## TT 16: Graphene II: Excitations and Nanoribbons (joint session O/TT)

Time: Monday 15:00–18:00 Location: H24

TT 16.1 Mon 15:00 H24

**Altering the lattice dynamics of graphene by hot-electron injection** — •Marcel Weinhold, Sangam Chatterjee, and Peter J. Klar — Institute of Experimental Physics I and Center for Materials Research (LaMa), Justus Liebig University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen

Graphene is discussed as material for next-generation (opto-)electronic devices. Among others, this is due to its exceptional properties including a large electron mobility, vast mechanical flexibility and durability, and its matchless linear and gap-less band structure. By combining graphene with metallic nanostructures that feature plasmonic characteristics its intrinsic properties can be tuned significantly. Those nanostructures lead to a near-field confinement of the incident light due to the excitation of localized surface plasmons (LSP). Further, LSPs decay non-radiatively into energy-rich electron-hole pairs. These 'hot-carriers' may be injected into the graphene and lead to a doping. However, plasmonic properties are very sensitive to geometry and dielectric environment. Therefore, single particle measurements are crucial for gaining further insights into the underlying physics. Here, we study the injection of hot-electrons in a model system, i.e., a single gold nanoparticle on a monolayer graphene substrate. We show that the injection of hot-electrons into graphene induces a quantifiable altering of graphene's phonon dispersion relation using specially resolved micro-Raman spectroscopy. In addition, we present an analysis procedure yielding further information on occurring temperature and strain distributions solely from the measured Raman shift maps.

TT 16.2 Mon 15:15 H24

**Single Spin Localization and Manipulation in Graphene Open-Shell Nanostructures** — •Jingcheng Li[1], Sofia Sanz[2], Martina Corso[2,3], Deung Jang Choi[2,3,5], Diego Peña[4], Thomas Frederiksen[2,5], and Jose Ignacio Pascual[1,5] — [1]CIC nanoGUNE, 20018 Donostia-San Sebastián, Spain — [2]DIPC, 20018 Donostia-San Sebastián, Spai — [3]Centro de Física de Materiales (CSIC-UPV/EHU), 20018 Donostia-San Sebastián, Spain — [4]3CIQUS, Santiago de Compostela (Spain) — [5]Ikerbasque, Basque Foundation for Science, 48013 Bilbao, Spain

Predictions state that graphene can spontaneously develop magnetism from the Coulomb repulsion of its $\pi$-electrons, but its experimental verification has been a challenge. Here, we report on the observation and manipulation of individual magnetic moments localized in graphene nanostructures on a Au(111) surface. Using scanning tunneling spectroscopy, we detected the presence of single electron spins localized around certain zigzag sites of the carbon backbone via the Kondo effect. Two near-by spins were found coupled into a singlet ground state, and the strength of their exchange interaction was measured via singlet-triplet inelastic tunnel electron excitations. Theoretical simulations demonstrate that electron correlations result in spin-polarized radical states with the experimentally observed spatial distributions. Hydrogen atoms bound to these radical sites quench their magnetic moment, permitting us to switch the spin of the nanostructure using the tip of the microscope.

TT 16.3 Mon 15:30 H24

**Molecular Spin Excitation by Electron Injection Through a Single Graphene Nanoribbon** — •Niklas Friedrich[1], Jingcheng Li[1], Néstor Merino-Díez[1,2], Dimas G. de Oteyza[2], Diego Peña[3], David Jacob[4,5], and Nacho Pascual[1,5] — [1]CIC nanoGUNE, San Sebastian (Spain) — [2]DIPC, San Sebastian (Spain) — [3]CIQUS, Santiago de Compostela (Spain) — [4]Departamento de Física de Materiales, UPV/EHU, San Sebastian (Spain) — [5]Ikerbasque, Basque Foundation for Science, Bilbao (Spain)

Graphene nanoribbons (GNRs) and GNR-hybrids can be synthesized on metal surfaces with atomic precision using on surface synthesis techniques. Previously, we constructed a system in which chiral (3,1)-GNRs act as leads contacting a magnetic porphyrin molecule on a Au(111) substrate. Characterizing the porphyrin's magnetic properties by inelastic electron tunneling spectroscopy (IETS) we showed that the porphyrin's spin survives up to 4 contacting GNRs.

As a further step towards fully functional molecular devices, we now characterize the transport properties of linear GNR-porphyrin-GNR systems. We created a transport junction by contacting the system at a GNR end with the STM tip and lifting the molecular complex partially from the surface. We investigate the porphyrin's spin state via IETS by electrons cotunneling through the semiconducting GNR. In this transport configuration inelastic tunneling excites the Fe spin with excitation energies similar to the one measured by STS on surface. However, some molecular structures were found to lie in a mixed-valence state that vanished as the porphyrin was lifted from the metal.

TT 16.4 Mon 15:45 H24

**Segregated transport channels in sidewall nanoribbons** — •Stephen Power[1,2,3], Johannes Aprojanz[4], Pantelis Bampoulis[5,6], Stephan Roche[1,7], Antti-Pekka Jauho[8], Harold Zandvliet[6], Alexei Zakharov[9], and Christoph Tegenkamp[4,5] — [1]ICN2, Bellaterra, Spain — [2]UAB, Bellaterra, Spain — [3]School of Physics, Trinity College Dublin, Ireland — [4]Institut für Physik, Technische Universität Chemnitz — [5]Institut für Festkörperphysik, Leibniz Universität Hannover — [6]MESA+Institute, University of Twente, The Netherlands — [7]ICREA, Barcelona, Spain — [8]CNG and DTU Nanotech, Denmark — [9]MAX IV Laboratory and Lund University, Sweden

Conductance quantization is a defining feature of electronic transport in quasi-one dimensional conductors. In the absence of a magnetic field, confinement results in a sequence of transverse sub-bands with an increasing number of nodes across the device width. Graphene nanoribbons grown on the sidewalls of SiC mesa structures have previously[1] been shown to present a 1D ballistic channel at the micron scale. New 2-point measurements reveal additional quantised channels at shorter probe separations[2]. Surprisingly, these channels are localised in different regions across the ribbon width. Here we demonstrate how this distribution of channels is consistent with a model accounting for both edge zigzag magnetism and asymmetric interfaces between the SiC and nanoribbon at each edge.

[1] J. Baringhaus et al, Nature 506 (2014) 349 [2] J. Aprojanz, S.R. Power et al, Nature Communications 9 (2018)4426

TT 16.5 Mon 16:00 H24

**Edge State Engineering of Graphene Nanoribbons** — •Ping Yu — School of Physical Science and Technology, ShanghaiTech University

Zigzag edges of graphene nanoribbons are predicted to be spin-polarized and could have great potential for spintronics. The ability to precisely engineer the zigzag edge state is of crucial importance for realizing its full potential functionalities in device nanotechnology. Here, by combining scanning tunneling microscopy and atomic force microscopy, the zigzag edge states are found to get energy splitting upon fusing manganese phthalocyanine molecule with the short armchair graphene nanoribbon termini. Moreover, the edge state splitting can be reversibly switched by adsorption and desorption of atom hydrogen on the magnetic core of manganese phthalocyanine. The engineering mechanism is found to be due to the zigzag edge local doping level by the charge transfer process, which provides a new route to functionalize graphene-based molecular devices.

TT 16.6 Mon 16:15 H24

**How Structural Defects Affect the Mechanical and Electrical Properties of Single Molecular Wires** — •Matthias Koch[1], Zhi Li[2], Christophe Nacci[1,3], Takashi Kumagai[1], Ignacio Franco[2], and Leonhard Grill[1,3] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]University of Rochester, Rochester, United States — [3]University of Graz, Graz, Austria

Graphene nanoribbons (GNRs) [1] are attractive candidates for molecular wires [2]; a key component in molecular nanotechnology. In addition to inheriting the supreme electromechanical properties of graphene [3], these narrow stripes offer a tunable band gap [4], which is crucial for electronic applications. Although many studies on molecular wires exist, the role of defects in the chemical structure has not been investigated. Here, we show how individual defects affect the properties of single GNRs [5]. Scanning tunnelling and atomic force microscopy (STM/AFM) pulling experiments access their electrical and mechanical properties simultaneously. We find, with the help of atomistic simulations, that defects substantially vary the molecule-substrate coupling and drastically increase the flexibility of the graphene nanoribbons while keeping their desirable electronic properties intact. Our study suggests that defected GNRs are suitable for molecular electronics that require flexible components, in contrast to rigid architectures.

[1] Cai, J. et al. Nature 466, 470 (2010) [2] Koch, M. et al. Nat. Nanotech. 7, 713 (2012) [3] Novoselov, K. S. et al. Nature 490, 192 (2012) [4] Han, M. Y. et al. Phys. Rev. Lett. 98, 206805 (2007) [5] Koch, M. et al. Phys. Rev. Lett. 121, 047701 (2018)

TT 16.7 Mon 16:30 H24

**Tailoring end states of graphene nanoribbons by magnetic dopants** — •Tobias Preis, Sujoy Karan, Tobias Frank, Jaroslav Fabian, Ferdinand Evers, Dieter Weiss, Jonathan Eroms, and Jascha Repp — University of Regensburg, Faculty of Physics - Regensburg, Germany

Zig-zag edges of graphene are predicted to host spin-polarized electronic states and hold great promise for future spintronic device applications [1]. With the help of scanning tunneling microscopy (STM), we investigated the short zig-zag edges of bottom-up synthesized armchair graphene nanoribbons (GNRs), which were fabricated according to the recipe of Cai et al. [2]. We deposited single Co atoms on the surface and positioned them with the help of the STM tip underneath the GNRs. dI/dV spectra taken at the adsorption positions of embedded Co atoms show the emergence of a Kondo-like peak, being distinctly different from any Kondo features of isolated Co adatoms on the Au(111) surface. The peak exhibits a peculiar dependence on the position with respect to the short GNR edge.

[1] K. Nakada et al., PRB 54, 24 (1996)
[2] J. Cai et al., Nature 466, 470 (2010)

TT 16.8 Mon 16:45 H24

**On-surface synthesis of chevron-like graphene nanoribbons** — •Koen Houtsma, Mihaela Enache, Ida Delac Marion, Tuan Anh Pham, Van Bay Tran, and Meike Stöhr — Zernike Institute for Advanced Materials, University of Groningen, Groningen, the Netherlands

Graphene nanoribbons (GNRs) are a novel material that has aroused much interest because of its excellent and tunable electronic properties. Using on-surface synthesis, GNRs can be produced with atomic precision. In our research, GNRs with chevron-like topology were created via Ullman-type coupling from the prochiral molecular precursor 6,12-dibromochrysene on a Au(111) surface. The structural properties of these GNRs, also in dependence of post-deposition annealing temperature, were investigated using scanning tunneling microscopy [1]. With scanning tunneling spectroscopy, we additionally characterized their electronic properties.

[1] T.A. Pham et al., Small 13 (2017) 1603675.

TT 16.9 Mon 17:00 H24

**Bottom-up fabrication of porous carbon nanoribbons on metal surfaces** — •Mirunalini Devarajulu, Martin Haller, Maximilian Ammon, Min-Ken Li, Shadi Sorayya, and Sabine Maier — Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

On-surface synthesis is a versatile technique to fabricate graphene-based nanoribbons from the bottom-up with high precision. We demonstrated that one-dimensional carbon nanoribbons with periodic hexagonal nanopores can be fabricated via Ullmann-type reactions on Ag(111) in combination with dehydrogenation reactions and the preprogrammed isomerization of the conformationally flexible precursor.[1] Here, we unveil the reaction mechanism and the N-doping of the porous nanoribbons in a low-temperature scanning tunneling microscopy study. We show that the rotation of *m*-phenylene units is a powerful design tool to promote structural control in the synthesis of porous covalent organic nanostructures on different metal surfaces. We find that the fabrication of porous nanoribbons proceeds on different terminations of the silver surface. However, the N-doping via triazine moieties influences the conformational selectivity of the molecular precursor, which affects the nanoribbon formation.

[1] M. Ammon, T. Sander, S. Maier, JACS, 2017, 139 (37), 12976

TT 16.10 Mon 17:15 H24

**Chevron-based graphene nanoribbons and heterojunctions by direct contact printing** — •Axel Enders[1], Jacob D Teeter[2], Paulo S Costa[2], Gang Li[2], and Alexander Sinitskii[2] — [1]Universität Bayreuth, Physikalisches Institut, 95440 Bayreuth — [2]University of Nebraska - Lincoln, Lincoln NE 68588, USA

Atomically precise graphene nanoribbons (GNRs) have been synthesized through a direct contact transfer (DCT) of molecular precursors on Au(111), followed by gradual annealing. This method provides an alternative to the conventional approach for the deposition of molecules on surfaces by sublimation and simplifies preparation of dense monolayer films of GNRs. We performed STM characterization of the precursors of chevron GNRs, and demonstrate that the assemblies of the intermediates of the GNR synthesis are stabilized by $\pi$ - $\pi$ interactions. DCT was then used to deposit a mixture of two structurally similar but visually distinct chevron-type molecular precursors. Annealing of the deposited mix resulted in heterojunctions composed of units of chevron GNRs (cGNRs) and new laterally extended chevron GNRs (eGNRs). The electronic properties of these GNRs across the heterojunctions were studied with scanning tunneling spectroscopy. The dI/dV maps show that the impact of heterojunctions as well as structural defects is highly local and usually stays within the corresponding GNR units even if they are bonded to structurally and electronically different neighbors. It is expected that this method of DCT is highly versatile and allows to combine other chevron-type GNRs as well, such as nitrogen-doped cGNRs, into a variety of new GNR heterojunctions.

TT 16.11 Mon 17:30 H24

**Expitaxially grown twisted bilayer graphene on SiC(0001)** — •You-Ron Lin[1,2], Nafiseh Samiseresht[1,2], Markus Franke[1,2], Shayan Parhizkar[1,2], François C. Bocquet[1,2], F. Stefan Tautz[1,2], and Christian Kumpf[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA) - Fundamentals of Future Information Technology, 52425 Jülich, Germany

Layer by layer stacking of 2D-materials such as graphene, hexagonal boron nitride (hBN) and transition metal dichalcogenides (TMDCs) has been widely investigated developing a field on its own [1]. It has been shown that apart from the material used for stacking, the twist angle between two layers also has an immense effect on the band structure of the stack [2]. We report a reproducible method for large scale epitaxial growth of graphene bilayers utilizing the precursor molecule borazine. The existence of both graphene layers is confirmed by angular-resolved photoemission spectroscopy (ARPES). Spot-profile analysis low electron energy diffraction (SPA-LEED) has been used to determine a twist of $30 \pm 0.46^\circ$.
[1] A. K. Geim *et al.*, *Nature*, **499**, 419, 2013.
[2] Y. Cao *et al.*, *Nature*, **556**, 43, 2018.

TT 16.12 Mon 17:45 H24

**Dielectric engineering in twisted bilayer graphene** — •Jose Pizarro[1], Malte Rösner[2], Ronny Thomale[3], and Tim Wehling[1] — [1]Universität Bremen — [2]University of Southern California — [3]Universität Würzburg

Twisted bilayer graphene (TBG) has appeared as a tunable testing ground to investigate the conspiracy of electronic interactions, band structure, and lattice degrees of freedom to yield exotic quantum many-body ground states in a two-dimensional semiconductor framework. While the impact of external parameters such as doping or magnetic field can be conveniently modified and analyzed, the lack of open accessiblity of the quasi-2D electron gas combined with its intricate internal properties pose a challenging task to characterize the quintessential nature of the different insulating and superconducting states found in transport experiments. We analyze the possible role of the dielectric environment for TBG on the internal electronic interaction profile, which could be conveniently adjusted in experiment, e.g. by varying the capping layer composition and thickness. We find that this allows to significantly modify the internal interaction strength. In doing so, we propose the experimental tailoring of the dielectric environment as a promising pursuit to provide further evidence for resolving the hidden nature of quantum many-body states in TBG.