TT 99: Poster Session: Transport

Time: Thursday 15:00–19:00 Location: Poster B

TT 99.1 Thu 15:00 Poster B

Interface coupling in magnetoconductance of Bi-films on Si(111) — •Doaa Abdelbarey[1], Philipp Kröger[1], Christoph Tegenkamp[1,2], and Herbert Pfnür[1] — [1]Inst. für Festkörperphysik, Leibniz Universität Hannover — [2]Institut für Physik, TU Chemnitz

Bi ultrathin epitaxial films are governed by strongly spin-polarized bands that determine to a large extent their magnetotransport properties. Magneto conductance of films with a thickness of 20 to 60 bilayers on a Si(111) substrate was measured mostly at T = 11 K and in B-fields up to 4 T. The B-field orientation was varied from perpendicular to parallel to the surface. For the in-plane B-field orientation strong variations ofscattering properties between the interfaces were observed that depend both on the angle between B- and E-fields as well as on the film thickness. For the thinnest films, direct interaction between interfaces leads to strong spin depolarization and to a conductance almost independent of B. Thicker films exhibit a dominance of weak antilocalization, if B and E are parallel, but *weak localization* for both in plane, but perpendicular to each other. The latter contribution disappears at 100 K, where only WAL was seen. Since the potential gradients on both interfaces point in opposite directions normal to the surface, the spin directions in the same Rashba-split electronic bands are opposite (and in plane) for a given $\vec{k}_{\parallel}$. This means that only within the same layer backscattering is forbidden, since scattering from $+\vec{k}_{\parallel}\uparrow$ to $-\vec{k}_{\parallel}\downarrow$ requires spin Umklapp, but for scattering between the interfaces no Umklapp for the same process is necessary. Therefore, it is allowed.

TT 99.2 Thu 15:00 Poster B

Controlling conductivity by quantum well states: ultrathin Bi(111) films. — Philipp Kröger[1], Doaa Abdelbarey[1], •Marvin Detert[1], Herbert Pfnür[1], and Christoph Tegenkamp[1,2] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover — [2]Institut für Physik, Technische Universität Chemnitz

Epitaxial Bi(111) films were subject to many and partly even controversial studies on the semimetal-semiconductor transition (SMSC) triggered by a robust quantum confinement. The remaining conductance was ascribed to conducting surface channels. We investigated ultra-thin crystalline Bi films on Si(111) as a function of film thickness between 20 and 100 bi-layers by means of electric transport measurements. Varying temperature and magnetic field, we disentangled essentially two transport channels. One remains indeed metallic at all thicknesses investigated with a slightly increasing conductance as a function of film thickness, d, whereas the second is activated with a d^{-1}-dependence of the activation energy, indicating a quasi-harmonic confining potential. Both channels reflect the properties of the whole quantized film and a strict separation into surface and bulk states, valid for electronic screening lengths much smaller than d, seems to be doubtful in these strongly quantum confined ultra-thin films. The metallic channel through the coupled edge states seems to be robust.

TT 99.3 Thu 15:00 Poster B

Transport spectroscopy of 3D Dirac materials — •Henry Legg and Achim Rosch — Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, D-50937, Köln, Deutschland

Many materials that realise a 3D Dirac or Weyl dispersion contain multiple Dirac nodes within their Brillouin zone; examples include Cd_2As_2, Na_3Bi, and $Pb_{1-x}Sn_xSe$. In this work we propose a new transport mechanism to 'spectroscopically' map the bulk electronic structure of a 3D Dirac or Weyl semi-metal with multiple nodes within the Brillouin zone.

A positive magnetoresistance occurs when parallel magnetic and electric fields are orientated in a direction perpendicular to a vector connecting a pair of these Dirac nodes. In the presence of long ranged impurities this magnetoresistance becomes strongly dependent on angle. This angular dependence provides information about the position of Fermi-surfaces within the Brillouin zone, the Fermi-wave vector, and the extent of impurities within the material. Our results are compared to experiments on $Pb_{1-x}Sn_xSe$.

TT 99.4 Thu 15:00 Poster B

Shot noise of contacts to Fe atoms and FeH_n — •Michael Mohr, Alexander Weismann, and Richard Berndt — Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, 24098 Kiel

The ballistic transport through contacts to pristine and hydrogenated Fe atoms on Au(111) surfaces is investigated with a 4 K scanning tunneling microscope. We observe a variation of the current shot noise measured from the two species suggesting an influence of hydrogen on the spin polarized transport.

This work was supported by SFB 677.

TT 99.5 Thu 15:00 Poster B

Extending the hierarchical quantum master equation approach to low temperatures and realistic band structures — •André Erpenbeck[1], Christian Hertlein[1], Christian Schinabeck[1], and Michael Thoss[1,2] — [1]Theoretische Festkörperphysik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

The hierarchical quantum master equation (HQME) approach, originally developed by Tanimura in the context of relaxation dynamics [1], has recently received renewed interest as an accurate method to describe quantum transport in interacting nanosystems [2-4]. Because the HQME approach relies on a decomposition of the bath correlation function in terms of exponentials, however, numerical complexity restricts its applicability to systems at higher temperatures coupled to leads with simple band structures. In this contribution, we outline an extension of the HQME approach, which uses a re-summation over poles and can be applied to calculate transient currents at a numerical cost that is independent of temperature and band structure of the leads. We demonstrate the performance of the extended HQME approach for noninteracting tight-binding model systems of increasing complexity as well as for the Anderson-Holstein model.

[1] Tanimura, J. Phys. Soc. Jpn. 75, 082001 (2006)
[2] Jin et al., JCP 128, 234703 (2008)
[3] Härtle et al., PRB 88, 235426 (2013)
[4] Schinabeck et al., PRB 94, 201407(R) (2016)

TT 99.6 Thu 15:00 Poster B

Molecular characterization in liquid and cryogenic environments — •Filip Kilibarda[1], Alexander Strobel[1], Mani Lokamani[1], Torsten Sendler[1], Michael Mortensen[2], Kurt Gothelf[2], and Artur Erbe[1] — [1]HZDR, 01328 Dresden, Germany — [2]Center for DNA Nanotechnology, 8000 Aarhus C, Denmark

Current industrial scaling processes are reaching limits. We see not only diminishing returns with further scaling attempts, but also physical limitations that come more and more into play. In our research we offer a novel approach, to use single molecules as electronic components. This approach offers not only size improvements, but also a reduction in power consumption and costs. Our research focuses on classifying different molecules with the help of Mechanically Controlled Break Junction (MCBJ). Here we present two different kinds of measurements. One is performed in liquid solution and under ambient conditions, and the other one in a cryogenic environment, under vacuum. As a test bed for these measurements we use salen and C_{60} molecules, respectively. In the case of salen molecules, we show, how chemical doping influences energy levels and affects electron transport through the molecule. The experimental results are supported by quantum chemical calculations. The C_{60} measurements demonstrate that we can remove the influence of the solvent by in situ molecular evaporation into the nanoscopic junction. Additionally, operation under vacuum allows us to use more reactive metals for the nano-junction, and thus vary metal-molecule orbital overlap, where in traditional approach contacts are made out of noble metals like gold.

TT 99.7 Thu 15:00 Poster B

Bias-dependent forces in single-molecule junctions — •Susanne Leitherer[1], Jonathan Brand[2], Nick P. Rübner[1], Nicolas Neel[2], Jörg Kröger[2], and Mads Brandbyge[1] — [1]Department of Micro- and Nanotechnology, Technical University of Denmark — [2]Institut für Physik, Technische Universität Ilmenau

We study the forces on single-molecule junctions formed by C_{60}-terminated Cu tips and C_{60} molecules adsorbed on Cu(111) employing first principles electronic structure and transport calculations based on density functional theory combined with non-equilibrium Greens functions (DFT-NEGF). The C_{60}-C_{60} bond force evaluated at different distances and voltages shows an asymmetric dependence on the bias polarity. This asymmetry can be related to bias-dependent electrostatic forces between the charge densities localized at the molecules, and also indicates the effect of current-induced forces. We discuss various ways to rationalize these forces in terms of transmission eigenchannels, charge redistribution, overlap populations and bond-currents. Our simulations support the results of scanning tunneling microscopy studies on the junctions using bias-dependent force spectroscopy, which cannot be explained without accounting for the non-equilibrium forces in single-molecule junctions.

TT 99.8 Thu 15:00 Poster B

Vibronic dephasing model for coherent-to-incoherent crossover in DNA — •Patrick Karasch, Dmitry A. Ryndyk, and Thomas Frauenheim — Bremen Center for Computational Materials Science, Universität Bremen, Germany

In this work we investigate the interplay between coherent and incoherent charge transport in cytosine-guanine (GC) rich DNA molecules. Our objective is to introduce physically grounded approach to dephasing in large molecules and to understand the length dependent charge transport characteristics and especially the crossover from coherent tunneling to incoherent hopping regime at different temperatures. Therefore, we apply a vibronic dephasing model and compare the results to the Büttiker probe model which is commonly used to describe decoherence effects in charge transport. Using the full ladder model and simplified 1D model of DNA, we consider molecular junctions with alternating and stacked GC sequences and compare our results to recent experimental measurements.

TT 99.9 Thu 15:00 Poster B

Electrical Characterization of Polyalanine Molecules — •Diana Slawig[1], Malte Böhsl[1], Herbert Pfnür[1], and Christoph Tegenkamp[1,2] — [1]Leibniz Universität Hannover, Germany — [2]TU Chemnitz, Germany

A new promising and effective approach for spintronics has emerged using spin selectivity in electron transport through chiral molecules, named Chiral Induced Spin Selectivity (CISS) [1]. Recently, by utilizing this effect a proof of concept for a new type of chiral-based Si-compatible universal magnetic memory device was demonstrated [2]. Therefore the electrical transport through helical peptides is of high interest. Our study focuses on polyalanine molecules for their high conductivity over a long range [3] and their large intrinsic dipole [4]. The molecules were contacted using mechanically controlled break junctions made of gold, operating in high vacuums.
Systematic conduction measurements revealed different states, which in turn are split up. This indicates different configurations either of the thiole-gold bond or configuration of the molecules itself.
Current Voltage measurements show a large asymmetry in the curves, which can be traced back to the dipole of the molecule [5,6].

[1] R. Naaman et.al., J. Phys. Chem. Lett. 3 (2012)
[2] O. Ben Dor et al., Nat. Commun. 4:2256 (2013)
[3] Y. Arikuma et.al., Angew. Chem., Int. Ed.,**49** (2010)
[4] D. Cristancho et al., J.Chem.Phys. **132**, 065102 (2010).
[5] S. Sek et al., J. Phys. Chem. B, 109 (2005).
[6] H. Uji, Phys. Chem. Chem. Phys. **757**, 15 (2013).

TT 99.10 Thu 15:00 Poster B

Charge transport in bottom-up synthesized graphene nanoribbon networks — •Zhou Zhou[1,2], Nils Richter[1,2], Alexander Tries[1,2,3], Kamal Asadi[3], Zongping Chen[3], Akimitsu Narita[3], Klaus Müllen[3,4], and Mathias Kläui[1,2] — [1]Institut für Physik, Johannes Gutenberg Universität, Mainz, Germany — [2]Graduate School of Excellence Materials Science in Mainz, Mainz, Germany — [3]Max Planck Institute for Polymer Research, Mainz, Germany — [4]Institut für Physikalische Chemie, Johannes Gutenberg-Universität, Mainz, Germany

Graphene nanoribbons (GNRs) attract attention due to physical phenomena resulting from their geometrical confinement which also depend crucially on their width and edge morphology [1]. Using GNR field-effect transistors, we perform a systematic study on the electronic properties of chemically synthesized and atomically perfect armchair GNRs with a width of 5 and 9 carbon atoms (aGNR5 and aGNR9)[2,3]. Our measurements reveal nuclear tunneling-assisted charge carrier hopping [4] as the dominant charge transport mechanism allowing us to apply a universal scaling law valid for charge transport in networks of both GNR structures over a large range of driving voltages and temperatures from room temperature down to 4 K [5].

[1] Son et al., Phys.Rev.Lett.97, 216803 (2006).
[2] Z. Chen et al., J.Am.Chem.Soc., 139, 9483-9486 (2017).
[3] Z. Chen et al., J.Am.Chem.Soc., 139, 3635-3638 (2017).
[4] K. Asadi et al., Nat.Commun. 4:1710 (2013).
[5] N. Richter et al., (manuscript in preparation 2018)

TT 99.11 Thu 15:00 Poster B

Coupling suspended carbon nanotubes to superconducting resonators — •Stefan Blien, Alexander Albang, Patrick Steger, Simon Reinhardt, Thomas Huber, and Andreas K. Hüttel — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

The dispersive coupling of nano-electromechanical systems (NEMS) to superconducting coplanar waveguide (CPW) resonators in the resolved sideband regime allows controlled energy transfer between the two systems and in particular the cooling of the vibration mode. Suspended carbon nanotubes as NEMS embody both single-electron tunneling devices as well as high quality mechanical resonators. They are already close to the mechanical quantum limit at cryogenic temperatures and single electron effects dominate the mechanical behaviour, making them an interesting testbed for novel optomechanical effects.

We show first results on clean carbon nanotubes that are pre-grown and successfully transferred to a niobium CPW resonator device. We have confirmed the high quality of the transferred nanotubes and the feasibility of transparent contacts by low-temperature transport measurements.

TT 99.12 Thu 15:00 Poster B

Clean $NbSe_2$-to-carbon nanotube contacts by all-dry transfer technique — •Christian Bäuml, Maria-Teresa Handschuh, Anh-Tuan Nguyen, Nicola Paradiso, and Christoph Strunk — University of Regensburg, Regensburg, Germany

The first demonstrations of devices sensitive to the presence of Majorana fermions (MFs) consisted of 1-dimensional semiconductors proximitized by a superconductor (SC) in the presence of spin-orbit interaction and of perpendicular magnetic field. Recent proposals suggested that MFs exist in carbon nanotubes (CNTs) contacted with a thin SC which retains its superconducting gap in presence of large in-plane field [1]. We demonstrate an all-dry technique for contacting CNTs with few-layer-thick flakes of $NbSe_2$, as SC layered material of the family of the transition metal dichalcogenides (TMDCs). The choice of $NbSe_2$ is motivated by its large critical in-plane magnetic field. We show that the $NbSe_2$-to-CNT contact resistance is comparable to that observed for other methods. Moreover, we demonstrate that, owing to the spin-valley locking in $NbSe_2$, few-layer devices stay superconducting up to fields of 10 Tesla, with only minor change in T_c. Our results demonstrate the first building blocks for the practical implementation of CNT-based devices for MF physics.

[1] R. Egger *et al. Phys. Rev. B* **85**, 235462 (2012);
M. Marganska *et al.* arXiv: 1711.03616

TT 99.13 Thu 15:00 Poster B

Shaping a single electron in a nanotube with an axial magnetic field — Magdalena Marganska[1], Daniel R. Schmid[2], Peter L. Stiller[2], Alois Dirnaichner[2], Christoph Strunk[2], Milena Grifoni[1], and •Andreas K. Hüttel[2] — [1]Institute for Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany — [2]Institute for Experimental and Applied Physics, University of Regensburg, 93053 Regensburg, Germany

Transport measurements on single wall carbon nanotubes allow fascinating insights into the interplay of molecular structure and electronic wave functions. Here, we analyze the magnetic field behaviour of quantum states in the limit of a single electron strongly confined to a quantum dot. An axial magnetic field (in the experiment up to 17T) exposes a very distinct behaviour of the two valleys. K' valley states experience an increase of the tunnel coupling at low field, followed by subsequent decoupling. In contrast, K valley states decouple from the leads monotonically.

This phenomenon stems from the unique combination of cylindrical topology and honeycomb atomic lattice. Longitudinal and transversal momentum are coupled, allowing manipulation of the longitudinal electronic wave function via the Aharonov-Bohm phase. At zero field, the nanotube acts similar to a $\lambda/4$ resonator, where a wave function amplitude is finite near one of the contacts. A large magnetic field restores quantum box behaviour comparable to a $\lambda/2$ resonator, where the amplitude vanishes on both sides. This is directly reflected in the tunnel rates.

TT 99.14 Thu 15:00 Poster B

Light-Driven Dynamics in Finite Graphene Nanostructures — •Jan-Philip Joost, Niclas Schlünzen, and Michael Bonitz — CAU Kiel, Germany

The understanding of carrier multiplication effects in nanoscale graphene structures is essential for various applications including solar energy harvesting [1]. In this work, we observe impact excitation effects within a few femtoseconds after an optical laser pulse excitation. The finite graphene clusters, such as nanoribbons, are described using an extended Hubbard model that takes into account the overlap of adjacent orbitals and hopping between up to third nearest neighbors. The system dynamics is provided by a nonequilibrium Green functions [2] (NEGF) approach, that has been thoroughly tested against DMRG [3], combined with the second Born (SOA) and GW selfenergy to account for electron correlations. Our description allows to predict the correlated nonequilibrium dynamics of excited graphene nanostructures of arbitrary geometry containing up to 100 carbon atoms for up to 25 fs.

[1] N. M. Gabor, Acc. Chem. Res. 46(6) 1348 (2013)
[2] K. Balzer and M. Bonitz, Lect. Notes Phys. 867 (2013)
[3] N. Schlünzen, J.-P. Joost, F. Heidrich-Meisner, and M. Bonitz, Phys. Rev B 95, 165139 (2017)

TT 99.15 Thu 15:00 Poster B

Proximity induced superconductivity in edge connected ballistic normal metal-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

Here, we present an experimental study of proximity induced superconductivity in edge connected normal metal-graphene-superconductor (N-G-S) junctions. The monolayer graphene sheet was sandwiched between two hexagonal boron nitride (h-BN) crystals creating a van der Waals heterostructure. Conductance spectra for these junctions in the superconducting state were measured as a function of magnetic field and charge carrier density. Our experimental results have been analyzed and can be explained with a generalized BTK model. In addition, Fabry-Pérot interferences were observed in the normal state for hole as well as electron doping of the graphene sheet. It can be explained by the formation of different interfaces in the vicinity of the contacts designed with two different materials.

TT 99.16 Thu 15:00 Poster B

Currents in graphene and possible Cooper pair formation — •Klaus Morawetz — Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil — Max-Planck-Institute for the Physics of Complex Systems, 01187 Dresden, Germany

Based on the quantum kinetic equations for systems with SU(2) structure, regularization-free density and pseudospin currents are calculated in graphene realized as the infinite mass-limit of electrons with quadratic dispersion and a proper spin-orbit coupling. The currents possess no quasiparticle part but only anomalous parts. The intraband and interband conductivities are discussed with respect to magnetic fields and magnetic domain puddles. For large Zeeman fields the dynamical conductivities become independent of the density and are universal. The optical conductivity agrees well with the experimental values using screened impurity scattering and an effective Zeeman field. The universal value of Hall conductivity is shown to be modified due to the Zeeman field. The pseudospin current reveals an anomaly since a quasiparticle part appears though it vanishes for particle currents. The density and pseudospin response functions to an external electric field are calculated. A frequency and wave-vector range is identified where the dielectric function changes sign and the repulsive Coulomb potential becomes effectively attractive allowing Cooper pairing.

[1] Phys. Rev. B 94 (2016) 165415, Phys. Rev. B 92 (2015) 245425
[2] errata: Phys. Rev. B93 (2016) 239904(E), Phys. Rev. B 92 (2015) 245426

TT 99.17 Thu 15:00 Poster B

Dependence of structure factor and correlation energy on the width of electron wires — Vinod Ashokan[4], Renu Bala[5], •Klaus Morawetz[1,2,3], and Kare Narain Pathak[4] — [1]Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — [2]International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil — [3]Max-Planck-Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [4]Centre for Advanced Study in Physics, Panjab University, 160014 Chandigarh, India — [5]Department of Physics, MCM DAV College for Women, 160036 Chandigarh, India

The structure factor and correlation energy of a quantum wire of thickness $b \ll a_B$ are studied in random phase approximation (RPA) and for the less investigated region $r_s < 1$. Using the single-loop approximation, analytical expressions of the structure factor are obtained. The exact expressions for the exchange energy are also derived for a cylindrical and harmonic wire. The correlation energy in RPA is found to be represented by $\epsilon_c(b, r_s) = \frac{\alpha(r_s)}{b} + \beta(r_s)\, ln(b) + \eta(r_s)$, for small b and high densities. For a pragmatic width of the wire, the correlation energy is in agreement with the quantum Monte Carlo simulation data.

[1] arXiv: 1708.06835

TT 99.18 Thu 15:00 Poster B

Universal short-time response and formation of collective mode — •Klaus Morawetz — Münster University of Applied Sciences, Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil — Max-Planck- Institute for the Physics of Complex Systems, 01187 Dresden, Germany

The short-time response of two distinct systems, the pump and probe experiments with a semiconductor and the sudden quench of cold atoms in an optical lattice, are found to be described by the same universal function. This analytic formula at short time scales is derived from the quantum kinetic-theory approach observing that correlations need time to form. The influence of the finite-trapping potential is derived and discussed along with Singwi-Sjølander local-field corrections including the proof of sum rules. The quantum kinetic equation allows to understand how two-particle correlations are formed and how the screening and collective modes are build up.

[1] Phys. Rev. B 90 (2014) 075303
[2] Phys. Rev. E 66 (2002) 022103
[3] Phys. Rev. E 63 (2001) 20102
[4] Phys. Lett. A 246 (1998) 311

TT 99.19 Thu 15:00 Poster B

Ultrafast collective response and possible photo-induced phase transition in the antiferromagnetic insulator Ca_2RuO_4 — •Parmida Shabestari[1,2], Hao Chu[1,2], Minjae Kim[1,2], Emily Huang[1,2], Maximilian Krautloher[1], Christopher Dietl[1], Joel Bertinshaw[1], Katrin Fürsich[1], Bernhard Keimer[1], and Stefan Kaiser[1,2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]University of Stuttgart, Germany

Among the diverse family of Ruthenates, the Antiferromagnetic Insulator Calcium Ruthenate, Ca_2RuO_4, has shown remarkable complexity in spin, orbital and phonons correlations. Raman Scattering [1] and Inelastic Neutron Scattering [2] experiments suggest strong spin-orbit coupling which manifests in the form of a complex Raman active Phonon, Magnon and collective Higgs mode responses. Utilizing ultrashort light pulses we are able to directly probe the interplay of these dynamics in time domain, disentangling the dynamics both in the ground state and possible light-induced metallic state, as a function of temperature and laser fluence.

[1] S. Souliou et al., Phys. Rev. Lett. 119, 067201 (2017)
[2] A. Jain et al., Nat. Phys. 13, 633 (2017).

TT 99.20 Thu 15:00 Poster B

Quantum correlation between two oscillators generated by non-local electron transport — •Felicitas Hellbach, Wolfgang Belzig, Fabian Pauly, and Gianluca Rastelli — Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany

Since the realization of high quality superconducting microwave cavities one can envisage the possibility to investigate the coherent interaction of light and matter. We study two parallel quantum dots arranged in the geometry of an Aharonov-Bohm interferometer (ABI) with each dot linearly coupled to a local harmonic oscillator. We explore how quantum correlation and entanglement between the two oscillators is generated by the coherent transport of a single electron traveling in two different paths of the ABI. We calculate the covariance by use of a diagrammatic perturbative expansion (Keldysh Green's functions) to the fourth order in the dot-oscillator coupling constant, taking into account vertex corrections.

TT 99.21 Thu 15:00 Poster B

Readout sensitivity of mechanical motion in inductively coupled nano-electromechanical devices

— •P. Schmidt[1,2,3], C. Utschick[1,2], D. Schwienbacher[1,2,3], L. Rosenzweig[1,2], N. Segercrantz[1,2], F. Deppe[1,2,3], A. Marx[1,2], R. Gross[1,2,3], and H. Huebl[1,2,3] — [1]Walther-Meißner-Institut, BAdW, Germany — [2]Physik-Department, TUM, Germany — [3]Nanosystems Initiative Munich, Germany

In recent years nano-electromechanics have demonstrated mechanical ground state cooling and the preparation of nonclassical states employing the linearized opto-mechanical interaction. However, the optomechanical coupling constant g_0 denoting the single photon - single phonon coupling rate has remained small compared to the cavity decay rate.

Here, we present an inductively coupled electromechanical system in contrast to the typically capactitively coupled mechanical elements. To this end, we place a dc-SQUID with a mechanical string resonator at the current anti-node of a superconducting microwave resonator. The electromechanical coupling is realized via the change of the SQUID loop area caused by the displacement of the string. Hereby, the coupling is increased as it is levered by the non-linear Josephson junctions of the dc-SQUID, approaching the resonator decay rate.

We focus on challenges related to the non-linearity of the microwave resonator. In particular, we compare the displacement noise of the thermal motion of the string resonator with the imprecision and the backaction noise imposed by the measurement.

TT 99.22 Thu 15:00 Poster B

Superconducting resonators for the study of Two-Level Systems — •Hartmut Schmidt[1], Alexander Bilmes[1], Jan Brehm[1], Shlomi Matityahu[2], Moshe Schechter[2], Alexander Shnirman[1], Georg Weiss[1], Alexey V. Ustinov[1,3], and Jürgen Lisenfeld[1] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Ben-Gurion University, Beer Sheva, Israel — [3]Russian Quantum Center, Moscow, Russia

Structural material defects, so called Two-Level Systems (TLS), received much recent interest due to their detrimental effect on various micro-structured quantum devices such as qubits, photon detectors and point contacts. In this work, we present superconducting lumped element resonators that enable one to resolve single TLS in deposited dielectric materials. We apply an electric field which, in addition to strain tuning by elastic chip deformation, permits us to manipulate the TLS' resonance frequency. This specific design allows us to study the TLS behavior under strain and external electric fields as well as to obtain the coupling-strength statistics of TLSs and their density. Especially, we study the resonator loss in presence of a TLS bath that is brought out of equilibrium via an electric-field sweep. We observe increased loss at intermediate sweep rates, which we explain by a theory based on Landau-Zener transitions.

TT 99.23 Thu 15:00 Poster B

Hybrid quantum circuits made of superconducting resonators and ferromagnetic magnons — •Tomislav Piskor[1], Marco Pfirrmann[1], Andre Schneider[1], Igor Golovchanskiy[2,3], and Martin Weides[1,4] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Moscow Institute of Physics and Technology, State University, 9 Institutskiy per., Dolgoprudny, Moscow Region, 141700, Russia — [3]National University of Science and Technology MISIS, 4 Leninsky prosp., Moscow, 119049, Russia — [4]Physikalisches Institut, Johannes Gutenberg University Mainz, Mainz, Germany

The field of Quantum Magnonics has evolved rapidly in the past few years. For example, for the growing field of quantum information, processing the coupling between natural spins and superconducting circuits is very promising for future implementations.

The aim of this work is to investigate the interaction between microwave photons in the GHz regime and magnetic spins. The coupling between superconducting resonators and ferromagnetic magnons will be investigated in order to study the hybrid system. Beside the Kittel mode showing the largest coupling strength, it is possible to observe weaker couplings, generated by magnetostatic spin waves. For periodic resonator structures, which is also the quantization condition, the spins can build up to propagating or standing spin waves. The coupling between the two systems is achieved by placing the ferromagnetic sample on top of the superconducting resonator structure.

TT 99.24 Thu 15:00 Poster B

Nonlocal thermoelectric effects in superconductor-ferromagnet hybrid structures — •Jonas Heidrich and Detlef Beckmann — Institute of Nanotechnology, Karlsruhe Institute of Technology, Karlsruhe, Germany

We report on our progress in experiments on nonlocal thermoelectric effects in superconductor-ferromagnet hybrid structures. In these samples thermoelectric effects are generated by the spin-dependent lifting of particle-hole symmetry. These latest efforts continue recent experiments [1].

[1] S. Kolenda *et al.*, Phys. Rev. Lett. **116**, 097001 (2016).

TT 99.25 Thu 15:00 Poster B

Electronic transport through quantum-dot spin valves - ISPI results — •Simon Mundinar, Stephan Weiss, and Jürgen König — Theoretische Physik, Universität Duisburg-Essen and CENIDE, Lotharstr. 1, 47048 Duisburg

We study an interacting quantum dot coupled to ferromagnetic leads that introduce spin-dependent tunneling. We use a path integral approach to derive the tunneling current as functional derivative of the Keldysh partition function. The lead degrees of freedom are integrated out exactly and the on-dot interaction is decoupled via a Hubbard-Stratonovich transformation. The resulting Keldysh path sum is calculated using the technique of iterative summation of path integrals (ISPI) [1]. ISPI is based on the truncation of lead-induced correlations after a characteristic memory time. This method enables us to calculate the tunneling current through the system for different system parameters, such as gate/bias voltage, polarization, angle between the two leads' magnetizations and Coulomb interaction strength.

[1] S. Weiss, R. Hützen, D. Decker, J. Eckel, R. Egger, and M. Thorwart, Phys. Status Solidi B **250**, 2298 (2013)

TT 99.26 Thu 15:00 Poster B

Full counting statistics of electron transport through a negative-*U* Anderson impurity — •Eric Kleinherbers, Philipp Stegmann, and Jürgen König — Theoretische Physik, Universität Duisburg-Essen and CENIDE, Lotharstr. 1, 47048 Duisburg

The process of electron tunneling through nanoscale systems (e.g. a metallic island or a quantum dot) is a stochastic process. Recent progress in nanotechnology has made it possible to monitor the transfer of individual electrons using sensitive electrometers (e.g. a quantum point contact). The resulting detector signal provides the full counting statistics (FCS) of the electron transport. A convenient tool to extract desired information out of the statistics are (generalized) factorial cumulants [1]. The sign of the cumulants reveals whether the transport of the electrons is statistically correlated or not.

Specifically, we focus on a single-level quantum dot with an *attractive* electron-electron interaction (negative -*U* Anderson impurity) subjected to a Zeeman field. Such a system has been observed in a recent experiment [2]. With FCS one can clearly differentiate between a repulsive and an attractive electron-electron interaction by analyzing the short-time limit [3] of the electron transport. Those differences are inaccessible by only measuring the net current or the current noise.

[1] P. Stegmann, B. Sothmann, A. Hucht, J. König, Phys. Rev. B 92, 155413 (2015)
[2] Cheng et al., Nature, 521, 196 (2015)
[3] P. Stegmann and J. König, Phys. Rev. B 94, 125433 (2016)

TT 99.27 Thu 15:00 Poster B

Probe independent mapping of electrostatic surface properties — Christian Wagner[1,2], •Niklas Friedrich[1,2,3], Pawel Chmielniak[4,5,2], Jeff Rawson[4,5,2], Taner Esat[1,2], Michael Maiworm[6], Ruslan Temirov[1,2], and F. Stefan Tautz[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany — [2]Jülich Aachen Reserach Alliance (JARA) - Fundamentals of Future Information Technology, Jülich, Germany — [3]CIC nanoGune, Donostia-San Sebastian, Spain — [4]Institute of Inorganic Chemestry, RWTH Aachen University, Germany — [5]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, Germany — [6]Institut for Automation Engineering (IFAT), Otto-von-Guericke University Magdeburg, Germany

Mapping electrostatic surface properties with high spacial resolution, as well as high precision in the energy resolution is a desired goal in today's surface and interface physics. However, for many scanning probe techniques it remains unclear to which extend the probing mechanism itself influences the measurement. Here we demonstrate that scanning quantum dot microscopy (SQDM) [1,2] is a technique suited to overcome this problem. Using this technique we investigate a single PTCDA molecule on Ag(111). Independent of the tip-sample distance we measure its surface dipole moment to |p| = -624 ± 38 mD. Furthermore, we show that the imaging process does not depend on the LUMO energy of the molecule used as the quantum dot during SQDM imaging.

[1] C. Wagner et al. Phys. Rev. Lett. 115, 026101 (2015)
[2] M. Green et al. Japan. J. Appl. Phys. 55, 08NA04-7 (2016)

TT 99.28 Thu 15:00 Poster B

Finite-Frequency Noise of a Time-Dependently Driven and Interacting Quantum Dot — •Niklas Dittmann[1,2,3] and Janine Splettstoesser[3] — [1]Institute for Theory of Statistical Physics, RWTH Aachen University, Germany — [2]Peter-Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich, Germany — [3]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Gothenburg, Sweden

We derive the current-noise spectrum stemming from a quantum dot weakly tunnel-coupled to a nearby electronic reservoir and driven by a time-dependent gate voltage. This experimentally relevant setup is frequently applied as an on-demand emitter of single electrons into a mesoscopic conductor. The presence of Coulomb interaction poses an additional challenge for a theoretical description. In this work, we extend a real-time diagrammatic technique to obtain the symmetric finite-frequency current noise. The derived noise spectrum reveals a rich interplay between different energy scales of this system, defined by the interaction strength, the tunnel-coupling strength, the temperature and the driving frequency. We discuss how the noise frequency probes features related to these energy scales.

TT 99.29 Thu 15:00 Poster B

Influence of the spin-polarized charge transport on the waiting time distribution in ferromagnet-quantum dot-superconductor systems — •Kacper Bocian and Ireneusz Weymann — Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614 Poznań, Poland

Based on the Markovian quantum master equation for the reduced density matrix we investigate the waiting time distribution of a single-level quantum dot (QD) system tunnel-coupled to the ferromagnetic (F) and/or superconducting (S) leads. Waiting times describe the delay times between the consecutive tunnelling events and carry the information about their dynamics. We compare the distributions of waiting times in different setups: F-QD-F, F-QD-S, and in the Cooper pair splitter geometry with two F and one S leads. By changing the spin-polarization of the ferromagnetic leads, the transition probabilities, and hence the waiting times, become modified. In the limiting case of the half-metallic leads all transitions can be blocked. We discuss the influence of presence of the superconductor on the waiting times and indicate the features of Cooper pair tunnelling. Furthermore, we analyze the impact of asymmetry of the couplings between the quantum dot and the external leads.

This work is supported by the National Science Centre in Poland as the Project No. DEC-2013/10/E/ST3/00213.

TT 99.30 Thu 15:00 Poster B

Non-spin-conserving effects in electronic transport through quantum dots — •Lucia Gonzalez[1,2], Jordi Pico[1], and Gloria Platero[1] — [1]Instituto de Ciencia de Materiales, CSIC, Cantoblanco, E-2 8049 Madrid, Spain — [2]Current affiliation: JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, 52425 Jülich, Germany

Pauli exclusion principle can lead to a spin dependant current blockade in a system of several quantum dots. This blockade is of great use for quantum manipulation and computation as it allows for spin-charge conversion, but non-spin-conserving processes can lift it by allowing the electrons to change its quantum numbers. Following previous research [1,2] on the effect in double quantum dots (DQD) of two of these processes, the hyperfine interaction and spin orbit coupling, we study theoretically their impact in transport in larger quantum dot systems.

[1] J. Danon, Yu. V. Nazarov. Phys. Rev. Lett. B **80** (2009) 041301R.
[2] N. Jouravlev, Yu. V. Nazarov, Phys. Rev. Lett. **96** (2006) 176804.

TT 99.31 Thu 15:00 Poster B

Correlation-induced refrigeration with superconducting single-electron transistors — •Rafael Sánchez — Universidad Autónoma de Madrid

The model of a superconducting tunnel junction is presented which refrigerates a nearby metallic island without any particle exchange. Heat extraction is mediated by charge fluctuations in the coupling capacitance of the two systems. The interplay of Coulomb interaction and the superconducting gap reduces the power consumption of the refrigerator. The island is predicted to be cooled down to temperatures close to 50 mK, for realistic parameters [1]. The results emphasize the role of non-equilibrium correlations in bipartite mesoscopic conductors. This mechanism can be applied to create local temperature gradients in tunnel junction arrays.

[1] R. Sánchez, Appl. Phys. Lett. 111, 223103 (2017).

TT 99.32 Thu 15:00 Poster B

Probing the interaction of single electron pumps using RF-SETs — •David Reifert[1], Niels Ubbelohde[1], Ralf Dolata[1], Vyacheslavs Kashcheyevs[2], Thomas Weimann[1], and Alexander Zorin[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig. Germany — [2]Faculty of Physics and Mathematics, University of Latvia, 25 Zellu street, LV-1002 Riga, Latvia

We utilize rf-driven semiconductor based quantum dots as single electron pumps (SEP). These SEPs transport a controlled number of n electrons per pump cycle and therefore create a precise quantized current $I = n \cdot e \cdot f$, where f is the pumping frequency. Since this current can achieve a high accuracy of 0.2 ppm, these SEPs can be utilized as a new primary standard for the unit ampere. To validate and improve the precision, we implemented an error counting scheme by operating several pumps in series and measuring the charge of the nodes in between them, with ultra-sensitive electrometers. For this purpose, we use semiconductor quantum dots, operating as single electron transistors (SET). To increase the measurement bandwidth, we applied rf-reflectometry, which allows us to read out the detector by analyzing the detuning of a LC-resonator due to the impedance change of the detector. This measurement setup enables us to investigate the transfer probabilities of the pumps operated solo or in series, and lets us test for correlations and coupling between two pumps operated in series. This allows us to examine the mechanism of the coupling between several pumps which is necessary to further improve the precision.

TT 99.33 Thu 15:00 Poster B

Open system dynamics with energy-dependent tunnel couplings — •Jens Schulenborg[1], Maarten Wegewijs[2], and Janine Splettstoesser[1] — [1]Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, Göteborg, Sweden — [2]Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany & JARA-FIT

A good theoretical understanding of the *dynamics* of tunnel-coupled electronic open nanosystems is crucial for the current strive towards controlled few-particle emission in the context of, e.g., metrology or quantum optics with electrons. However, while often experimentally relevant[1], most analytical studies on decay dynamics with strong local Coulomb interaction have so far neglected the energy structure of the tunnel barriers themselves, focussing only on the wideband limit.

Recently, we have shown the so-called *fermion-parity duality*[2] to be particularly insightful for such time-dependent problems. This work extends our approach to a general class of fermionic open systems with energy-dependent bare couplings in the Markovian, sequential tunneling limit. For the simplest relevant example of a spin-degenerate interacting single-level quantum dot, we show the duality to be similarly powerful as in the wideband limit. Even in an environment far away from equilibrium, it enables us to analyze the entire dot decay dynamics, including time-dependent particle- and energy current, in terms of simple-to-understand stationary equilibrium observables.

[1] J. D. Fletcher et al., Phys. Rev. Lett. **111**, 216807 (2013)
[2] J. Schulenborg et al., Phys. Rev. B **93**, 081411 (2016)

TT 99.34 Thu 15:00 Poster B

Investigation and application of propagating two-mode squeezed microwaves — •Minxing Xu[1,2], K. G. Fedorov[1,2], S. Pogorzalek[1,2], B. Ghaffari[1,2], P. Eder[1,2,3], M. Fischer[1,2,3], E. Xie[1,2,3], A. Marx[1], F. Deppe[1,2,3], and R. Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748

Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

Josephson parametric amplifiers (JPAs) can be employed for the generation of itinerant quantum signals in the form of propagating two-mode squeezed (TMS) states, which are essential for quantum communication and sensing protocols with superconducting quantum circuits. In our work, we employ two flux-driven JPAs at the inputs of an entangling hybrid ring in order to generate two-mode squeezing between the hybrid ring outputs and investigate the resulting TMS states. In particular, we study the robustness of quantum entanglement and other nonclassical correlations, such as quantum discord, in the TMS states to external noise. Finally, we experimentally implement a remote state preparation protocol with an analog feed-forward using propagating squeezed states and determine detrimental effects of losses and noise on the protocol based on a theoretical model.
The authors acknowledge support from DFG through FE 1564/1-1.

TT 99.35 Thu 15:00 Poster B

Chains of nonlinear and tunable superconducting resonators — •M. Fischer[1,2,3], P. Eder[1,2,3], S. Pogorzalek[1,2], E. Xie[1,2,3], K. Fedorov[1,2], F. Deppe[1,2,3], A. Marx[1], and R. Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

We present theoretical predictions and characterization measurements of a quantum simulation system of the Bose-Hubbard-Hamiltonian in the driven dissipative regime in the realm of circuit QED. The system consists of series-connected, capacitively coupled, nonlinear and tunable superconducting resonators. The nonlinearity is achieved by galvanically coupled SQUIDs, placed in the current anti-node of each resonator and can be tuned by external coils and on-chip antennas.
The authors acknowledge support from the German Research Foundation through FE 1564/1-1, the doctorate program ExQM of the Elite Network of Bavaria, the IMPRS 'Quantum Science and Technology'.

TT 99.36 Thu 15:00 Poster B

Fabrication and Characterization of SQUID-Array Parametric Amplifiers — •Daniel Arweiler[1,2], Kirill G. Fedorov[1,2], Stefan Pogorzalek[1,2], Peter Eder[1,2,3], Michael Fischer[1,2,3], Edwar Xie[1,2,3], Achim Marx[1], Frank Deppe[1,2,3], and Rudolf Gross[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physik-Department, TU München, 85748 Garching, Germany — [3]Nanosystems Initiative Munich (NIM), 80799 München, Germany

In the rapidly evolving field of quantum information processing and circuit QED, Josephson parametric amplifiers (JPAs) have emerged as key building blocks. They consist of a coplanar waveguide resonator coupled to a dc superconducting quantum interference device (SQUID). The latter acts as flux-tunable nonlinearity enabling parametric effects, including quantum-limited amplification of weak signals and generation of squeezed microwave light.

In our work, we investigate advanced versions of JPAs with dc-SQUID arrays instead of a single dc-SQUID to enhance the dynamic range and 1-dB compression point. We employ the well-established technologies of electron-beam lithography and aluminium shadow evaporation to fabricate our samples. We characterize our JPAs at millikelvin temperatures using transmission microwave measurements with a network analyzer and conclude by comparing key properties such as gain and 1-dB compression point between various designs.

The authors acknowledge support from DFG through FE 1564/1-1.

TT 99.37 Thu 15:00 Poster B

Josephson vortex dynamics in nanoscale Josephson junction parallel arrays — •Micha Wildermuth[1], Amadeus Dieter[1], Yannick Schön[1], Martin Weides[1], Hannes Rotzinger[1], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

One-dimensional parallel arrays of Josephson junctions are very interesting with respect to the rich dynamics inherent in this system. In quantum regime new physical phenomena are expected, which we aim to explore. The investigated system consists of several ultra-small Josephson junctions, which are arranged in parallel configuration forming an array of loops. We present preliminary measurements of such Josephson junction arrays, with novel I-V characteristics features.

TT 99.38 Thu 15:00 Poster B

Superconducting and insulating behaviour in granular aluminium oxide nano-wires — •Jan Nicolas Voss[1], Yannick Schön[1], Dominik Dorer[1], Micha Wildermuth[1], Sebastian T. Skacel[1], Hannes Rotzinger[1], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

Granular aluminium oxide (AlOx) nano-wires are a promising alternative to Josephson tunnel junctions as a non-linear element in superconducting quantum circuits. Due to the internal structure, the sheet resistance of this material can be adjusted over a wide kOhm range [1]. Due to the high flexibility of this approach, we employ an electron beam lithography nano-fabrication process, with the intention of being used for highly coherent superconducting quantum circuits. The fabricated 20 nm wide nano-wires have a very clean interface to the sapphire substrate and no remaining fabrication residue in the vicinity of the circuit. Experimentally, we explore the phase transition from superconducting to insulating behavior in nano-wires with a length span between 50 nm and 1 μm.
[1] H. Rotzinger, S. T. Skacel, M. Pfirrmann, J. N. Voss, J. Müunzberg, S. Probst, P. Bushev, M. P. Weides, A. V. Ustinov and J. E. Mooij, Supercond. Sci. Technol. **30**, 025002 (2016)

TT 99.39 Thu 15:00 Poster B

Switching Current Distributions of Granular Aluminum micro-SQUIDs — •Felix Friedrich[1], Patrick Winkel[1], Hannes Seeger[1], Nataliya Maleeva[1], Christoph Sürgers[1], Ioan M. Pop[1], and Wolfgang Wernsdorfer[1,2,3] — [1]PHI, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]INT, Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany — [3]Institut Néel, CNRS, Grenoble, France

Granular aluminum (GrAl) is a strongly disordered superconductor consisting of nm-sized aluminum (Al) grains separated by aluminum oxide (AlO_x) tunnel barriers. The material shows both increased critical temperature and critical field compared to pure Al. Furthermore, its high kinetic inductance makes GrAl interesting for e.g. high inductance superconducting detectors or circuits [1]. In order to obtain a better understanding, we performed transport measurements in GrAl micro-SQUIDs and will present first results. We measure IV curves and analyze switching current distributions as a function of temperature, current sweep rate, as well as in- and out-of-plane magnetic field. Our micro-SQUIDs have loop areas in the order of 1 μm^2 and are interrupted by constrictions with a few 100 nm length and less than 100 nm width. We find strong deviation from the standard RCSJ-model that we try to relate to the granular nature of the junctions. As the grain size is much smaller than the junctions' dimensions, we expect Josephson junction arrays formed from the coupled Al/AlO_x grains to define the switching current modulation.
[1] H. Rotzinger, *et al.*, Supercond. Sci. Technol. 30, 025002 (2017)

TT 99.40 Thu 15:00 Poster B

Design considerations for a superconducting granular aluminum nano-wire qubit — •Yannick Schön[1], Jan Nicolas Voss[1], Sebastian T. Skacel[1], Alexander Stehli[1], Jochen Braumüller[1], Martin Weides[1], Hannes Rotzinger[1], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

At feature sizes of nano-meter scale, superconducting wires made from a material with a high normal conducting sheet resistance show a pronounced non-linear microwave response. If such a nano-wire is embedded in a self-resonating circuit, the non-linearity can be observed even at very low photon numbers. Unfortunately, these materials often show a rather high photon loss, which makes them unusable for long lived quantum circuits.

Granular aluminium is a new material for superconducting quantum circuits which features not only a very high kinetic inductance but also high quality factors. [1] To explore the potential of nanowires fabricated from granular aluminium, we propose a new type of superconducting qubit. Replacing the Josephson tunnel junction in a transmon qubit, the granular aluminium nano-wire is operated in a high-impedance Josephson weak-link regime. We present design considerations and preliminary measurements of first samples.

[1] H. Rotzinger, *et al.*, Supercond. Sci. Technol. **30**, 025002 (2016)

TT 99.41 Thu 15:00 Poster B

Fluxonium superconducting qubit using a granular aluminum superinductor — •Martin Spiecker[1], Lukas Grünhaupt[1], Nataliya Maleeva[1], Hannes Rotzinger[1], Alexey V. Ustinov[1,2], and Ioan M. Pop[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia

Superconducting quantum circuits have already shown several important milestones towards quantum information processing. An interesting subtype of superconducting qubits is the fluxonium. It consists of a Josephon junction shunted with a large 'super' inductance, which results in an offset charge insensitive qubit with an anharmonic level-structure. The superinductor is typically implemented using Josephson junction arrays. I will present an alternative path, based on the use of a high kinetic inductance material, namely granular aluminum.

TT 99.42 Thu 15:00 Poster B

Implementing an inductively shunted transmon qubit with tunable transverse and longitudinal coupling — •Sebastian T. Skacel[1], Nataliya Maleeva[1], Daria Gusenkova[1], Susanne Richer[2], David DiVincenzo[2], and Ioan M. Pop[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, D-76131 Karlsruhe, Germany — [2]JARA Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany

We discuss some of the challenges in the physical implementation of an inductively shunted transmon qubit with flux-tunable transverse and longitudinal coupling to an embedded harmonic mode. The inductive shunt consists of a combination of compact, low-loss and linear inductances, in the range of several nH, and chains of Josephson junctions. The former could be realized by superconducting strips consisting of a high kinetic inductance material, granular aluminum, while the latter can be made from standard thin-film aluminum. The electrical connections between these different metallic layers could be realized using recently developed argon ion cleaning and contacting techniques which preserve the coherence of the circuit. The sample is enclosed in a 3D waveguide which offers the advantage of strong coupling for the resonator mode inside the designed pass band between 6 and 8 GHz, while the qubit mode can be efficiently decoupled from the microwave environment.

TT 99.43 Thu 15:00 Poster B

Investigation of a superconducting quantum metamaterial — •Jan David Brehm[1] and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

Quantum metamaterials extend the idea of classical metamaterials to a regime where the quantum coherence of the meta-atoms exceeds the typical propagation time of an impinging wave through the medium. In recent works, it was proposed that this gives rise to various collective light-matter interaction effects such as selfinduced transparency, quasi-superradiant phase transitions and lasing. Superconducting qubits are strong candidates for an implementation of meta-atoms in the quantum regime because they feature well controllable properties, have sub-wavelength dimensions, and are known to have sufficiently long coherence times. First implementations of quantum metamaterials made of arrays of superconducting flux [1] and transmon [2] qubits were targeted at studying their collective interaction with a single mode of a microwave resonator. Here, we investigate a one-dimensional quantum material which consists of an array of transmon qubits coupled to a continuum of the light modes in a coplanar waveguide.

[1] P. Macha et al., Nature Commun. 5, 5146 (2014)
[2] K. V. Shulga et al., JETP Lett. 105, 47 (2017)

TT 99.44 Thu 15:00 Poster B

Local density of states in clean 2D SNS heterostructures — •Danilo Nikolic[1], Wolfgang Belzig[1], and Juan Carlos Cuevas[2] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Spain

The advent of 2D materials like graphene have reignited the interest in the study of the proximity effect in clean hybrid superconducting structures. Here, we present a systematic analysis of the local density of states in a clean 2D normal metal coupled to superconducting leads. By solving the Eilenberger equations in the framework of the quasiclassical theory of superconductivity, we are able to describe the impact in the Andreev bound state spectrum of these hybrid systems of, among others, a superconducting phase difference, a finite transmission of the interfaces or the presence of a weak magnetic field. Our results shed light on recent experiments on the Andreev bound states in graphene-based hybrid superconducting structures.

[1] L. Bretheau, J.I.J. Wang, R. Pisoni, K. Watanabe, T. Taniguchi, P. Jarillo-Herrero, Nature Physics, doi:10.1038/nphys4110 (2017)

TT 99.45 Thu 15:00 Poster B

Josephson junctions induced by strain in an individual few-layer $NbSe_2$ monocrystal — •Karl Enzo Kloss, Anh-Tuan Nguyen, Sofia Blanter, Paul Linsmaier, Christoph Strunk, and Nicola Paradiso — Institut für experimentelle und angewandte Physik, University of Regensburg

Superconducting transition metal dichalcogenides offer the opportunity to study superconductivity in the limit of clean 2D *monocrystals*. This opens the way to the study of phenomena that cannot be observed on bulk or disordered samples. One example is the impact of crystal distortions on the local superconducting order parameter. In this work we study the transport characteristics of few-layer $NbSe_2$ flakes with a crystal fold which divides them in two halves separated by a strained region. This latter may act as a weak link or as a strong barrier, depending on the crystal stress. The weak link corresponds to Josephson junction within the same monocrystal. This is confirmed by our finite-bias measurements in perpendicular field, which reveal a typical Fraunhofer pattern.

TT 99.46 Thu 15:00 Poster B

On unambigous quantum signatures in driven swept-bias Josephson junctions — •Harald Losert[1], Karl Vogel[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm — [2]Institute for Quantum Science and Engineering (IQSE), Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843

Josephson junctions are one of the best examples for the observation of macroscopic quantum tunneling. In the case of a current-biased Josephson junction the phase difference behaves like the position of a particle in a tilted washboard potential. The escape of this phase-particle corresponds to the voltage switching of the associated junction. The escape from the potential can be explained by quantum tunneling from the ground state, or an excited state. However, it has been shown [1][2], that in the case of periodic driving the experimental data for quantum mechanical key features, e.g. Rabi oscillations or energy level quantization, can be reproduced by completely classical calculations.

Motivated by this discussion, we focus on the escape process in a swept-bias Josephson junction setup. We point out how a large or a small critical current of the junction affects the distinction between quantum and classical effects. In particular, we contrast the switching current distributions resulting from a quantum and a classical description of the time evolution in each case.

[1] Marchese*et al.*, *Eur. Phys. J. Special Topics* **147**, 333 (2007)
[2] Blackburn *et al.*, *Phys. Rev. B* **85**, 104501 (2012)

TT 99.47 Thu 15:00 Poster B

Reliability of different fabrication processes for window- and cross-type $Nb/Al-AlO_x/Nb$ Josephson junctions — •F. Bauer, F. Zimmerer, A. Ferring, M. Wegner, S. Kempf, and C. Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Josephson tunnel junctions (JJs) are the basic element of many superconducting electronic devices such as SQUIDs or qubits. To allow for a successful and predictable operation of these devices, JJs having high quality and well-defined parameters are needed. The fabrication of window-type JJs is an often used approach to reliably produce such junctions. However, restrictions in alignment accuracy practically limits the junction size if not using advanced technologies such as e-beam lithography. Additionally, the overlap between the base electrode and the top wiring as well as the minimum junction size leads to constraints with respect to the junction capacitance and therefore to practical design parameters of SQUIDs and qubits. Both issues can be addressed by introducing a cross-type JJ fabrication process.

Within this context, we present different fabrication processes for $Nb/Al-AlO_x/Nb$ based JJs. This includes not only our well-established, anodization-free fabrication process for window-type JJs but also different types of fabrication processes for cross-type JJs. We will compare all processes with each other by means of different figures of merit such as the ratio of subgap to normal resistance R_{sg}/R_n or the characteristic voltage $R_{sg}I_c$ and show that our JJs exhibit a very high quality.

TT 99.48 Thu 15:00 Poster B

Low frequency excess flux noise in dc-SQUIDs — •A. Ferring, S. Kempf, and C. Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Low frequency excess flux noise strongly impairs the performance of superconducting quantum devices (SQDs) such as SQUIDs and Qubits. It is, for example, the dominating mechanism causing decoherence in flux or phase Qubits and makes SQUID based measurements of low frequency signals rather challenging. But even though it has been extensively studied for many years, many open questions concerning its origin and properties remain. Recent experiments, for example, hint for surface adsorbates as a potential origin of noise contributions. It remains however unclear whether additional sources of low frequency excess flux noise exist. Therefore further investigations need to be done.

In this contribution, we first discuss a detailed study of low frequency excess flux noise in SQDs made of different materials like Nb, Al and PbIn, that hints for a material- and device-type dependence. We also show indications for a correlation between the $1/f$-noise amplitude of dc-SQUIDs and the dc-magnetization of the used insulating SiO_2 layer originating from magnetic contaminations introduced during the actual fabrication process. Finally, we present noise measurements on dc-SQUIDs having all Nb/Al-AlO_x/Nb Josephson Junctions but using washers made from different materials.

TT 99.49 Thu 15:00 Poster B

Optimal control pulses for a superconducting circuit with low anharmonicity — •Nicolas Wittler, Shai Machnes, and Frank Wilhelm-Mauch — Universität des Saarlandes, Saarbrücken, Deutschland

In order to perform specific operations on a superconducting quantum device with a desired fidelity, we investigate theoretical methods for shaping optimal control pulses of such systems. The 3D Transmon, a Josephson junction embedded in a microwave cavity, achieves a low sensitivity to charge noise, while retaining small, but sufficient anharmonicity, to allow for distinct transition frequencies. Because of this low anharmonicity, the difference in transition frequencies will be small, so that a pulse designed to drive a selected transition will also drive the neighboring transitions. Performing a desired quantum gate with a certain accuracy on the device requires driving pulses, that don't effect undesired transitions. With pulse shaping techniques such as **DRAG**[1] and **GOAT**[2], that engineer the frequency spectrum of a control pulse to suppress unwanted transitions, an increase in fidelity or shortening of the gate time can be achieved. The analytical method **DRAG** (**D**erivative **R**emoval by **A**diabatic **G**ate) presents an approach, where an initial pulse is shaped by adding its derivative with a suitable amplification factor to suppress certain transitions. **GOAT** (**G**radient **O**ptimization of **A**nalytic Con**T**rols) shapes pulses by numerically solving a differential equation for the control parameters, to find the optimial pulse.

[1] F. Motzoi *et al.*, Phys.Rev.Lett. 103 (2009) 110501,
[2] S. Machnes *et al.*, arXiv:1507.04261

TT 99.50 Thu 15:00 Poster B

Model Studies of High Fidelity Entangling Gates — •Joel Christin Pommerening and David DiVincenzo — JARA Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany

We study high-fidelity operations on two coupled superconducting qubits. We consider the cross-resonance gate, presenting a straightforward analytic derivation of its action based on the theory of Makhlin invariants.

Starting from an effective J coupling between the qubits, this derivation relies on a single rotating wave approximation to make the Hamiltonian time-independent in the frame that is rotating both qubits at the frequency of the cross-resonant drive. At that point no further frame or basis transformations are necessary, and the model can be solved exactly. A time evolution locally equivalent to a CNOT gate can then be found in multiple bases in the limit of small coupling strength J, and in one basis in particular for any J.

In practice the qubit basis is of course not arbitrary, but can be defined by the measurement basis or the basis in which single-qubit gates are applied. In this context we study how the (always-on) two-qubit coupling affects single-qubit measurements, and more specifically the measurement basis. In doing so we eventually seek to better understand the errors that arise from a possible mismatch between measurement and qubit basis.

TT 99.51 Thu 15:00 Poster B

Remote entanglement stabilization and distillation by quantum reservoir engineering — Didier Nicolas[2], •Jérémie Guillaud[1], Shyam Shankar[3], and Mazyar Mirrahimi[1] — [1]Inria Paris, Paris, France — [2]Rigetti Computing, Berkeley, USA — [3]Yale University, New Haven, USA

Quantum information processing protocols based on teleportation require highly entangled pairs of distant qubits as a primary resource. We present a new protocol that achieves an autonomous remote entanglement distillation using two-mode squeezed light as an imperfect source of entanglement. Two remote cavities are driven at distance using a three-wave mixing device that generates a two-mode squeezed light at resonance with the cavities. The autonomous distillation is performed through the local dispersive couplings of qubits to cavities and some additional local drives on the qubits. We will illustrate (numerically and analytically) how this protocol stabilizes a maximally entangled Bell state of the qubits regardless of the applied squeezing strength. We also study the robustness study of this reservoir engineering protocol in presence of various sources of imperfection and decoherence. This study is done through numerical simulations and systematic model reduction techniques such as adiabatic elimination of stable fast dynamics.

TT 99.52 Thu 15:00 Poster B

Effect of parasitic capacitances on Bloch oscillations measured via dual Shapiro steps — •Lisa Arndt, Fabian Hassler, and Ananda Roy — JARA-Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany

Measurement of Bloch oscillations in a single Josephson junction in the phase slip regime is a crucial element of metrology that links the current to the frequency standard. Bloch oscillations can be measured by applying a periodic drive to a DC-biased Josephson junction. Phase-locking between the two oscillations then gives rise to dual Shapiro steps. Unlike the normal Shapiro steps, a measurement of these dual Shapiro steps is impeded by parasitic capacitances. These parasitic capacitances can be screened by an on-chip superinductance. However, as the system is constantly driven, the energy has to be dissipated. To that end, we propose to add an additional large off-chip resistance. We investigate the resulting system by a set of analytical and numerical methods. We show that even in the presence of parasitic capacitances, it is possible to observe Bloch oscillations with realistic system parameters. In particular, we show that the leading effect of the parasitic capacitance is a reduction of the critical voltage of the phase slip junction by a factor of $\exp(-10\,\mathrm{k}\Omega/Z)$ where Z is the characteristic impedance formed by the parasitic capacitance and the superinductance.

TT 99.53 Thu 15:00 Poster B

Decoherence dynamics of the quantum Ising model in the strong coupling regime — •Hannes Weisbrich, Wolfgang Belzig, and Gianluca Rastelli — Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany

We study the decoherence dynamics of the 1D quantum Ising model within the framework of the Lindblad equation. We consider spins forming a 1D ring lattice uniformly coupled to a single bath via the spin component parallel to a transverse magnetic field. The system is analysed in the strong coupling regime in which the interaction strength is much larger than the transversal field, such that the spin chain has two degenerate ground states. We will focus on the dynamics between the ground states and the lowest excited states of the system. We find a decoherence free subspace as long as the dissipative coupling is parallel to the transverse magnetic field. Finally, we show that even if a more realistic model of non-uniform dissipative interaction is assumed, i.e. the local dissipation is uncorrelated with the rest of the ring, the decoherence free subspace is preserved due to parity conservation.