TT 29: Transport: Poster Session

In case the presenters cannot be present at their posters for the full duration of the poster session, they are kindly requested to leave a note at their poster indicating when they will be available for discussion.

Time: Thursday 15:00–18:00 Location: P1

TT 29.1 Thu 15:00 P1

Relaxation dynamics in two quantum dots coupled to the environment: The role of coupling asymmetry — •Lukas Litzba, Eric Kleinherbers, Nikodem Szpak, and Jürgen König — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany

We study a strongly interacting two-site Fermi-Hubbard model representing two coupled quantum dots and couple them each with different strengths to Markovian baths. We start with the Born-Redfield equation (without second Markov approximation) and approximate it by the coherent Lindblad master equations [1]. Using this technique we observe that the long-time dynamics of a quantum state, in particular the contribution from the energy coherences, depends strongly on the asymmetry between the bath coupling strengths of the dots. In contrast to the Born-Redfield equation and the coherent Lindblad master equations the popular secular approximation fails to properly describe the interdot and bath-dot currents in the asymmetric coupling case. To compare the quality of the approximations we use the exact solution in the case of no Coulomb interaction.
[1] E. Kleinherbers, N. Szpak, J. König, R. Schützhold, Phys. Rev. B 101, 125131 (2020)

TT 29.2 Thu 15:00 P1

Manipulating molecular spins with carbon nanotube SQUIDs — •Tim Althuon, Aljoscha Auer, Tino Cubaynes, and Wolfgang Wernsdorfer — Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe

Single-molecule magnets (SMMs) are promising candidates for spin-qubits due to their small size, cheap and reproducible chemical synthesis in a bottom-up approach and the opportunity to engineer their chemical properties such as the magnetic moment. However, an integration of SMMs with nanoscale diameters into electronic circuits is challenging. A solution to this problem could be to graft these molecules on carbon nanotubes (CNTs) which are comparable to SMMs in the diameter and possess unique sensing properties.

The CNT can be included as a weak-link Josephson junction into a superconducting quantum interference device (SQUID). Such a nano-SQUID is expected to have a large coupling between the magnetic moment of a molecule grafted on the CNT and the flux through the SQUID loop, giving rise to a very simple and precise detection of the spin of a single molecule.

Our CNTs are grown on separate chips with chemical vapor deposition and can then be integrated into prepatterned electronic circuits. For this purpose we use a novel, ultraclean, dry-transfer technique of CNTs where the CNTs are never exposed to air. This contribution will mainly focus on the integration of suspended CNTs into electronic circuits including preliminary results on the characterization of the devices at room and milli-Kelvin temperatures.

TT 29.3 Thu 15:00 P1

A carbon-nanotube nanoelectromechanical system coupled to a single-molecule magnet — •Aljoscha Auer, Svenja Müller, Tim Althuon, Tino Cubaynes, and Wolfgang Wernsdorfer — Karlsruher Institut für Technologie, 76131 Karlsruhe

The one-dimensional structure of carbon nanotubes (CNTs) as well as their low weight and high Young*s modulus make them an excellent candidate for nanoelectromechanical systems (NEMS). With their mechanical resonance frequency in the hundreds of MHz regime combined with a large quality factor they are suited for high sensitivity experiments. In addition, the conductivity of CNTs can be tuned nicely by applying an electric field tuning the energy levels of charge carriers. For our experiments we want to use a suspended, top-down fabricated carbon nanotube, grown by chemical vapour deposition connecting two electrodes or using a stamping technique where the CNT is grown on a separate chip. Five local gates below the suspended nanotube enable us to manipulate the system by application of a tunable electric field. Furthermore, we want to attach a single-molecule magnet (SMM) to the nanotube by thermal evaporation, therefore creating a system using spin-phonon-coupling to address a single individual spin. The possible measurements in this configuration are manifold, ranging from magnetoresistive effects, spin valves respectively, and double quantum dot transport measurements to electron-phonon coupling measurable in transport measurements in a mechanical resonator.

TT 29.4 Thu 15:00 P1

Investigation of Hall effects in freestanding $SrRuO_3$ nanomembranes — •Stefan Petersen, Roman Hartmann, Elke Scheer, and Angelo Di Bernardo — University of Konstanz, Konstanz, Germany

$SrRuO_3$ (SRO) is a one of the most intensively studied ferromagnetic oxides with a Curie temperature of about 150 K. In addition to being ferromagnetic, SRO is also interesting because of its high conductivity at low temperatures, high chemical stability and good lattice matching with other oxides.

Recently, a new technique has been developed to manufacture freestanding nanomembranes of oxide thin films grown on a water-soluble $Sr_3Al_2O_6$ (SAO) sacrificial layer [1]. In our group, we have recently reproduced this process and been able to obtain freestanding nanomembranes of SRO.

We have investigated the anomalous Hall effect (AHE) and topological hall effect (THE) in SRO nanomembranes as a function of thickness and temperature, using SRO thin films grown on $SrTiO_3$ substrates as benchmark for comparison. We have also studied the evolution of these effects in SRO nanomembranes under a voltage-driven strain exerted by a piezoelectric substrate in contact with the nanomembrane. Our results are preliminary to the fabrication of devices with electric control of the AHE and THE.
[1] D. Lu et al., Nat. Mater. 15, 1255 (2016)

TT 29.5 Thu 15:00 P1

Curvature control of the superconducting proximity effect in diffusive ferromagnetic nanowires — •Tancredi Salamone[1], Henning Hugdal[1], Morten Amundsen[2], and Sol Jacobsen[1] — [1]QuSpin Center for Quantum Spintronics, NTNU, Trondheim, Norway — [2]Nordita, KTH Royal Institute of Technology, Stockholm, Sweden

There is currently great interest in the inclusion of superconducting components in spintronic devices, because they can provide dissipationless currents, greatly enhancing device performances for spin-based data processing. Coupling a conventional s-wave superconductor to a ferromagnet allows, via the proximity effect, to generate superconducting triplet correlations. The generation of triplet correlations can be employed to achieve a superconducting triplet spin-valve effect in superconductor-ferromagnet (SF) hybrid structures, for example by switching the magnetizations of the ferromagnets between parallel and antiparallel configurations in F_1SF_2 and SF_1F_2 trilayers, or in SF bilayers with both Rashba and Dresselhaus spin-orbit coupling. It was recently reported that geometric curvature can control the generation of long ranged triplets [1]. In our most recent work [2], we use this feature to show that the superconducting critical temperature of the hybrid structure can be tuned by varying the curvature of the ferromagnetic wire alone, with no need of another ferromagnet or SOC. Furthermore, we show that the variation of the critical temperature as a function of the curvature can be exploited to obtain a robust, curvature-controlled, superconducting triplet spin-valve effect.
[1] Phys. Rev. B **104**, L060505
[2] Phys. Rev. B **105**, 134511

TT 29.6 Thu 15:00 P1

Electronic transport through single-molecule junctions of photoswitchable diarylethenes — •Valentin Barth[1], Lukas Holz[1], Thomas Huhn[1], Franz Herbst[1], Gautam Mitra[1], Christopher Weaver[2], Sergii Snegir[1], Tim Albrecht[2], and Elke Scheer[1] — [1]University of Konstanz, Konstanz, Germany — [2]University of Birmingham, Birmingham, UK

Single-molecule junctions represent the conceptually simplest molecular devices. It is important to determine their electronic transport properties. Here we report on the transport characteristics of diarylethene-oligophenylene (DAE-OPE) molecule junctions at room and low temperature [1]. DAE molecules exist in two distinct stable states switched by irradiation of either visible or UV-light. Measurements are executed with the mechanically controllable break junction (MCBJ) method. Connection between the molecule and the gold electrodes is achieved by thiol end groups. The aim of the project is to distinguish the two states by their electrical transport properties. For this purpose, conductance histograms and current-voltage curves are measured separately for both states and compared afterwards. At room temperature, the conductance histograms of the states show small differences. These can be highlighted with the help of dimension reduction methods and neural networks [2]. Molecular vibration modes and thereby the current pathway through the molecule are determined for both states, by Inelastic electron tunneling spectroscopy (IETS).

[1] Sendler et al., Adv. Sci. 2 (2015) 1500017
[2] Albrecht et al., Nanotechnology 28 (2017) 423001

TT 29.7 Thu 15:00 P1

Low-temperature contact engineering for MoS_2 microtubes — •Jonathan Neuwald[1], Robin T. K. Schock[1], Matthias Kronseder[1], Wolfgang Möckel[1], Simon Reinhardt[1], Luka Pirker[2], Maja Remškar[2], and Andreas K. Hüttel[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Solid State Physics Department, Institute Jožef Stefan,1000 Ljubljana, Slovenia

Planar molybdenum disulphide MoS_2, a 2d material similar to graphene, displays a multitude of interesting electronic properties. Nevertheless, only few electronic experiments on MoS_2 nanotubes and microtubes exist. A central reason for this is the difficulty of obtaining stable and transparent Ohmic contacts to transition metal dichalcogenides in general. At the metal-semiconductor interface, the Fermi level in MoS_2 is typically strongly pinned close to the conduction band edge. To avoid a high contact resistance from the formation of a Schottky-barrier, low-work function metals have to be chosen. However, these etch into the MoS_2 structure and therefore damage the tube. Following a recent publication,[1] we use the half-metal bismuth as a contact material, which disables the Fermi level pinning. We optimize the bismuth layer thickness to lower contact resistance and therefore improve the controllability and clarity of transport effects at millikelvin temperatures.

[1] P.C. Shen *et al.*, Nature 593, **211** (2021)

TT 29.8 Thu 15:00 P1

Andreev reflection in gated bilayer graphene — •Panch Ram[1], Detlef Beckmann[2], Romain Danneau[2], and Wolfgang Belzig[1] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, D-76021 Karlsruhe, Germany

In this poster, we will present our recent theoretical study of the NS junction Andreev reflection and differential conductance on the bilayer graphene including different (equal and opposite) onsite potential for each monolayer graphene. We employ the Dirac-Bogoliubov de Gennes (DBdG) equation for the low-energy bilayer graphene Hamiltonian and calculate the Andreev reflection (retroreflection as well as specular) and differential conductance (within the Blonder-Tinkham-Klapwijk formalism [1-2]) for the junction in two different parameters limits: (i) interlayer coupling is larger energy scale (ii) superconducting-side doping potential is larger energy scale [3-5]. We obtain the Andreev retroreflection (specular reflection) below (above) the normal-side Fermi energy when the bias voltage is less than the superconducting gap. We also observe that both retro and specular Andreev reflections are strongly modified by the gate field.

[1] A. F. Andreev, Sov. Phys. JETP 19, 1228 (1964)
[2] G. E. Blonder et. al, Phys. Rev. B 25, 4515 (1984)
[3] C. W. J. Beenakker, Phys. Rev. Lett. 97, 067007 (2006)
[4] T. Ludwig, Phys. Rev. B 75, 195322 (2007)
[5] D. K. Efetov and K. B. Efetov, Phys. Rev. B 94, 075403 (2016)

TT 29.9 Thu 15:00 P1

Coulomb blockade effects in minimally twisted bilayer graphene — •Patrick Wittig[1], Fernando Dominguez[1], Cristophe De Beule[2], and Patrik Recher[1,3] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg — [3]Laboratory of Emerging Nanometrology, 38106 Braunschweig, Germany

In the presence of a finite interlayer electric field, minimally twisted bilayer graphene displays a triangular network of chiral valley Hall states that propagate along the AB/BA interfaces and scatter at the metallic AA regions. Previous studies model the chiral network using a phenomenological scattering matrix approach based entirely on the symmetries of the system. So far, the physics of the metallic AA scattering regions has been disregarded, and indeed, the finite size of the AA regions (order of nm) can give rise to similar physics as quantum dots: a discrete energy spectrum and also interacting effects such as Coulomb blockade physics. In our contribution, we include these effects and study the resulting network of chiral modes and quantum dots through the energy spectrum and magneto-conductance calculations.

TT 29.10 Thu 15:00 P1

Interaction effects in graphene/2D polymer heterostructures — •Francesca Falorsi[1], Kejun Liu[2], Miroslav Polozij[2], Christian Eckel[1], Thomas Heine[2], Xinliang Feng[2], Renhao Dong[2], and Thomas Weitz[1] — [1]I. Physical Institute -Georg-August-University, Friedrich-Hund-Platz 1 37077 Göttingen Göttingen — [2]Faculty of chemistry and food chemistry, Technische Universität Dresden, Mommsenstraße 4 01069 Dresden

This work explores the interlayer interaction effects of van-der-Walls heterostructures (HS) formed by graphene and a new class of two-dimensional polymers bonded by covalent bonds (C2DPs). These materials can be synthesized with multiple compositions and topology and therefore offer large tunability of their electronic properties. Via density functional theory calculations, it was possible to predict that coupling of different C2DPs with monolayer graphene should generate new interesting physical phenomena, including band flattening and trivial and non-trivial bandgap opening. The first system studied is the HSs formed by a mechanically exfoliated graphene on top of a C2DP that comprises metal-free porphyrin and perylene units linked by imide bonds. Different techniques are used for the first characterization of the structure: Raman, KPFM, SNOM, and ARPES. These different measurement techniques indicate the existence of interaction effects in the HSs. Electrical measurements on the HSs were also performed and showed that the polymer highly p-dopes the graphene.

TT 29.11 Thu 15:00 P1

Inductive coupling schemes in nano-electromechanics — •Lukas Niekamp[1,2], Thomas Luschmann[1,2,3], Philip Schmidt[1,2], Frank Deppe[1,2,3], Achim Marx[1], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich

Nano-electromechanics studies the opto-mechanical interaction between microwave frequency resonators and mechanical components in the nanometer regime. Recently, the concept of inductive coupling has been demonstrated, allowing for the modulation of the resonator frequency by the mechanical displacement [1, 2]. This coupling scheme results in higher vacuum opto-mechanical coupling rates compared to previous capacitive coupling schemes. Therefore, devices based on inductive coupling are considered as potential pathway for realizing vacuum strong-coupling. This regime allows to harness the full nonlinearity of the optomechanical interaction offering opportunities like the generation of mechanical quantum states. The device presented here consists of a flux-tunable dc-SQUID with mechanically compliant strings integrated into a microwave resonator. The mechanical displacement of the strings modulates the external flux and hence the microwave resonator's frequency. Here, we present recent experiments on the path to strong photon-phonon interaction.

[1] Rodrigues, Bothner, Steele, Nat. Commun. 10, 5359 (2019)
[2] Schmidt et al., Commun. Phys. 3, 233 (2020)

TT 29.12 Thu 15:00 P1

Full counting statistics in periodically driven systems — •Johann Zöllner, Eric Kleinherbers, and Jürgen König — Theoretische Physik, Universität Duisburg-Essen and CENIDE, Lotharstr. 1, 47048 Duisburg

By calculating the full counting statistics of tunnelling electrons one can obtain information about quantum dot systems. We focus on the factorial cumulants [1] of the full counting statistics in periodically driven systems, which can be calculated using Floquet theory [2]. Higher-order factorial cumulants show signatures that can not be observed in the tunnelling current. To obtain analytical expressions we use the adiabatic approximation for small frequencies or the Magnus expansion for large frequencies. For the adiabatic limit we observe frequency-doubling in all factorial cumulants.

[1] P. Stegmann et al., Phys. Rev. B 92, 155413 (2015)
[2] E. Potanina et al., Phys. Rev. B 99, 035437 (2019)

TT 29.13 Thu 15:00 P1

Light emission in ΔT-driven mesoscopic conductors — •Matthias Hübler and Wolfgang Belzig — University Konstanz

The scattering approach paves the way for the description of electron transport and current fluctuations in mesoscopic conductors. If fluctuations are coupled to an electromagnetic field, then they are related to the rate at which the field transfers energy to or receives energy from the conductor. The non-symmetrized current-current correlator characterizes the emission and absorption spectrum. Recent interest is concerned with ΔT noise, which is the non-equilibrium noise caused by a temperature difference between the terminals. Here we generalize the notion of ΔT noise to the non-symmetrized current-current correlator at finite frequencies. The spectrum is investigated for energy-independent scattering and for a resonant level as an example of energy-dependent scattering. We find that a temperature difference ΔT leads to a partially negative ΔT noise spectrum. This is a consequence of temperature broadening in combination with a frequency shift of the involved Fermi distributions. In the case of energy-independent scattering, the lowest order is a quadratic $\propto (\Delta T)^2$ correction of the thermal-like noise spectrum. For the resonance, there arises an additional contribution to the ΔT noise spectrum that is $\propto \Delta T$ at the lowest order.

TT 29.14 Thu 15:00 P1

Symmetry-protected Bose-Einstein condensation of interacting hardcore bosons — •Reja Wilke[1], Thomas Köhler[2], Felix Palm[1], and Sebastian Paeckel[1] — [1]Department of Physics, Arnold Sommerfeld Center for Theoretical Physics, University of Munich, Germany — [2]Department of Physics and Astronomy, Uppsala University, Sweden

We introduce a mechanism stabilizing a one-dimensional quantum many-body phase, characterized by a certain wave vector via the protection of an emergent Z2 symmetry. We illustrate this mechanism by constructing the solution of the full quantum many-body problem of hardcore bosons on a wheel geometry, which are known to form a Bose-Einstein condensate. The robustness of the condensate is shown numerically by adding nearest-neighbor interactions to the wheel Hamiltonian. We discuss further applications such as geometrically inducing finite-momentum condensates.

TT 29.15 Thu 15:00 P1

Low temperature photoluminescence investigation of light-induced degradation in boron doped CZ-silicon — •Katharina Peh[1], Kevin Lauer[1,2], Aaron Flötotto[1], Dirk Schulze[1], and Stefan Krischok[1] — [1]TU Ilmenau, Institut für Physik und Institut für Mikro- und Nanotechnologien, Ilmenau, Germany — [2]CiS Forschungsinstitut für Mikrosensorik GmbH, Konrad-Zuse-Str. 14, 99099 Erfurt, Germany

Light-induced degradation (LID) in boron doped Czochralski grown (CZ) silicon is a severe problem for silicon devices such as solar cells or radiation detectors. In this contribution boron doped CZ silicon is investigated by low temperature photoluminescence (LTPL) spectroscopy. As already demonstrated on indium p-doped silicon samples, we suspect an ASi-Sii defect also in boron p-doped silicon samples [1]. To find the defect in connection with an additional LID PL peak which was also published by Vaqueiro-Contreras et al. [2], we carried out numerous measurements on boron-doped samples with the help of LTPL at 10 K.

[1] K. Lauer, C. Möller, D. Schulze, C. Ahrens, AIP Advances 5, 017101 (2015)
[2] M. Vaqueiro-Contreras, V.P. Markevich, J. Coutinho, P. Santos, I.F. Crowe, M.P. Halsall, I. Hawkins, S.B. Lastovskii, L.I. Murin, A.R. Peaker, J. Appl. Phys. 125, 185704 (2019)

TT 29.16 Thu 15:00 P1

Design and construction of low temperature probe for transport measurement — •Reza Firouzmandi, Vilmos Kocsis, Pablo Pedrazzini, Tino Schreiner, Danny Baumann, and Bernd Büchner — Leibniz Institute for Solid State and Materials Research (IFW), 01069 Dresden, Germany

Electrical and thermal transport experiments are fundamental tools of basic research not only because of their potential to reveal new phenomena in condensed matter physics but also to discover novel applications. Here we report on our newly constructed, highly versatile, custom-built, low-temperature transport probes, which will allow us to perform high-precision measurements of electrical and thermal transport properties in a wide series of materials. The probes will allow measurements in the temperature range between 5K and 300K, under applied magnetic fields up to 16T, as well as high electric voltages up to 500V. The probes will be used in the investigation of novel quantum materials and multiferroics.

TT 29.17 Thu 15:00 P1

Lab::Measurement – measurement control with Perl 5 — Mia Schambeck, Erik Fabrizzi, Fabian Weinelt, Simon Reinhardt, and •Andreas K. Hüttel — Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany

`Lab::Measurement` is a collection of object-oriented Perl 5 modules providing control of test and measurement devices. It allows for quickly setting up complex tasks with diverse hardware. Instruments can be connected via GPIB (IEEE 488.2), USB or VXI-11 / raw network sockets on Ethernet. Internally, third-party backends as, e.g., Linux-GPIB, the NI-VISA library, or Zurich Instruments' LabOne API are used, in addition to lightweight drivers for USB and TCP/IP-based protocols. The wide range of supported backends enables cross-platform portability of measurement scripts between Linux and Windows machines. Based on roles within `Moose` that provide communication standards such as SCPI, dedicated instrument driver classes take care of internal details. A high-level sweep layer allows for fast and flexible creation of nested measurement loops, where, e.g., several input variables are varied and data is logged into a customizable folder structure. Features include live plotting or obtaining attested timestamps for measurement data.

`Lab::Measurement` is free software and available at `https://www.labmeasurement.de/` — Reference: S. Reinhardt *et al.*, Comp. Phys. Comm. **234**, 216 (2019)

TT 29.18 Thu 15:00 P1

Theory of difference frequency quantum oscillations — •Valentin Leeb[1] and Johannes Knolle[1,2,3] — [1]Department of Physics TQM, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [3]Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom

Quantum oscillations (QO) describe the periodic variation of physical observables as a function of inverse magnetic field in metals. The Onsager relation connects the basic QO frequencies with the extremal areas of closed Fermi surface pockets, and the theory of magnetic breakdown explains the observation of sums of QO frequencies at high magnetic fields. Here we develop a quantitative theory of *difference frequency* QOs in metals with multiple Fermi pockets with parabolic or linearly dispersing excitations. We show that a non-linear interband coupling, e.g. in the form of interband impurity scattering, can give rise to otherwise forbidden QO frequencies which can persist to much higher temperatures compared to the basis frequencies. We discuss the experimental implications of our findings, for example, for materials with multifold fermion excitations.