilepsy as well as allowing instantaneous treatment by electrical stimulation. **Vranic (Uni of Manchester)** presented live-cell imaging results from experiments with reduced graphene oxide (GO), concluding that GO is taken up in the lysosomes and sometimes cause an inflammatory response especially for large GO.

Rice (Fraunhofer ISI) presented the key results from the Technology and Innovation Roadmap for wearable applications. The market trend is showing a strong growth, with health monitoring being the largest segment. The interviews and workshops conducted by his team allowed identification of several challenges on the road to commercialisation of graphene-

based bio sensors, such as regulations, energy supply and the lack of focus on one specific application.

Zanardi (ISOF-CNR) showed the results of the ChemSens spearhead, which aims at developing a multifunctional plaster sensor for human skin, based on functionalized graphene able to detect several analytes: glucose, electrolyte and lactid acid. The device is aimed at monitoring athletes' sweat for at least 2 h and has a paper-based fluidics system. **Miskovic (Universite Libre De Bruxelles)** talked about wound healing in space (zero gravity) and smart bandages with graphene that promote healing and have sensors for temperature, pH, moisture and O_2.

Roepert (Interactive Wear AG) talked about the results from the WearGraph spearhead, with the goal to produce self-powered graphene-based textiles for wearable electronics. One example was cooling textiles. He mentioned the importance of collaboration between the different actors along the value chain.

Bouchiat (Grapheal) presented how his company is using graphene in a plaster to mitigate the effects of chronic wounds by speeding up the healing and allowing monitoring of the healing process without the need to remove the bandage. **M. Banach (Flexenable)** discussed how 2D materials (especially MoS_2) are attractive new materials for flexible displays.

Moeller (Luxembourg Institute of Science and Technology) gave an overview of the different legist (nano-specific) provisions and recent policy developments. The importance of regulation was also highlighted during a short panel discussion that followed her presentation.

Figure 2. Panel discussion during Graphene Innovation Forum for Wearables

Electronics and Optoelectronics

Graphene is especially an interesting material for electronics and optoelectronics application; graphene-based devices are fast and can operate in a very broad range. Several speakers mentioned the increasing demands and growing market that are emerging due to the rise of new technologies such as artificial intelligence and augmented reality. There is therefore a lot of research and development on these topics, reflected in practice by the two poster sessions on this topic and the large number of presentations during the Graphene Week.

Neumaier (AMO) talked about possibilities and challenges with graphene in electronic devices and mentioned that transfer is a bottle neck to successful manufacturing. **Banerjee (University of Texas at Austin)** put out some crazy ideas of e.g. a Bi-layer pseudo Spin Field Effect Transistor or a Bose condensate in Graphene/TMD heterostructures. **Stampfer (Aachen)** pointed out that flatness is what matters and talked about electron-phonon couplings.

Ryhänen (Emberion Oy) presented his company, which produces monolithically CMOS-integrated graphene-enhanced image sensors for a large wavelength range (especially in the infrared). Applications could be chemical composition determinations, sorting materials (e.g. fresh produce, or recycling), LIDAR, rescue missions or medical imaging. One of the hurdles is power consumption.

Ferrari (University of Cambridge) gave an overview of the possibilities with graphene for photonics devices. **Templ (Nokia)** and **Bigongiari (Ericsson)** presented how graphene-based devices such as modulator, receiver and switches could be used by their companies. They mentioned challenges such as signal propagation and cost/yield for industrial production. **Bigongiari (Ericsson)** said the way forward is through collaboration between producers, with an important milestone being the production of demonstrators and prototypes.

Romagnoli (CNIT) presented the results from the spearhead “Graphene-Photonics Integrated Circuits for the 5G Era”, which aims to demonstrate flexible and scalable graphene photonic integrated circuit. **Hu (The University of Manchester)** discussed the results from the “Printable Sensors Integrated with RFID Antenna” spearhead where the goal is to produce self-powered graphene-based textiles for wearable devices.

Figure 3. The Graphene Innovation Forum included opportunities for networking between industry and academia.

Energy

Döscher (Fraunhofer ISI) presented the key results from the Technology and Innovation Roadmap for energy applications, especially on the emerging perovskite photovoltaics, supercapacitors and lithium-ion batteries.

Brunetti (CHOSE) presented printable flexible perovskite solar cells and discussed polymer solar cells with large surface area for higher donor-acceptor interactions. **Agresti (University of Rome Tor Vergata)** showed the results of the spearhead "Graphene-Perovskite Solar Farm". He discussed challenges with efficiency, stability, cost and scaling-up. **Gerardi (Enel Green Power)** showed graphene based solar cells with better efficiency in warm climates compared to standard ones.

Stangl (Varta Micro Innovation GmbH) reviewed the results from the spearhead "Technology of Silicon Graphene Lithium-Ion Batteries for Large Scale Production" batteries. The major hurdle is to increase the energy density. A Si/FLG[1] + NCM/NCA

[1] Silicon/Few layers graphene + Nickel Manganese Cobalt/Nickel Cobalt Aluminium Oxide

resulted in 60% more specific energy[2]. Graphene can also help overcome the Si problem of volume expansion and heat build-up. **Wendelbo (Abalonyx)** talked about their Li-S cathode with graphene oxide and large-scale energy storage for e.g. the aviation market.

Britnell (Eksagon group) presented the company he is working for and how they are aiming at using graphene-based fuel cell membranes.

Mattevi (Imperial Collage London) showed their 3D-printed micro-super capacitors with features down to 100 µm. **Bondavalli (Thales)** presented their work on super capacitors. In comparison to batteries, there is no limit of cycles and they can provide high charge/discharge. A large surface area is obtained by carbon nanotubes + graphene/graphite. Roll-to-roll production will be ready in October.

Figure 4. The room was filled to its capacity during the Graphene Innovation Forum for 5G technologies

Other Topics

Liu (Chalmers) showed recent results from a thermally conducting paper based on graphene. The in-plane thermal conductivity of the paper, developed using molecular self-assembly method, can reach up to 3200 W/mK. The observed cooling power of a carbon hybrid micro heatsink was 10 times more efficient than cupper.

[2] Energy per unit of mass

Kinloch (Uni. Manchester) gave insight in what are good conditions/systems to use with graphene as an additive in composites, namely that the difference of stiffness between the matrix and graphene will greatly influence the degree of reinforcement improvement. The analysis he presented showed that the extremely low modulus of elastomers, relative to that of platelets, means that a similar degree of reinforcement is obtained independently to the thickness of the platelets.

Gogotsi (Drexel University) talked about MXenes (2D metal carbides and nitrides). These materials have high metallic electrical conductivity, are strong and stiff, are transparent in thin film form and come in different colours depending on the metal involved. Some applications are solar cells, electromagnetic shielding, transparent printable antennas, better than gold electrodes and gas sensors.

Vijayaraghavan (Uni. Manchester) gave an overview of several projects he had to improve rubber using graphene. He mentioned shoe soles made with soft rubber for good grip but with enhanced durability due to graphene inclusions. Moreover, he mentioned some interesting characterisation techniques; Rheo-SIPLI (shearing induced polarised light imaging), Rheo-SAXS and Rheopecty.

Schmoch (Fraunhofer ISI) presented an overview of the patent landscapes for graphene applications and **Clarke (EPO)** gave a detail analysis on the composite patent applications. In general, the number of patents, which had been increasing since 2007 is since 2016 saturating, typical of more mature application areas. The trend analysis can also show several promising application areas for graphene, such as paints, ceramics, health and printed circuits.

Concordia station, Antactica called into Graphene Week and shared their experience of isolation and harsh conditions. Parallels to human space explorations were discussed. They are 13 people at the base during winter which is placed on top of 3200 m ice and they haven't seen any other people since February. Areas where graphene could potentially help their work is in non-fogging goggles, batteries for cold climate (less dependence on diesel), better solar panels and cleaning of instrument surfaces from snow and ice.

The members of the Graphene Flagship Ethics Advisory Board, **Hohlneicher (AstraZeneca AB)**, **Savage (Swedish Defence Research Agency)** and **Patrignani (Politecnico of Torino)** presented the objectives of the Board and the current thinking on the Basics of Responsible Research and Innovation (RRI). Together with **Fagerström (VTT)**, they also shared some

example of ethical dilemmas associated with graphene research which were discussed with the audience.