DY 39: Graphene: Spintronics, Transistors, and Sensors (joint session HL/DY/DS/MA/O/TT)

Time: Thursday 15:00–18:00 Location: POT 081

DY 39.1 Thu 15:00 POT 081

Graphene's RF Potential: How harmful is the Zero Bandgap? — Kyle D. Holland[1], Navid Paydavosi[1], Neophytos Neophytou[2], •Diego Kienle[3], and Mani Vaidyanathan[1] — [1]Department of Electical and Computer Engineering, University of Alberta — [2]Institute for Microelectronics, Technical University of Vienna — [3]Institute of Theoretical Physics I, University of Bayreuth

With the aid of self-consistent quantum-mechanical simulations and simple expressions for the radio-frequency (RF) metrics, we examine the impact of a lack of a bandgap on limiting the RF potential of graphene transistors. Considering various RF figures of merit, we show that the lack of a bandgap leads to all RF metrics being optimal when the bias point is chosen such that the drain Fermi level aligns with the Dirac point at the midpoint of the channel. We further quantify the precise extent to which the lack of a bandgap limits the transistor's cutoff frequencies, an issue that has been flagged as requiring crucial attention to make graphene transistors competitive. For an 18-nm channel length, we show that the extrinsic unity-current-gain frequency could be improved by 300 GHz and the unity-power-gain frequency could be doubled if a bandgap could be introduced to reduce the output conductance to zero. [1] K. D. Holland, N. Paydavosi, N. Neophytou, D. Kienle, and M. Vaidyanathan, IEEE Trans. Nanotechnol. 12, 566 (2013).

DY 39.2 Thu 15:15 POT 081

Atomic layer deposited aluminum oxide on epitaxial graphene without surface activation — •Peter Wehrfritz[1], Florian Speck[2], Felix Fromm[1], Stefan Malzer[3], and Thomas Seyller[1] — [1]TU Chemnitz, Institut für Physik, Chemnitz, Deutschland — [2]FAU Erlangen-Nürnberg, Department Physik, Erlangen, Deutschland — [3]FAU Erlangen-Nürnberg, Angewandte Physik, Erlangen, Deutschland

Graphene with its high charge carrier mobility is a promising material for analog RF field effect transistors. The preparation of the required insulating layer is still challenging. Atomic layer deposition (ALD) has been extensively studied in the context of alternative dielectrics for silicon-based field effect transistors owing to its capabilities to produce high-quality, homogeneous oxide layers. However, nucleation of ALD growth is strongly suppressed on inert graphene surfaces.

In this contribution we present an approach to obtain conformal aluminum oxide (Al_2O_3) on epitaxial monolayer graphene on silicon carbide (SiC). We demonstrate that closed layers of Al_2O_3 can be deposited on the so called buffer layer. This buffer layer covered by ALD-Al_2O_3 can then be decoupled from the SiC substrate by means of hydrogen intercalation yielding quasi-freestanding monolayer graphene with an insulating dielectric on top. We investigated the quality of the graphene layer and ALD-Al_2O_3 using X-ray photoelectron spectroscopy (XPS), Raman spectroscopy, AFM, and Hall effect measurements.

DY 39.3 Thu 15:30 POT 081

Spin-dependent negative differential resistance in composite graphene superlattices — •Christopher Gaul[1,2], Javier Munárriz[2], Andrey V Malyshev[2], Pedro A Orellana[3], Cord A Müller[4], and Francisco Domínguez-Adame[2] — [1]Max-Planck-Institut für Physik Komplexer Systeme, Dresden — [2]Universidad Complutense de Madrid, Spain — [3]Universidad Técnica Federico Santa María, Casilla 110 V, Valparaíso, Chile — [4]Fachbereich Physik, Universität Konstanz

We propose and study a compound system of a graphene nanoribbon and a set of ferromagnetic insulator strips deposited on top of it. The periodic array of ferromagnetic strips induces a proximity exchange splitting of the electronic states in graphene, resulting in the appearance of a superlattice with a spin-dependent energy spectrum. We find clear signatures of spin-dependent negative differential resistance. The electric current through the device can be highly polarized and both the current and its polarization manifest non-monotonic dependence on the bias voltage. The device operates therefore as an Esaki spin diode, which opens possibilities to design new spintronic circuits.

Phys. Rev. B 88, 155423 (2013)

DY 39.4 Thu 15:45 POT 081

Exchange coupling between localized defect states in graphene nanoflakes — •Matthias Droth and Guido Burkard — University of Konstanz, Germany

Graphene nanoflakes are interesting because electrons are naturally confined in these quasi zero-dimensional structures, thus eluding the need for a bandgap. Defects inside the graphene lattice lead to localized states and the spins of two such localized states may be used for spintronics. We perform a tight-binding description on the entire system and, by virtue of a Schrieffer-Wolff-transformation on the bonding and antibonding states, we extract the coupling strength between the localized states. The coupling strength allows us to estimate the exchange coupling, which governs the dynamics of singlet-triplet spintronics.

DY 39.5 Thu 16:00 POT 081

Novel fabrication method of lateral spin valve devices based on graphene on hexagonal boron nitride — Marc Drögeler[1], Frank Volmer[1], •Maik Wolter[1], Bernat Terrés[1], Kenji Watanabe[3], Takashi Taniguchi[3], Gernot Güntherodt[1], Christoph Stampfer[1,2], and Bernd Beschoten[1] — [1]2nd Institute of Physics and JARA-FIT, RWTH Aachen University, 52074 Aachen, Germany, EU — [2]Peter Grünberg Institute (PGI-8/9), Forschungszentrum Jülich, 52425 Jülich, Germany, EU — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

Despite tremendous efforts in improving graphene-based spin transport devices the measured spin lifetimes are still orders of magnitude less than theoretically predicted. Contact-induced spin dephasing has recently been identified as the bottleneck for spin transport through Co/MgO spin injection and detection electrodes. It can, however, significantly be suppressed for devices with large contact resistance area products [1]. Simultaneously, a strong reduction of the charge carrier mobility is usually observed. We present a new method to fabricate graphene-based non-local spin valves on hexagonal boron nitride yielding spin lifetimes above 3 ns, spin diffusion length above 10 μm and large charge carrier mobilities above 30.000 cm^2/Vs.

[1] F. Volmer *et al.*, Phys. Rev. B **88**, 161405(R) (2013).

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DY 39.6 Thu 16:15 POT 081

Suppression of contact-induced spin dephasing in graphene/Co/MgO_x spin-valve devices by successive oxygen treatments — Frank Volmer, •Christopher Franzen, Marc Drögeler, Eva Maynicke, Nils von den Driesch, Maren Laura Boschen, Gernot Güntherodt, and Bernd Beschoten — 2nd Institute of Physics and JARA-FIT, RWTH Aachen University, 52074 Aachen, Germany

By successive oxygen treatments of graphene non-local spin-valve devices we achieve a gradual increase of the contact resistance area products R_cA of the Co/MgO_x spin injection and detection electrodes and a transition from linear to non-linear characteristics in the corresponding dV/dI-curves. With this manipulation of the contacts both spin lifetime and amplitude of the spin signal can significantly be increased by a factor of seven in the same device. This demonstrates that contact-induced spin dephasing is the bottleneck for spin transport in graphene devices with small R_cA values [1]. With increasing R_cA we furthermore observe the appearance of a second charge neutrality point (CNP) in gate dependent resistance measurements. Simultaneously we observe a decrease of the gate voltage separation between the two CNPs. The strong enhancement of the spin transport properties as well as the charge transport will be explained by the same gradual suppression of a Co/graphene interaction by improving the oxide barrier.

Work was supported by DFG/FOR 912 and EU/Graphene Flagship.

[1] F. Volmer *et al.* Phys. Rev. B **88**, 161405 (2013).

Coffee break (15 min.)

DY 39.7 Thu 16:45 POT 081

Development of an amperometric H2O2 sensor based on graphene — •Masoumeh Sisakhti[1], Alexander Zöpfl[2], Jonathan Eroms[1], Thomas Hirsch[2], and Christoph Strunk[1] — [1]Institut für Experimentelle und Angewandte Physik,Universität Regensburg —

[2]Institut für analytische Chemie,Universität Regensburg

The precise detection of Hydrogen peroxide (H2O2) has been a widely researched topic and the focus of a vast amount of attention, owing to its vital role in biological systems, as well as its utility in food, pharmaceutical and biochemical industries.

The objective of this work is to investigate a novel nonenzymatic, amperometric sensor for reliable determination of H2O2 based on graphene.

We produced graphene sensors based on three types of graphene: exfoliated graphene, CVD grown graphene and reduced graphene oxide and carried out cyclic voltammetry and amperometric experiments using a CH Instrument electrochemical analyzer. We demonstrate that all three graphene materials show excellent sensitivity to the catalytic reduction of H2O2 and are able to detect H2O2 concentrations down to 0.1 mM. rGO as well as graphene prepared by CVD are promising candidates for sensor applications since they are able to detect hydrogen peroxide with high sensitivity at moderate electrode potentials. Both materials are superior in the signal-to-noise ratio compared to exfoliated graphene. A further conjugation of enzymes to the defects within the carbon nano material as well as the assembly of 2D-layered composite materials will be perspective to biosensor applications.

DY 39.8 Thu 17:00 POT 081

Controlled chemical modification of graphene for applications in biosensing — •Marco R. Bobinger, Max Seifert, Anna Cattani-Scholz, and Jose A. Garrido — Walter Schottky Institut, Technische Universität München, Germany

Given its exceptional chemical and mechanical stability as well as its unique electronic properties, graphene is an extremely promising platform for biosensors. In order to use graphene in the biological environment and to improve sensing specificity and device performance, chemical functionalization schemes are needed to allow stable grafting of organic and bioorganic molecules onto graphene. In particular for applications in bioelectronics, the influence of the chemical functionalization of graphene on the generation of defects, strain, and doping has to be balanced with the desired modulation of the electronic properties of the produced graphene-organic hybrid material. In this work the effect of the controlled chemical modification of large area CVD-grown graphene via ozone treatment is investigated. This process creates sp3-like defects, related to covalently bound surface groups, e.g. OH-. Such ozone-treated surfaces are characterized by Raman- and X-ray photoelectron spectroscopy in order to investigate the degree of surface modification and the chemical composition of the surface terminations. The generated anchor groups are further used as binding sites for the modification of graphene with organic molecules.

DY 39.9 Thu 17:15 POT 081

Functionalization of Graphene for Bioelectronic Applications — •Alina Lyuleeva[1], Lucas Hess[1], Frank Deubel[2], and Jose Antonio Garrido[1] — [1]Walter Schottky Institut, TU München, 85748 Garching — [2]Wacker Chemie AG, 81379 München, Germany

With its fascinating structural, chemical and electronic properties, graphene outperforms many materials and is expected to pare the way for a vast range of applications such as transparent electrodes, energy storage devices, high-frequency electronics, or biosensors. The performance of the devices for these various applications can be enhanced with the help of surface functionalization, allowing a versatile modification of the properties of this material. Here, we report on the covalent and thus robust functionalization of CVD graphene with enzymes for the development of novel devices for bioelectronic applications. Graphene solution-gated field-effect transistors (SGFETs) are functionalized using a controlled grafting of polymethacrylate (PMA) brushes. We will show how this material platform can be used for further functionalization with the enzyme acetylcholinesterase (AChE). The enzymes' activity can be monitored with the modified-graphene transistor allowing both the measurement of the concentration of the neurotransmitter acetylcholine as well as the inhibition of the enzyme by neurotoxins such as nerve agents or pesticides. Our study demonstrates the potential of graphene-based functionalized transistors for biosensing and bioelectronic application.

DY 39.10 Thu 17:30 POT 081

Coupling of electrogenic cells to graphene devices — Michael Sejer Wismer, Felix Rolf, Damia Viana, •Martin Lottner, Lucas Hess, and Jose A. Garrido — Walter Schottky Institut - Technische Universität München, Am Coulombwall 4, 85748 Garching

In this contribution, we will demonstrate the electrical coupling between electrogenic cells and graphene-based solution-gated field effect transistors (SGFETs). To this end, HEK293 and HL1 cells were cultured on 8x8 arrays of graphene SGFETs with feature sizes of 10 mu x 20 mu. Graphene was grown by chemical vapour deposition (CVD) on copper foil and transferred to sapphire substrates, on which field effect transistors were fabricated using standard semiconductor technology. The devices show a typical maximum transconductance of >100 muS at 0.1 V drain-source voltage. This value is stable over months of storage. HEK293 cells were used to analyse the electrical coupling between cells and transistors. A model considering the distribution of ions within the cell transistor cleft and ion sensitivity of the graphene SGFETs fits the measured signals very well. Additionally, nano-transistors were defined by e-beam lithography, which allowed feature sizes down to 50 nm. With these nanoscale devices a signal-to-noise ratio of 2.5 could be obtained within single recordings of HL1 activity. Analysis of the measured ionic currents allowed to draw conclusions about local inhomogeneities of ion channel concentration within the membrane. Further, experiments for the stimulation of PC12 cells using arrays of graphene SGFET and graphene-based microelectrode arrays (MEAs) are under preparation.

DY 39.11 Thu 17:45 POT 081

Graphene solution-gated field effect transistors on flexible substrates — •Andrea Bonaccini Calia, Benno M. Blaschke, Lucas H. Hess, Max Seifert, and Jose A. Garrido — Walter Schottky Institut, Technische Universität München, Germany

Graphene based solution-gated field effect transistors (SGFETs) hold great promise for biosensors and bioelectronic applications. Due to its unique combination of electronic, mechanical, and chemical properties, such as high charge carrier mobility, flexibility and good biocompatibility, graphene has been shown to be an excellent material for sensing in electrolyte environments. Sensors based on graphene SGFETs have already been realized on rigid substrates for various analytes, as well as for the detection of cell signals. However, this technology hold some severe problems for biomedical and in vivo applications. One of the major problems is the rigidity of the substrate itself, which does not allow a proper mechanical matching to the biological tissue, resulting in the formation of scar tissue. Therefore, flexible devices are currently considered as a major step towards the development of more biocompatible implants. In this work, an array of graphene SGFETs is fabricated on a flexible polymer substrate. We present a detailed electrical characterization of the flexible graphene SGFETs in electrolyte and compare their performance to graphene SGFETs on rigid substrates. In addition, we analyze the effect of changes in the electrolyte's pH and ionic strength on the transistor performance and present a model to explain the obtained results. Furthermore, the low-frequency noise performance of graphene devices on flexible substrates is discussed.