TT 64: Poster Session: Transport

Time: Thursday 15:00–18:30 Location: Poster D

TT 64.1 Thu 15:00 Poster D

Spin effects in resonant transport through interacting quantum dots — •Simon Mundinar, Jürgen König, and Stephan Weiss — Theoretische Physik, Universität Duisburg-Essen and CENIDE, 47048 Duisburg, Germany

We report on numerically exact iterative path-integral calculations (ISPI) for spin-dependent transport through small interacting quantum dots [1-3]. Our ISPI method builds upon the truncation of exponentially vanishing real-time correlations at finite temperature and/or bias voltage. In particular, we study two distinct systems (i) a spin-valve, where ferromagnetic leads induce spin-dependent tunnel couplings between leads and dot [2] and (ii) a hybrid structure, where the quantum dot is coupled to a normal and a superconducting lead [3]. For the spin-valve setup, the observable of interest is the tunneling magnetoresistance through the quantum dot, which is investigated for various system parameters. We find that, especially at low temperatures, resonant tunneling effects are dominant and the sequential picture does not apply. The role of Coulomb interactions together with changing the temperature of the system is explored. Within the hybrid system, a finite gap parameter Δ induces anomalous self energies in the Keldysh partition function. ISPI calculations are performed to deduce, e.g. the impact of Coulomb interactions on the Andreev bound state spectrum in a nonequilibrium situation.

[1] S. Weiss, et. al, Phys. Status Solidi B, **250** (11), 2298-2314 (2013).
[2] S. Mundinar, J. König, and S. Weiss, in preparation (2018).
[3] S. Weiss and J. König, in preparation (2018).

TT 64.2 Thu 15:00 Poster D

Synchronization of coherent charge oscillations of two coupled double quantum dots — •Eric Kleinherbers, Philipp Stegmann, and Jürgen König — Theoretische Physik, Universität Duisburg-Essen and CENIDE, Lotharstr. 1, 47048 Duisburg

In a double-dot system, charge oscillates coherently between two tunnel-coupled quantum dots. These oscillations have a distinct impact on the electron transport through the system and can be detected by means of the finite-frequency noise or the waiting-time distribution [1].

Here, we discuss how the oscillations of two distinct double-dot systems influence each other by means of electrostatic coupling. The electron transport is modeled by a generalized master equation obtained from a real-time diagrammatic approach [2]. By calculating the waiting-time distribution and performing a spectral analysis, synchronization effects are revealed.

[1] T. Brandes, Ann. Phys. **17**, 477 (2008)
[2] B. Wunsch, M. Braun, J. König, and D. Pfannkuche, Phys. Rev. B **72**, 205319 (2005)

TT 64.3 Thu 15:00 Poster D

Superconducting proximity effect and conductance quantization in bilayer graphene quantum wires — •Vanessa Gall[1,2] and Igor Gornyi[1,2] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute for Condensed Matter Theory, Karlsruhe Institute of Technology, Karlsruhe, Germany

Quantum wires or Quantum Point Contacts (QPCs) built from two dimensional material, like bilayer graphene (BLG), might pave the way towards quantum circuits. We consider a gate defined BLG based quantum wire with a perpendicular magnetic field and both superconducting and non superconducting leads. In the superconducting regime we study the magnetic interference pattern in rectangular junctions by means of a semi-classical model. A similar study was recently conducted on BLG QPCs, where it could be shown, that a variation in the gate potentials leads to a tailoring of the supercurrent. Here we find a dependence on the aspect ratio, where scattering off the side edges is of high importance in narrow junctions, but not in wide ones. In the normal conducting regime, we investigate the quantized conductance due to finite size effects and the emergence of Landau levels. We find an accidential degeneracy for wide channels and large gaps. The experimental confirmation in the case of BLG QPCs was recently given. The conduction plateaus of height $4\frac{e^2}{h}$ are clearly visible and the first step has a height of $8\frac{e^2}{h}$ for certain values of the splitgate. The conditions for this accidential degeneracy can be expressed analytically by means of the effective two band hamiltonian.

TT 64.4 Thu 15:00 Poster D

Fluctuation relations in interacting quantum pumps — •Roman-Pascal Riwar[1] and Janine Splettstoesser[2] — [1]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, Germany — [2]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Sweden

The understanding of out-of-equilibrium fluctuation relations in small open quantum systems has been a focal point of research in recent years. Here, we consider symmetries and fluctuation relations of the charge and energy current statistics in time-dependently driven, interacting quantum systems, such as quantum dot pumps. In particular, we study slowly driven pumps, where we systematically expand the full-counting statistics in orders of the driving parameter. We find that while in zeroth (instantaneous) order, it suffices to consider the charge current cumulants separately to formulate fluctuation relations, for the first order, this is no longer possible. The energy displacement currents necessarily appear as extra terms, as a consequence of the highly geometric nature of the pumping current statistics. Surprisingly, there is one exception: when the Coulomb interactions disappear in the dot, so does this correction. We therefore find that it is possible to recover the standard equilibrium fluctuation-dissipation theorem, notably in presence of a non-equilibrium pump, as long as the system is noninteracting.

TT 64.5 Thu 15:00 Poster D

Control of the critical temperature of Nb by spin-helix reorientation in the chiral magnet MnSi — •Julius Grefe, Bastian Rubrecht, Nico Steinki, David Schroeter, Stefan Süllow, and Dirk Menzel — Institut für Physik der Kondensierten Materie, Technische Universität Braunschweig

Theory has predicted the possibility to control the critical temperature T_C of a superconductor via a proximity effect with a non-collinear magnet. The chiral magnet MnSi as a representative of the cubic B20 structure shows such a magnetic behavior below $T_N = 29.5$ K and $B_{C1} = 100$ mT. To examine this prediction, Nb ($T_C = 9.2$ K) thin films have been deposited by molecular beam epitaxy on (111)-oriented MnSi monocrystalline substrates grown by the Chochralski process. The dependence of the critical temperature of Nb on the orientation of the spin helices in MnSi switched by an external magnetic field has been investigated. The critical temperature of the superconducting Nb films has been determined by four-point resistance and SQUID susceptibility measurements. For comparison, diamagnetic CoSi substrates have been used as reference samples. This proximity effect can be used for switching a superconducting spin valve consisting only of a single magnetic layer.

TT 64.6 Thu 15:00 Poster D

Low temperature MCBJ measurements of C_{60} Fullerenes — •Alexander Strobel[1,2], Filip Kilibarda[1,2], Elke Scheer[2], and Artur Erbe[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]University of Konstanz, Faculty of sciences, 78457 Konstanz, Germany

Current industrial semiconductor scaling processes are reaching limits. We see not only diminished returns with further scaling attempts, but also physical limitations that come more and more into play. In our research we offer a novel approach, where we try to drop altogether the concept of 3D scaling of electronic components and go to practically 1D molecular systems. This approach offers not only reduction in power consumption and costs, but also a deeper understanding of the electron transport behavior of molecules. Our research focuses on classifying different molecules with the help of Mechanically Controlled Break Junction (MCBJ) technique.

The Poster shows the investigation of the conductance of C_{60} Fullerene molecules using a unique mechanical controllable break junction (MCBJ) setup. The C_{60} molecule with its high stability and symmetry is convenient to investigate the Bonding between electrodes (Au) and molecule. The MCBJ setup enables to evaporate in situ and measure under high vacuum conditions. Furthermore low temperatures measurements down to 10 K are possible. From conductance histograms preferred conductance values of single C_{60} molecules are

deduced. I-V and dI-dV curves give rise to a deeper understanding of electron transport mechanisms in C_{60} molecules.

TT 64.7 Thu 15:00 Poster D

Thermoelectric transport in nanosystems: A hierarchical quantum master equation approach — •Jakob Bätge, Ka Chun Chan, and Michael Thoss — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany

A variety of interesting transport phenoma exist in nanoelectronic systems. Recently, quantization of heat transport has been observed [1] and counterintuitive thermal stabilization in molecular junctions has been predicted [2]. In this context, we investigate voltage and temperature driven electron and heat transport from a theoretical point of view. In particular, we are interested in the interplay of electronic and vibrational degrees of freedom. For this purpose, we use the hierarchical quantum master equation method [3], which generalizes perturbative master equation methods by including higher-order contributions as well as non-Markovian memory and allows for the systematic convergence of the results.

[1] L. Cui *et al.*, Science **355**, 1192 (2017).
[2] R. Härtle *et al.*, Phys. Rev. B **98**, 081404(R) (2018).
[3] C. Schinabeck *et al.*, Phys. Rev. B **94**, 201407(R) (2016).

TT 64.8 Thu 15:00 Poster D

Quantum Transport through Single-molecule Junctions: Non-adiabatic Effects — •Christoph Kaspar, Christian Schinabeck, and Michael Thoss — Albert-Ludwigs-Universität, Freiburg, Germany

The coupling of electronic and nuclear degrees of freedom is an important mechanism in non-equilibrium charge transport in molecular junctions and may result in a variety of interesting phenomena such as decoherence, switching and local cooling or heating [1]. While the effect of adiabatic polaron-type coupling has been studied in great detail, new phenomena are expected for non-adiabatic coupling scenarios which correspond to a breakdown of the Born-Oppenheimer approximation. In this contribution, we present results of a model study of non-adiabatic effects employing the hierarchical quantum master equation approach [2, 3]. This method generalizes perturbative master equation methods by including higher-order contributions as well as non-Markovian memory and allows for the systematic convergence of results. In particular, we observe a quantum transport behavior strongly influenced by the interaction with the vibrational modes.

[1] Härtle *et al.*, Phys. Rev. B **98**, 081404 (2018)
[2] Jin *et al.*, J. Chem. Phys. **128**, 234703 (2008)
[3] Schinabeck *et al.*, Phys. Rev. B **94**, 201407R (2016)

TT 64.9 Thu 15:00 Poster D

Thermal conductivity and thermal diffusivity of suspended few-layer h-BN using the 3ω method — •Sofia Blanter, Nicola Paradiso, Denis Kochan, and Christoph Strunk — Institut für experimentelle und angewandte Physik, Universität Regensburg, Universitätstr. 31, 93053 Regensburg

We present measurements of thermal conductivity and thermal diffusivity for few-layer suspended hexagonal boron nitride. The measurements are performed on 15 nm thick suspended h-BN flakes using the 3ω method.

The flakes are exfoliated and transferred on top of a SiN membrane with an etched slit, using the all-dry viscoelastic stamping method [1].

We use the 1D diffusion model [2], that allows us to extract the thermal conductivity and thermal diffusivity of our flakes between 25 and 300 K. The temperature dependence of the thermal conductivity is consistent with previous measurements using a different technique [3], and demonstrates the reliability of the method. First results on few-layer $MoSe_2$ flakes are presented.

[1] A. Castellanos-Gomez et al., 2D Materials **1** (2014), 011002
[2] A. Sikora et al., Rev. Sci. Instrum. **83** (2012), 054902
[3] I. Jo et al., Nano letters **13.2** (2013), 550-554

TT 64.10 Thu 15:00 Poster D

Zero-dimensional contacts to carbon nanotubes encapsulated by hexagonal boron nitride — Christian Bäuml, •Michaela Eichinger, Nicola Paradiso, and Christoph Strunk — University of Regensburg, Regensburg, Germany

Edge contacts to carbon nanotubes (CNTs) have a contact interface of only a handful of atoms. Nevertheless, they display a resistance less than 30 kΩ, comparable to the most transparent contacts obtained with previous techniques [1].

In this work we present an alternative method for edge contacting CNTs. Unlike the method demonstrated by Huang et. al., we do not pick up the CNT. Instead we grow CNTs directly on few-layer hexagonal boron nitride (hBN) by chemical vapor deposition. We cover the interesting CNT portion by a second hBN layer by simple dry stamping in nitrogen atmosphere. Edge contacts are then fabricated using a similar recipe as for the production of graphene edge contacts. The simplicity of our approach is particularly suited for the fabrication of hybrid 2D-1D material structures based on ultra-clean CNTs.

[1] J.-W. Huang et. al. Nano Lett. **15**, 6836 (2015)

TT 64.11 Thu 15:00 Poster D

Lab::Measurement – measurement control with Perl — Simon Reinhardt[1], Christian Butschkow[1], Stefan Geissler[1], Alois Dirnaichner[1], Florian Olbrich[1], Charles E. Lane[2], and •Andreas K. Hüttel[1] — [1]Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany — [2]Department of Physics, Drexel University, Philadelphia, USA

`Lab::Measurement` is a collection of Perl 5 modules providing control of test and measurement devices. It allows for quickly setting up varying and evolving complex measurement tasks with diverse hardware. Instruments can be connected by means such as GPIB (IEEE 488.2), USB-TMC, or VXI-11 / raw network sockets via Ethernet. Internally, third-party backends as, e.g., Linux-GPIB, National Instruments' NI-VISA library, or Zurich Instruments' LabOne API are used, as well as lightweight drivers for USB and TCP/IP-based protocols. The wide range of supported connection backends enables cross-platform portability. Dedicated instrument driver classes relieve the user from taking care of internal or vendor-specific details. A high-level layer provides fast and flexible creation of nested measurement loops, where, e.g., several input variables are varied and output data is logged into a customizable folder structure. `Lab::Measurement` has already been successfully used in several low temperature transport spectroscopy setups. It is free software and available at `http://www.labmeasurement.de/`

[1] S. Reinhardt *et al.*, Comp.Phys.Comm. **234**, 216 (2019)

TT 64.12 Thu 15:00 Poster D

Optomechanics of a suspended carbon nanotube quantum dot coupled to a coplanar microwave resonator — Stefan Blien, Patrick Steger, •Niklas Hüttner, Richard Graaf, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany

A clean, suspended single wall carbon nanotube is the ultimate limit of a nanomechanical beam resonator, where the fundamental transversal vibration mode reaches resonance frequencies on the order of 100MHz – 1 GHz and mechanical quality factors up to 10^6. Placing a nanotube next to a coplanar resonator at cryogenic temperatures results in a microwave optomechanical system with dispersive coupling. This system, however, has a fundamentally new property: the nanotube is also a quantum dot, and strong interaction of motion and single electron tunneling dominates its behaviour.

We have implemented a transfer technique to integrate such a nanotube into a superconducting circuit, and present measurements on a combined device coupling a suspended quantum dot to a microwave resonator mode at millikelvin temperatures. The dispersively coupled optomechanical system is characterized via two-tone spectroscopy (red side band photon upconversion) as well as optomechanically induced transparency (OMIT). The interaction of charge transport and vibration, via Coulomb blockade and single electron tunneling, leads to a strongly enhanced, tunable optomechanical coupling.

TT 64.13 Thu 15:00 Poster D

Carbon nanotube transfer into complex devices with commercial quartz tuning forks — •Patrick Steger, Niklas Hüttner, Richard Graaf, Alexander Albang, Stefan Blien, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, University of Regensburg, 93040, Regensburg, Germany

Our work focuses on coupling suspended, clean carbon nanotubes (CNTs) to a superconducting coplanar waveguide (CPW) resonator for experiments in the field of optomechanics. However, device fabrication is challenging. To increase our fabrication yield we separate the CVD process for CNT growth from the rest of the device fabrication. CNTs are then transferred to the device in a second step. Our transfer setup allows in situ precharacterization of the CNT during the transfer process. When a suitable CNT is found, the transfer process is finished

by cutting the tube with current pulses at both ends.

Using commercial quartz tuning forks as CNT growth substrate produces high quality samples with a good yield and relatively low fabrication effort. Fabrication of customized fork structures might help to further enhance the yield.

TT 64.14 Thu 15:00 Poster D

Proximity induced superconductivity in normal metal/h-BN encapsulated graphene/superconductor junctions — •Preeti Pandey[1], Romain Danneau[1], Ralph Krupke[1,2], and Detlef Beckmann[1] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Department of Materials and Earth Sciences, Technical University Darmstadt, Darmstadt, Germany

We present an electronic transport study of multiterminal normal metal/graphene/superconductor (NGS) junctions. In these junctions, the monolayer graphene sheet was encapsulated between two h-BN crystals. The graphene channel contacts the superconductor and the normal metal electrodes in orthogonal SGS and NGN junction configuration. We have observed clear signs of Josephson effect in the SGS junction when the graphene channel is driven to the n-doped as well as to the p-doped regime using a gate electrode. We have investigated the effect of the current through the NGN junction, which acts as a controlling parameter, on the Josephson current through the SGS junction.

TT 64.15 Thu 15:00 Poster D

Correlation Effects on the Electronic Structure of Graphene Nanoribbon Heterojunctions — •Jan-Philip Joost, Niclas Schlünzen, and Michael Bonitz — Institute of Theoretical Physics and Astrophysics, Kiel University, 24098 Kiel, Germany

Due to their tunable band gap graphene nanoribbons (GNRs) emerged as a promising candidate for various applications in nanoelectronics and optoelectronics [1]. Compared to macroscopic graphene, in GNRs electron–electron correlations are enhanced by the quantum confinement of the electrons. An accurate description, therefore, has to go beyond the often used mean-field approaches [2]. Here, we decribe the GNRs using an extended Hubbard model that improves the common tight-binding models by taking into account electron–electron interactions. The model is solved by a nonequilibrium Green functions [3] (NEGF) approach combined with the GW self-energy to account for electron correlations. As a particular application we study the electronic structure of GNR heterojunctions and compare to the experimental observations of Ref. [4].

[1] J. P. Llinas *et al.*, Nat. Commun. **8**, 633 (2017)
[2] J.-P. Joost *et al.*, Phys. Status Solidi B, in press
[3] K. Balzer and M. Bonitz, Lect. Notes Phys. **867** (2013)
[4] D. J. Rizzo *et al.*, Nature **560**, 204 (2018)

TT 64.16 Thu 15:00 Poster D

Thermal-induced currents and spin caloritronics in a graphene nanostructure — •Thi Thu Phùng[1,2], Andreas Honecker[1], and Javad Vahedi[1] — [1]Laboratoire de Physique Théorique et Modélisation, CNRS UMR 8089, Université de Cergy Pontoise, 95302 Cergy-Pontoise, France — [2]University of Science and Technology of Ha Noi, 18 Hoang Quoc Viet, Ha Noi, Vietnam

We study a spin caloritronics device based on a heterostructure consisting of a hexagonal graphene flake with anti-ferromagnetic zigzag edges as central region connecting two leads [1] using the non-Equilibrium Green's Function (NEGF) technique combined with a mean-field approximation for the Hubbard model. Spin-up and spin-down currents are simultaneously generated and flow in opposite directions when leads are at different temperatures. Thanks to the magnetization at the zigzag-edges of the graphene flake, the resulting spin-up current is much larger such that both total spin current and net charge current are obtained. The key ingredients are the imbalance of charge carrier concentrations which is determined by the Fermi distribution at the source and drain, transmission spectra and on-site Coulomb repulsion U. These currents not only exhibit a negative differential thermoelectric resistance, but also can be modulated easily by the gate voltage. By adjusting parameters suitably, the efficiency of the spin-filtering effect might achieve nearly 100%. These findings make the proposed device a promising candidate for spin caloritronics applications.

[1] A. Valli, A. Amaricci, V. Brosco, and M. Capone, Nano letters **18**, 2158 (2018).

TT 64.17 Thu 15:00 Poster D

Structural and electronic properties of graphene/MoS_2 bilayer heterostructures — •Somepalli Venkateswarlu, Andreas Honecker, and Guy Trambly de Laissardière — Laboratoire de Physique Théorique et Modélisation, CNRS UMR 8089, Université de Cergy-Pontoise, France

Graphene and two-dimensional materials based on transition metal dichalcogenides have gained increasing attention because of their fascinating features in electronics and optical properties [1]. Combining a single layer of graphene with a transition metal dichalcogenide layer in a Van der Waals heterostructure offers an intriguing means of controlling the electronic properties through these bilayer heterostructures [2]. Here, we report the structural and electronic properties of graphene/MoS_2 bilayer heterostructures. For the theoretical calculations, we use Density Functional Theory with Van der Waals corrections, as implemented in the Abinit package [3]. We analyze the interlayer spacing between the graphene and MoS_2 layers and also the location of Dirac points near the Fermi level. In particular, we focus on the structural and electrical properties of bilayer heterostructures with different supercell geometries and give particular attention to the effect of relaxing the lattice structure. These heterostructures are based on different supercell geometries (4:3, 5:4, and 9:7), having different magnitudes of the lattice mismatch.

[1] E. S. Kadantsev, P. Hawrylak, Solid State Comm. **152**, 909 (2012)
[2] S. Singh, C. Espejo, A. H. Romero, Phys. Rev. B **98**, 155309 (2018)
[3] X. Gonze et al., Comp. Mat. Sci. **25**, 478 (2002); https://www.abinit.org