TT 49: Poster Session: Superconductivity

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

TT 49.1 Wed 15:00 Poster D

High pressure study of hydrogen sulfide — •Takaki Muramatsu, Owen Moulding, Yan Zhou, Martin Kubal, and Sven Friedemann — HH Wills Laboratory, University of Bristol, UK

High T_c superconductivity (about 200K) of hydrogen sulfide (H_2S) was discovered by Drozdov *el al.* in 2015 and it was observed in its high-pressure metallic phase ($P > 100$ GPa). Several groups reported that new structural phase (H_3S) is synthesized in the high-pressure superconducting phase. The temperature must be kept below around 200 K while pressure is increased up to 100 GPa to form the high T_c superconducting phase. In this work we show our sample loading system capable of liquefying and pressurising H_2S in a diamond-anvil high-pressure cell to beyond 100 GPa. We show Raman spectroscopy and electrical transport measurements. For a pressurisation at room temperature, the Raman results show the dissociation of H_2S resulting in hydrogen and elemental sulphur. The latter is detected as a superconducting phase above 100 GPa with resistance measurements. Our studies highlight the sensitivity of the high-pressure synthesis of superconducting hydrogen sulphide.

TT 49.2 Wed 15:00 Poster D

High-Pressure Measurements of Upper and Lower critical fields in 2H-$NbSe_2$ — •Israel Osmond and Sven Freidemann — H.H Wills Physics Laboratory, University of Bristol

With superconductivity often found in the vicinity of ordered states such as charge density waves (CDW) and antiferromagnetism, the ability to tune materials through these states serves as a vital tool in exploring the interplay of these phases with superconductivity. For characterising a given superconductor, magnetic measurements provide a non-invasive method of studying vortex dynamics and measuring critical temperatures and fields.

Likewise, pressure measurements serve as a continuous tuning parameter across many of these phases. As such, the application of pressure provides a method to both access novel structures not available at ambient pressure, and to explore the competition between phases such as the CDW and superconducting order. This work develops current pressure cell technology compatible with commercial SQUID magnetometers, with both piston cylinder and gemstone anvil type cells.

Previous research into 2H-$NbSe_2$ has shown multiband superconductivity, CDW ordering, and the existence of a quantum critical point beneath the superconducting state. Here, we use the aforementioned pressure cells for magnetic susceptibility measurements, mapping the behavior of both upper and lower critical fields in 2H-$NbSe_2$ with temperature and pressure.

TT 49.3 Wed 15:00 Poster D

Electrical properties of $[SnSe]_m[NbSe_2]_n$ ferecrystals with $m = 6, 9$ and $n = 1$ — •Klara Mihov[1], Olivio Chiatti[1], Martina Trahms[1], Corinna Grosse[1], Kyle Hite[2], Matty B. Alemayehu[2], Dave C. Johnson[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Solid State Chemistry, Inorganic Chemistry, Electrochemistry and Materials Science, University of Oregon, Eugene, OR 97403-1253, U.S.A.

In the last years, much attention has been paid to the electrical properties of layered superconducting thin films [1]. The ferecrystals provide a possible model systems for layered superconductors. In this work, the ferecrystals are composed of a superconducting transition metal dichalgonide ($NbSe_2$) stacked repeatedly with metal monochalgogenide (SnSe)[2]. Here, we examine ferecrystals with $m = 6, 9$ and $n = 1$ which show a superconducting phase below a critical temperature. The Ginzburg-Landau coherence lengths are determinded from the critical magnetic fields and give information about the coupling between the superconducting $NbSe_2$-layers[3]. In addition, the investigated ferecrystals provide a striking opportunity to investigate superconducting fluctuations above the critical temperature.

[1] C. Grosse *et al.*, Scientific Reports **6**, 33457, (2016).
[2] C. Grosse *et al.*, Crystal Research and technology **52**(10), (2017).
[3] M. Trahms *et al.*, Superconductor Science and Technology **31**(6), (2018).

TT 49.4 Wed 15:00 Poster D

Growth and characterization of high-quality $Tl_2Mo_6Se_6$ crystals and nanowires — •Yongjian Wang, Mengmeng Bai, Mahasweta Bagchi, Zhiwei Wang, and Yoichi Ando — Institute of Physics II, University of Cologne, D-50937 Cologne, Germany

Topological superconductor (TSC) has attracted extensive interest because of its potential application to topological quantum computation, which is based on Majorana fermion (MF). Recently, the long-existed quasi-one-dimensional superconductor, $Tl_2Mo_6Se_6$, was predicted to be a new TSC [1]. Here we report the growth and characterizations of high-quality superconducting $Tl_2Mo_6Se_6$ crystals and nanowires. Fiber-shaped crystals with typical size of $0.3\times0.3\times10$ mm^3 were grown by reacting the starting raw materials in a quartz tube. The highest critical temperature (T_c) was observed to be 6.7 K from both resistivity and magnetic susceptibility measurements. The highest shielding fraction was estimated to be 100%. The upper critical field (H_{c2}) behaviour shows an upturn with lowering temperature, which is similar to the results reported before [2], suggesting unconventional superconductivity. $Tl_2Mo_6Se_6$ nanowires with typical diameter of 100 nm were obtained by exfoliating $Tl_2Mo_6Se_6$ crystals, which were used for fabricating devices by e-beam lithography for transport measurements. Superconductivity with T_c up to 6 K was observed.

[1] S. M. Huang et al., Phys. Rev. B 97, 014510 (2018)
[2] R. Brusetti et al., Phys. Rev. B 49, 8931 (1994)

TT 49.5 Wed 15:00 Poster D

Mapping the nematic axis of $Cu_xBi_2Se_3$ at high doping — •Mahasweta Bagchi, Jens Brede, Jeison Fischer, Thomas Michely, and Yoichi Ando — Physics Institute II, University of Cologne, Germany

Recently, NMR Knight-shift measurements[1] and measurements of angular dependent specific heat in a magnetic field[2] show spontaneous symmetry breaking in the superconducting state of bulk samples of $Cu_xBi_2Se_3$. Both observations firmly establish an odd parity nematic superconducting state in $Cu_xBi_2Se_3$. More recently, STM experiments[3] demonstrated mapping of the elongation of the vortex core in the vortex state of $Cu_xBi_2Se_3$ under an applied magnetic field. The orientation of the vortex core with respect to the crystallographic axis of the sample, as inferred from atomic-resolution images, gives the orientation of the nematic axis.

Here, we study $Cu_xBi_2Se_3$ with varying x. In particular, we study samples near optimum doping (x=0.3) and at higher doping levels (x=0.6) with an STM operated at 350 mK and under applied magnetic field and determine the nematic axis as a function of x.

[1] K. Matano *et al.*, Nat. Phys. **12**(9) 852 (2016)
[2] S. Yonezawa *et al.*, Nat. Phys. **13**(2) 123 (2017)
[3] R. Tao *et al.*, Phys. Rev. X **8**(4) 041024 (2018)

TT 49.6 Wed 15:00 Poster D

Toward the theory of the higher harmonic in superconducting gap dispersion of hole- and electron-doped cuprates — •Mikhail Malakhov[1,2], Mikhail Eremin[2], and Daniil Kochergin[2] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, Universitätsstraße 150, DE-44801 Bochum, Germany — [2]Institute of Physics, Kazan Federal University, Kazan, 420008 Russia

Numerical solutions of the Bardeen-Cooper-Schrieffer equation are obtained, taking into account superexchange, three site correlation term, spin-fluctuation, plasmon, and phonon mediated mechanisms. Expression for charge and spin susceptibilities derived beyond RPA approximation. For both e- and h- doped cuprates at carrier concentrations close to optimal the energy gap dispersions where approximated by expression $\Delta_{\mathbf{k}} = \Delta_0(B\cos(2\phi) + (1 - B)\cos(6\phi))$, where the angle is measured from the antinodal direction in the Brillouin zone. In agreement with ARPES data we have got $(1 - B) > 0$ for h- doped cuprates and $(1 - B) < 0$ for e-doped one and right value of Δ_0. In $Bi_2Sr_2CaCu_2O_8$ we found that the amplitude before $\cos(6\phi)$ is determined by spin-fluctuation and phonon mediated mechanisms. In case $Pr_{0.89}LaCe_{0.11}CuO_4$ the higher-harmonic is originated from spin-fluctuation and plasmon (Coulomb) pairing mechanisms. Numerically and analytically shown that role of three site correlations is weakening superexchange interaction.

TT 49.7 Wed 15:00 Poster D

Superconductivity in doped tungsten oxide: a first principles description — •Antonio Sanna[1], Camilla Pellegrini[1], and Henning Glawe[2] — [1]Max Planck Institute of microstructure physics, Halle (Saale), Germany — [2]Max Planck Institute for the structure and dynamics of matter, Hamburg, Germany

Tungsten Oxide (WO_3), its bronzes (M_xWO_3), oxygen vacant (WO_{3-x}) and fluorine doped ($WO_{3-x}F_x$) are a family of crystals showing a large variety of electronic properties, including superconductivity. Most measurements report a consistent scenario of low T_c, although there have been some reports on possible high-T_c low dimensional and metastable superconductivity in sodium doped surfaces, at the W/WO_3 interface and upon H doping. We attempt a characterization of superconductivity in doped WO_3 by *ab initio* methods, focusing on the two key questions:
- Are the stable low temperature superconducting phases driven by conventional electron phonon pairing? or, like in $BaBiO_3$, conventional approaches fail and the correct pairing mechanism is still an open problem.
- Can electron phonon coupling, in any geometry and doping regime, provide enough coupling strength to lead to high-T_c?

TT 49.8 Wed 15:00 Poster D

Effects of self-consistency in mean-field theories of disordered systems: Superconductor Insulator Transition — •Matthias Stosiek and Ferdinand Evers — Institute of Theoretical Physics, University of Regensburg, Germany

Our general interest is in aspects of self-consistency with respect to disorder in the mean-field treatment of disordered interacting systems. The example we here consider is the Superconductor Insulator Transition (SIT), where the superconducting gap is calculated in the presence of short-range disorder. Our focus is on disordered films with conventional s-wave pairing that we study numerically employing the negative-U Hubbard model within the standard Bogoliubov-deGennes approximation. The general question that we would like to address concerns the auto-correlation function of the pairing amplitude: Does it qualitatively change if full self-consistency is accounted for? Our research might have significant impact on the understanding of the SIT, if extra correlations appear due to the self-consistency condition that turn out sufficiently long-ranged. Such correlation effects are ignored in major analytical theories. To study the long-range behavior of the order parameter correlations, the treatment of large system sizes is necessary. Due to the self-consistency requirement, the relevant sizes (e.g. 10^6 sites) are numerically very expensive to achieve. For this reason, we have developed a parallelized code based on the Kernel Polynomial Method. We present data that indicates the existence of very long ranged (power-law) correlations that may indeed change the critical behavior in a significant way.

TT 49.9 Wed 15:00 Poster D

Dynamics of nanostructured superconductors in curl-free vectorpotentials — •Björn Niedzielski and Jamal Berakdar — Martin-Luther-Universität Halle-Wittenberg, Insitut für Physik, Germany

In the theory of macroscopic quantum materials, like superconductors, the electromagnetic vectorpotential plays a crucial role. We show for nanoscopically structured superconductors how vectorpotentials with zero curl can be used to manipulate the state of such a system. It is demonstrated how a relation between flux quantization and the Aharonov-Bohm effect can be used to drive and control superconducting tunneling devices in a non-invasive way.

TT 49.10 Wed 15:00 Poster D

Spin effects in a superconductor in proximity to an antiferromagnetic insulator — Akashdeep Kamra[1], •Ali Rezaei[2], and Wolfgang Belzig[2] — [1]Center for Quantum Spintronics, Department of Physics, NTNU, Norway — [2]Department of Physics, University of Konstanz, Germany

Inspired by recent feats in exchange coupling antiferromagnets to an adjacent material, we demonstrate the possibility of employing them for inducing spin-splitting in a superconductor, thereby avoiding the parasitic effects of ferromagnets employed to this end. We derive the Gor'kov equation for the matrix Green's function in the superconducting layer, considering a microscopic model for its disordered interface with a two-sublattice magnetic insulator. We find that an antiferromagnetic insulator with effectively uncompensated interface induces a large, disorder-resistant spin-splitting in the adjacent superconductor, thereby addressing the feasibility of a wide range of devices involving spin-split superconductors. In addition, we find contributions to the self-energy stemming from the interfacial disorder. Within our model, these mimic impurity and spin-flip scattering, while another breaks the symmetries in particle-hole and spin spaces. The latter contribution, however, vanishes in the quasi-classical approximation and thus, does not significantly affect the superconducting state. Our results illustrate the potential of antiferromagnets for superconducting spintronics avoiding stray fields usually accompanying ferromagnets.

[1] Akashdeep Kamra, Ali Rezaei, Wolfgang Belzig, arXiv:1806.10356 (2018); accepted in PRL

TT 49.11 Wed 15:00 Poster D

Phonon anomalies in FeS — •Leander Peis[1,2], Andreas Baum[1,2], Ana Milosavljević[3], Nenad Lazarević[3], Miloš M. Radonjić[3], Božidar Nikolić[4], Merlin Mitscheck[1,2], Zahra Inanloo Maranloo[1], Maja Šćepanović[3], Mirjana Grujić-Brojčin[3], Nenad Stojilović[3,5], Matthias Opel[1], Aifeng Wang[6], Cedomir Petrovic[6], Zoran V. Popović[3,7], and Rudi Hackl[1] — [1]Walther-Meissner-Institut, 85748 Garching, Germany — [2]Fakultät für Physik, Technische Universität München, 85748 Garching, Germany — [3]Institute of Physics Belgrade, 11080 Belgrade, Serbia — [4]Faculty of Physics, University of Belgrade, Belgrade, Serbia — [5]Department of Physics and Astronomy, University of Wisconsin Oshkosh, Oshkosh, WI 54901, USA — [6]Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory, Upton, NY 11973, USA — [7]Serbian Academy of Sciences and Arts, 11000 Belgrade, Serbia

Tetragonal FeS is studied using Raman spectroscopy. We identify the A_{1g} and B_{1g} phonon modes, a second order scattering process, and contributions from potentially defect-induced scattering. The temperature dependence between 300 and 20 K of all observed phonon energies is governed by the lattice contraction. The increase in energy of all modes below 20 K may indicate short range magnetic order. Lattice-dynamical simulations and a symmetry analysis for potential overtones are in good agreement with the experiments. The two-phonon excitation observed in a gap between the optical branches presumably becomes observable due to significant electron-phonon interaction.

TT 49.12 Wed 15:00 Poster D

Microscopic phase diagram of LaFeAsO single crystals under pressure: A Mössbauer study — •Philipp Materne[1], Wenli Bi[2,1], Jiyong Zhao[1], Michael Yu Hu[1], Rhea Kappenberger[3,4], Sabine Wurmehl[3,4], Saicharan Aswartham[3], Bernd Büchner[3,4], and Esen Ercan Alp[1] — [1]Argonne National Laboratory, Lemont, IL 60439, USA — [2]Department of Geology, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA — [3]Leibniz Institute for Solid State and Materials Research (IFW) Dresden, D-01069, Germany — [4]Institute of Solid State and Materials Physics, TU Dresden, D-01069 Dresden, Germany

We investigated a LaFeAsO single crystal by means of synchrotron Mössbauer spectroscopy under pressure up to 7.5 GPa and down to 13 K and provide a microscopic phase diagram. A continuous suppression of the magnetic hyperfine field with increasing pressure was found and it completely vanishes at $\sim$ 7.5 GPa which is in contrast to the behaviour in polycrystalline samples where the magnetic order vanishes at $\sim$ 20 GPa. We discuss the sample dependence of the magnetic order among different single and polycrystalline samples and its relationship to the structural parameters.

[1] P. Materne *et al.*, Phys. Rev. B. **98**, 174510 (2018)

TT 49.13 Wed 15:00 Poster D

Observation of a highly ordered vortex lattice in LiFeAs — •Sven Hoffmann[1], Christian Salazar[1], Pavlo Khanenko[1], Danny Baumann[1], Ronny Schlegel[1], Saicharan Aswartham[1], I. Morozov[2], Bernd Büchner[1], and Christian Hess[1] — [1]IFW Dresden, Helmholtzstraße 20, D-01069 Dresden — [2]MSU, Leninskiye Gory 1, R-119991 Moscow

Unlike other Fe-based superconductors, LiFeAs is a stoichiometric superconductor, showing no trace of nematic order, charge ordering or magnetic ordering and no Fermi surface nesting, while still maintaining a fairly high transition temperature. To gain additional information about the order parameter in this material we performed low temperature scanning tunneling microscopy and spectroscopy measurements. Differential conductance maps revealed a highly ordered vortex lattice, even at high magnetic fields. These findings contradict previous reports, where substantially disordered vortex lattices were observed at a broad range of magnetic fields, indicative of a strong pinning effect and small coherence length in LiFeAs. Our data therefore suggest weaker pinning and a substantially larger coherence length for this sample as compared to previous reports.

TT 49.14 Wed 15:00 Poster D

The nematic phase of $LaFe_{1-x}Co_xAsO$ single crystals probed by thermodynamic methods — •Francesco Scaravaggi[1,2], Sven Sauerland[3], Rhea Kappenberger[1,2], Liran Wang[3], Saicharan Aswartham[1], Sabine Wurmehl[1], Rüdiger Klingeler[3], Anja U. B. Wolter[1], and Bernd Büchner[1,2] — [1]Leibniz-Institute for Solid State and Materials Research, IFW Dresden, Dresden, Germany — [2]Institute for Solid State Physics, TU Dresden, Dresden, Germany — [3]Kirchhoff Institute for Physics, Heidelberg University, Heidelberg, Germany

The phase diagram of electron doped LaFeAsO has been extensively studied on polycrystalline samples, showing significant differences when compared with other members of the FeAs family. The electronic nematic phase present in the parent compound, gradually suppressed by doping, appears to be separated from the emerging superconducting phase by a fairly abrupt transition. The interplay between these two phases in Iron-based superconductors as well as the origin of the nematic order are still under debate. By measuring single crystalline samples [1], we report the study of the evolution of the nematic phase in LaFeAsO as a function of Co doping by magnetization, specific heat and thermal expansion measurements. Macroscopic faceted single crystals allow us to effectively trace the structural order parameter (δ) as a function of temperature and doping by high resolution dilatometry.

[1] R. Kappenberger et al., J. Cryst. Growth 483, 9 (2018)

TT 49.15 Wed 15:00 Poster D

Elastotransport and Nernst effect in 122- and 1111-Fe-based superconductors: Evidence for superconductivity driven by nematic fluctuations — •Christoph Wuttke[1], Federico Caglieris[1], Xiaochen Hong[1], Steffen Sykora[1], Frank Steckel[1], Seunghyun Kim[1], Rhea Kappenberger[1], Saicharan Aswartham[1], Sabine Wurmehl[1], Sheng Ran[2], Paul C. Canfield[2], Bernd Büchner[1,3], and Christian Hess[1] — [1]Leibniz-Institute for Solid State and Materials Research, IFW-Dresden, 01069 Dresden, Germany — [2]Ames Laboratory and Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA — [3]Institut für Festkörperphysik, TU Dresden, 01069 Dresden, Germany

The role of nematic fluctuations in the appearance of high temperature superconductivity is still controversial. In this work we investigate the phase diagrams of $BaFe_2As_2$ and LaFeAsO as a function of electron-doping through elastotransport and Nernst effect measurements. We obtain an anomalously large Nernst coefficient in the tetragonal phase, upon doping its magnitude strikingly mimicking the superconducting dome. Similar but slightly different non-monotonic behavior is found for the elastoresistivity. Using a minimal orbital model for iron-based superconductors we show that the Nernst coefficient couples directly to the nematic fluctuations. We explain the difference between elastoresistivity and Nernst effect by incorporating the coupling to a soft phonon mode in our theory. Thus, our experimental results provide supportive evidence that nematic fluctuations are crucial for the formation of the superconducting state in iron-based superconductors.

TT 49.16 Wed 15:00 Poster D

NMR investigations of the iron-pnictide superconductor KFe_2As_2 near the upper critical field — •Sh. Yamamoto[1], S. Molatta[1], F. Hardy[2], R. Lortz[3], J. Wosnitza[1], and H. Kühne[1] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institute for Solid State Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]Department of Physics, The Hong Kong University of Science and Technology, Kowloon, Hong Kong

Recent measurements by thermodynamic probes provided evidence for a Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state in the iron-pnictide superconductor KFe_2As_2 beyond the Pauli limit for in-plane applied fields. We report two aspects of the ^{75}As nuclear magnetic resonance in KFe_2As_2 near the upper critical field (H_{c2}). First, according to the angular and temperature dependence of spin-echo measurements, no observable line broadening above the Pauli limit was observed for a high-quality single crystal. The result gives a spectroscopic viewpoint on the proposed FFLO state. Second, we observed an angle-independent line broadening of the central and the satellite peak below 500 mK near H_{c2}. Furthermore, two distinct nuclear spin-lattice relaxation times were observed at low temperatures. These results are compatible with the existence of charge order or charge fluctuations that has been, so far, only observed under pressure (KFe_2As_2) or in zero field ($RbFe_2As_2$) in strongly hole-doped 122 iron-based superconductors.

TT 49.17 Wed 15:00 Poster D

Fermi-surface topology of $(Rb,Cs)Fe_2As_2$ — •Tobias Förster[1], Johannes Klotz[1], Seunghyun Khim[2], Saicharan Aswartham[3], Helge Rosner[2], Ilya Sheikin[4], and Jochen Wosnitza[1] — [1]Dresden High Magnetic Field Laboratory (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [3]Leibniz Institute for Solid State and Materials Research (IFW), Dresden Germany — [4]Laboratoire National des Champs Magnétiques Intenses (LNCMI-EMFL), Grenoble, France

The unique Fermi-surface topology of many iron-pnictide superconductors stimulates a number of theories on the nature of the pairing interactions in these materials. In the case of $(K,Rb,Cs)Fe_2As_2$, there is an ongoing discussion whether a Lifshitz transition is connected to the superconducting properties of these 122 iron arsenides. Studies of the pressure dependence of H_{c2} did not find evidence for that kind of transition [1]. In contrast, high-resolution band-structure calculations show a van Hove singularity close to the Fermi energy, favoring a Lifshitz transition. In order to investigate the possible impact of this feature, a precise knowledge of the electronic structure is eminent. We, therefore, calculated the Fermi surface in $(Rb,Cs)Fe_2As_2$ and investigated the de Haas-van Alphen effect of $(Rb,Cs)Fe_2As_2$ in static fields up to 38 T. In our contribution, we show the results of our torque-magnetometry measurements and use them to refine band-structure calculations.

[1] F. F. Tafti et al., Phys. Rev. B. **89**, 134502 (2014).

TT 49.18 Wed 15:00 Poster D

Design of a 30 mK STM for spin-polarized measurements — •Sebastian Schimmel, Danny Baumann, Alexander Horst, Ralf Voigtländer, Dirk Lindackers, Saicharan Aswartham, Sabine Wurmehl, Bernd Büchner, and Christian Hess — IFW-Dresden; Helmholtzstraße 20; 01069 Dresden

We present a scanning tunneling microscope (STM) system which is especially designed to perform investigations with spin-polarization and very high resolution in energy as well as in real space. Using a ^{3}He/^{4}He Dilution refrigerator allows to cool the tip and sample to a measurement temperature of 30 mK which improves the energy resolution to the micro-eV-scale and enables to study all classes of unconventional superconductors, also including heavy fermion compounds. Long-term measurements at base temperature can be performed for up to 7 days. A UHV system will be employed to prepare tips and samples for spin-polarized STM measurements. Furthermore, a 9-4 T vector magnet allows the systematic in-situ manipulation of the spin-polarization axis. The whole apparatus is suspended on a sophisticated two-stage passive/ active damping system. Therefore, this instrument constitutes a novel approach to reveal the ubiquitous interplay of superconductivity, magnetism and electronic order in unconventional superconductors.

TT 49.19 Wed 15:00 Poster D

Out-of-plane electronic contributions in Bi-cuprates studied by resonant photoelectron spectroscopy at the Cu 2p edge — •Christoph Janowitz[1] and Dieter Schmeisser[2] — [1]Humboldt Universität, Institut für Physik — [2]Brandenburgisch Technische Universität Cottbus-Senftenberg

In high-temperature superconductors with a layered crystal structure out-of-plane contributions are often neglected, while the copper-oxygen planes are commonly considered to dominate the electronic properties around the Fermi energy. Here we report on a resonant photoemission study of (Pb,Bi)2201 and (Pb,Bi)2212 single crystals to unravel the resonant decay mechanisms at the Cu 2p absorption edge. We demonstrate a pronounced polarization dependence caused by two different Auger processes for in-plane and out-of-plane orientations. We deduce that the lowest energy valence state being involved in the two Auger processes, consists of three-dimensional contributions by admixed out-of-plane Sr, Bi, and O 2p states. It also suggests that the doping-induced charge density is dynamic, fluctuating within the Cu-O plane, and spills out perpendicular to it.

[1] C. Janowitz and D. Schmeißer, Supercond. Sci. Technol. 31,

045006 (2018)

TT 49.20 Wed 15:00 Poster D

Lifetime of the magnetic resonance mode in high-temperature superconductors — •Davide Valentinis[1], Toshinao Loew[2], and Joerg Schmalian[1] — [1]Institute for Theoretical Condensed Matter physics, Karlsruhe Institute of Technology, Wolfgang-Gaede Straße 1, 76131 Karlsruhe (DE) — [2]Max Planck Institute for Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart (DE)

The spin-resonance collective mode emerges in the electronic spectrum of high-temperature superconductors as a consequence of the sign-changing pairing symmetry of the superconducting gap [1], as measured by inelastic neutron scattering. A detailed study of the spectral lineshape for the spin resonance thus yields valuable insight on the microscopic interactions which promote or compete with pairing [2]. In this work, we analyze new neutron inelastic scattering measurements on $YBa_2Co_3O_{6.55}$ in terms of the spin-fermion model near the antiferromagnetic instability in 2 dimensions [3], where self-energy corrections from disorder are treated in Born approximation. We compare quantitatively the calculated temperature dependence of resonance energy and linewidth with experiments, thus inferring characteristic energy scales for pairing and disorder strength.

[1] P. Hlobil, B. Narozhny and J. Schmalian, Phys. Rev. B **88**, 205104 (2013)
[2] M. Eschrig, Adv. Phys. **55**, 47 (2006)
[3] A. Abanov, A. V. Chubukov and J. Schmalian, Adv. Phys. **52**, 119 (2003)

TT 49.21 Wed 15:00 Poster D

Triplet superconducting correlations: Magnet-superconductor hybrid structures in nonequilibrium — •Kevin Marc Seja[1], Oleksii Shevtsov[2], and Tomas Löfwander[1] — [1]Chalmers University of Technology, Göteborg, Sweden — [2]Northwestern University, Evanston (IL), United States

We examine a superconductor that is in contact with a normal metal via a spin-active interface. Using quasiclassical theory of superconductivity, we study the system in equilibrium as well as in nonequilibrium induced by a voltage bias. Earlier investigations have shown that in equilibrium the interface gives rise to Andreev bound states that induce a spin magnetization in the supercon- ductor. It was found that this equilibrium magnetization is related to non- trivial triplet superconducting correlations, a key feature of unconventional superconductivity. Out of equilibrium there is an additional contribution to spin imbalance related to spin-filtering and spin-mixing mechanisms. [1,2] However, in non-equilibrium the possible connection between magnetization and superconducting triplet correlations is not yet understood. We examine this relation, the change in distribution as well as the structure and spatial behavior of these correlations in non-equilibrium configurations.

[1] Shevtsov O and Löfwander T, J. Phys Conf. Ser. 568, 2 (2014)
[2] Shevtsov O and Löfwander T, Phys. Rev. B 90, 085432 (2014)

TT 49.22 Wed 15:00 Poster D

Single-Channel Josephson Effect in a High-Transmission Atomic Contact — Jacob Senkpiel[1], •Simon Dambach[2], Markus Etzkorn[1], Robert Drost[1], Ciprian Padurariu[2], Björn Kubala[2], Wolfgang Belzig[3], Alfredo Levy Yeyati[4], Juan Carlos Cuevas[4], Joachim Ankerhold[2], Christian R. Ast[1], and Klaus Kern[1,5] — [1]Max-Planck-Institut für Festkörperforschung, Germany — [2]Institut für komplexe Quantensysteme, Universität Ulm, Germany — [3]Fachbereich Physik, Universität Konstanz, Germany — [4]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Spain — [5]Institut de Physique, École Polytechnique Fédérale de Lausanne, Switzerland

The Josephson effect in scanning tunneling microscopy is an excellent tool to probe the properties of the superconducting order parameter on a local scale through the Ambegaokar-Baratoff (AB) relation. Using single atomic contacts created by means of atom manipulation, we demonstrate that in the extreme case of a single transport channel through the atomic junction, modifications of the current-phase relation lead to significant deviations from the linear AB formula. Using the full current-phase relation for arbitrary transmission, we model the Josephson effect in the dynamical–Coulomb-blockade regime because the charging energy of the junction capacitance cannot be neglected. We find excellent agreement with the experimental data. Projecting the current-phase relation onto the charge-transfer operator shows that at high transmission multi–Cooper-pair tunneling processes may occur.

[1] J. Senkpiel et al., arXiv:1810.10609.

TT 49.23 Wed 15:00 Poster D

Development of RF-Power Dividers for the Josephson Arbitrary Waveform Synthesizer — •Hao Tian, Oliver Kieler, Ralf Behr, Rüdiger Wendisch, Rolf-Werner Gerdau, Karsten Kuhlmann, and Johannes Kohlmann — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

The JAWS, based on pulse-driven series arrays of SNS Josephson Junctions (JJs) at 4 K, enables spectrally pure AC voltages to be synthesized from DC up to MHz. To make the experimental set-up less complex and to increase the JJs operated by a single PPG channel, we designed two types of on-chip power dividers. One type is a serial-parallel power divider, the second type is a Wilkinson power divider. Each output of the power divider is equipped with a DC-block capacitor. Different designs were simulated, integrated to JJs arrays and fabricated. The results showed that the test chips containing a 2-stage serial-parallel power divider and 2000 JJs are operational up to a maximal clock frequency of 8 GHz. However, the operation margins are rather small and spectrally pure sinusoidal waveforms could be synthesized with sigma-delta code amplitudes $< 30\%$. The 1-stage Wilkinson power divider with 1000 JJs is operating up to a clock frequency of 15 GHz. We successfully synthesized spectrally pure output voltages of 11.7 mV (RMS). The operation margins are much larger than for the previous design.

This work was partly supported by the EMPIR programme co-financed by the Participating States and from the EU H2020 programme (JRP 15SIB04 QuADC) and by the German BMWi (project ZF4104104AB7).

TT 49.24 Wed 15:00 Poster D

Driving optomechanics with quantum microwaves from inelastic Cooper pair tunneling — •Surangana Sengupta, Björn Kubala, Ciprian Padurariu, and Joachim Ankerhold — Institute for Complex Quantum Systems and IQST, Ulm University, 89069 Ulm, Germany

In cavity optomechanics the radiation-pressure forces of optical-light or microwave excitations of a resonator have been harnessed for a wide variety of purposes [1]: from cooling and the observation of quintessential quantum-mechanical effects, to archetypal nonlinear-dynamics phenomena, and the quantum-classical crossover between these regimes. On the other hand, inelastic Cooper-pair tunneling across a dc-biased junction can create diverse quantum states of microwave light in a cavity connected in series with the junction; owing to the inherent nonlinearity of the Josephson coupling [2].

Here, we theoretically investigate, how such states may be exploited to drive a mechanical degree of freedom to supplement or substitute classical or squeezed drives explored previously. Various possible coupling scenarios and first results of a semiclassical analysis will be discussed.

[1] Markus Aspelmeyer, Tobias J. Kippenberg, and Florian Marquardt, Rev. Mod. Phys. **86**, 1391 (2014).
[2] M. Westig, B. Kubala, O. Parlavecchio, Y. Mukharsky, C. Altimiras, P. Joyez, D. Vion, P. Roche, M. Hofheinz, D. Esteve, M. Trif, P. Simon, J. Ankerhold, and F. Portier, Phys. Rev. Lett. **119**, 137001 (2017).

TT 49.25 Wed 15:00 Poster D

Proximity-induced superconductivity in Pd/$(Bi_{1-x}Sb_x)_2Te_3$ heterostructures — •Mengmeng Bai[1], Fan Yang[1], Andrea Bliesener[1], Gertjan Lippertz[1], Martina Luysberg[2], Alexey Taskin[1], Joachim Mayer[2], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne, 50937 Cologne, Germany — [2]Forschungszentrum Jülich GmbH, Ernst Ruska-Centrum, 52425 Jülich, Germany

Josephson junctions (JJs) based on topological insulators (TIs) are interesting because of the possibility to generate Majorana fermions. Previous reports on TI–based JJs have employed deposited superconducting films such as Al and Nb for proximitization, which inevitably faces the challenge of the interface quality. In fact, the transparency of the JJs reported so far has been limited. Here we report that simply sputtering Pd on MBE–grown $(Bi_{1-x}Sb_x)_2Te_3$ (BST) thin films naturally gives us a superconducting layer due to an epitaxial alloy formation at the interface. This superconducting layer allows us to fabricate JJ devices which show dissipationless supercurrents below a critical temperature of 0.9 K, confirming a strong proximity effect on

the TI surface.

TT 49.26 Wed 15:00 Poster D

Phase separation and proximity effects in itinerant ferromagnet/ superconductor heterostructures — •Christian Martens[1], Andreas Bill[2], and Götz Seibold[1] — [1]Institut für Physik, BTU Cottbus-Senftenberg, Postfach 101344, 03013 Cottbus, Germany — [2]Department of Physics and Astronomy, California State University, Long Beach, California 90840, USA

Heterostructures made of itinerant ferromagnets and superconductors are studied. In contrast to most previous models, ferromagnetism is not enforced by an effective Zeeman field but induced in a correlated single-band model (CSBM) that displays itinerant ferromagnetism as a mean-field ground state. In this model superconductivity and magnetism are both calculated self-consistently. We calculate the magnitude of the magnetization, the superconducting correlations, and variations of the charge density self-consistently for a superconductingmagnetic bilayer by solving the Bogoliubov-de Gennes equations on a two-dimensional lattice. We determine all three quantities as a function of the Coulomb repulsion U and the ferromagnetic exchange interaction J. The CSBM displays a variety of features not present in the Zeeman exchange model-for example, the occurrence of electronic phase separation and the competition of magnetic and superconducting orders far away from the interface.

TT 49.27 Wed 15:00 Poster D

Coulomb blockade experiments beyond orthodox theory — •Laura Sobral Rey, Susanne Sprenger, and Elke Scheer — Universität Konstanz, 78467 Konstanz, Deutschland

A single electron transistor (SET) can be built by connecting a island with two tunnel junctions to their respective leads and a gate electrode. Previous works were focused on studying all superconducting SET (SSS) [1] or a normal island with superconducting leads (SNS)[2]. The contributions to the current through these devices (related to Coulomb blockade (CB)) are quantitatively covered by the orthodox theory in this weak-coupling regime. The strong-coupling regime can be studied by replacing one tunnel junction by a mechanically controlled break junction (MCBJ) [3]. In this regime, in a SSS SET, new effects not covered by the orthodox theory appear, like for instance multiple Andreev reflection (MAR).

To further investigate the non-orthodox Josephson quasiparticle cycle we design a SSN SET to suppress the Josephson coupling of the island to one of the leads. This should be done by using Cu lead connected to the island by a CuO_x barrier. All the coupling regimes can be addressed by opening or closing the MCBJ: MAR is expected when it's closed and tunnelling transport when it's broken.

[1] R. J. Fitzgerald, Phys. Rev. B 57, R11073(R) (1997)
[2] J.M. Hergenrother, Phys. Rev. Lett. 72, 1742 (1994)
[3] T. Lorenz, J. Low Temp. Phys. 191, 301 (2017)

TT 49.28 Wed 15:00 Poster D

Multi-level Rabi transitions 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 a well-known model system for the observation of quantum tunneling. The phase difference in a current-biased junction behaves like the position of a particle in a tilted washboard potential.

The escape of this phase-particle 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 presence of a periodic driving field even a classical theory reproduces the experimental data for quantum mechanical key features, e.g. energy level quantization.

Resuming this discussion, we theoretically investigate the multi-peak structures observed in the switching current distributions of swept-bias experiments. We identify these resonances as (higher order) Rabi oscillations between various energy levels of the washboard potential and suspect that this phenomenon cannot be explained by a classical model.

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

TT 49.29 Wed 15:00 Poster D

Gate-tunable supercurrent in epitaxial Al-InAs-based Josephson junctions — •Christian Baumgartner[1], Nicola Paradiso[1], Geoffrey C. Gardner[2], Michael J. Manfra[2,3], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Station Q Purdue, Purdue University, West Lafayette, Indiana 47907, USA — [3]Department of Physics and Astronomy, Purdue University, West Lafayette, Indiana 47907, USA

Coupling an s-wave superconductor to a two-dimensional semiconductor with strong spin-orbit interaction (SOI) offers new technological and research opportunities. Carriers in proximitized semiconductors acquire superconducting correlations while maintaining the charge tunability and the long mean free path typical of high mobility semiconductors. In the presence of strong SOI and an external magnetic field, several exotic phenomena are expected to emerge as, e.g., anisotropic supercurrent and φ_0-Josephson junctions.

We study SNS Josephson junctions where the SC is epitaxial Al and the weak link in between the banks is an InGaAs/InAs 2D electron gas. A challenge in the fabrication of such devices is the etching of the superconductor, which must preserve the high mobility of the 2DEG underneath. We demonstrate several working quantum point contacts and SNS junctions, whose supercurrent can be controlled by gating. A regular Fraunhofer pattern is observed, indicating a good homogeneity of the junction. These results constitute essential building block towards the implementation of more complex topological devices.

TT 49.30 Wed 15:00 Poster D

Josephson current switches on topological insulators — •Oleksii Maistrenko[1], Benedikt Scharf[2], Ewelina Hankiewicz[2], and Dirk Manske[1] — [1]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany — [2]Institut für theoretische Physik (TP4), Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

Magnetic Josephson junctions based on triplet-superconductors, such as Sr_2RuO_4, offer promising possibilities for building several types of Josephson current switches [1]. In topological insulator/superconductor heterostructures, triplet pairing correlations are induced in the Dirac surface states, offering a potential alternative to native triplet-superconductors. Introducing magnetization to the system via an external magnetic field or a nearby ferromagnet changes the spin structure of the anomalous Green's function and hence the superconducting d-vector. We study how this affects charge and spin transport properties of the Josephson junction. We calculate the current phase relation analytically using the Green's function technique and numerically with a tight-binding model. Our model addresses both quantum spin Hall edge states as well as surface states of three-dimensional topological insulators.

[1] B. Kastening, D. K. Morr, D. Manske, K. Bennemann, Phys. Rev. Lett. **96**, 47009 (2006)

TT 49.31 Wed 15:00 Poster D

A superconducting detector that counts microwave photons up to two — •Andrii Sokolov[1,2] and Frank Wilhelm-Mauch[1] — [1]Saarland University, Saarbrücken, Germany — [2]Institute of Physics of the National Academy of Sciences, Kyiv, Ukraine

In the last decade, there has been a substantial interest in Josephson junction based detectors. The detectors that have been demonstrated [1, 4] provide no information besides the presence or absence of photons. However, a number resolving photon detector may be of use for optimal discrimination of coherent states [2], qubit readout [3], and various quantum optics experiments in the microwave domain.

To resolve one- and two-photon inputs, we propose to use a two-photon transition. First, at least two photons are necessary to deliver a click. Then, if the detector does not fire, one can quickly tune it such that a single photon is enough to give a click. Using this method, the vacuum state, single-photon state, and states with two and more photons can be distinguished. We present a theory of our detector and evaluate its performance.

[1] Y.-F. Chen et al., Phys. Rev. Lett. 107, 217401, (2011)
[2] Ch. Wittmann et al., Phys. Rev. A 81, 062338 (2010)
[3] A. Sokolov, Phys. Rev. A 93, 032323 (2016)
[4] A. Opremcak et al., Science 361, 1239 (2018)

TT 49.32 Wed 15:00 Poster D

Chip-based magnetic traps for superconducting levitation of μm-sized particles — •Martí Gutierrez Latorre, David Niepce, Matthias Rudolph, and Witlef Wieczorek — Quantum

Technology Laboratory, Chalmers University of Technology, Gothenburg, Sweden

Levitated mechanical resonators are a unique platform capable of reaching unrivaled performance in sensing and, potentially, in realizing macroscopic superposition states. This is based on their expected ultra-low coupling to the environment resulting in unprecedented high mechanical quality factors. As a first step, we develop chip-based magnetomechanical devices for superconducting magnetic levitation. We present FEM simulations of integrated trap architectures for levitation of μm-sized particles. The force on the levitated particle and its potential energy are calculated, showing that trapping frequencies of a few hundreds of kHz are readily achievable. Additionally, we demonstrate the fabrication of integrated magnetic traps and particles made of Nb films on Si substrates via conventional micro-fabrication techniques. Our results pave the way to observing superconducting levitation of μm sized particles at 4K.

TT 49.33 Wed 15:00 Poster D

Nb SQUIDs for the detection of the motion of macroscopic mechanical oscillators — •K. Uhl[1], M. Rudolph[1], J. Hofer[2], J. Slater[2], M. Aspelmeyer[2], C. Schneider[3], M. L. Juan[3], D. Zoepfl[3], G. Kirchmair[3], O. F. Kieler[4], T. Weimann[4], R. Kleiner[1], and D. Koelle[1] — [1]Physikalisches Institut and Center for Quantum Science (CQ) in LISA$^+$, Universität Tübingen, Germany — [2]Vienna Center for Quantum Science and Technology, University of Vienna, Austria — [3]Institute for Experimental Physics, University of Innsbruck, Austria — [4]Fachbereich Quantenelektronik, Physikalisch-Technische Bundesanstalt (PTB) Braunschweig, Germany

Macroscopic mechanical oscillators can be used to investigate fundamental questions in macroscopic quantum physics and for quantum sensing applications. Such systems, however, suffer from decoherence effects, e.g. due to parasitic coupling to the environment or light absorption. Levitating solid-state objects, like a superconducting particle in a magnetic trap or a cantilever with a superconducting strip, offer a unique approach to the realization of nano- or even micro-sized quantum systems with potentially minimal decoherence. In combination with cryogenic temperatures, the coherence times in the quantum mechanical ground state can be increased significantly. To gain information on position and oscillatory behavior, a dc SQUID is employed. To optimize magnetic coupling between oscillator and SQUID, we performed numerical simulations based on London equations and evaluated various SQUID designs The results of the numerical simulations and experimentally determined SQUID performance will be presented.

TT 49.34 Wed 15:00 Poster D

YBCO nanoSQUIDs on bi-crystal MgO — •Jianxin Lin, Benedikt Mueller, Julian Linek, Max Karrer, Reinhold Kleiner, and Dieter Koelle — Physikalisches Institut and Center for Quantum Science (CQ) in LISA+, Universität Tübingen, Germany

We report on the fabrication and characterization of nanopatterned YBa2Cu3O7 (YBCO) dc SQUIDs based on grain boundary Josephson junctions (GBJJs). The nanoSQUIDs are fabricated by epitaxial growth of YBCO films via pulsed laser deposition on MgO bicrystal substrates with 24* misorientation angle. Nanopatterning is performed by Ga focused ion beam (FIB) milling. Due to its much lower dielectric permittivity , as compared to SrTiO3 (STO), the use of MgO substrates avoids a significant stray capacitance of the GBJJs and hence provides nonhysteretic current-voltage characteristics (IVCs) at low temperature (4.2 K), even without a resistively shunting Au layer on top of YBCO. Hence, our approach of using MgO instead of STO offers the potential of achieving a much larger characteristic voltage and therfore a significantly improved noise performance of unshunted YBCO nanoSQUIDs.

On the other hand, the role of Au on top of YBCO as a protection layer during FIB milling has not been clarified yet. Here, we present experimental results on electric trans*port and noise properties of our YBCO nanoSQUDs on MgO that have been fabricated with different Au shunt layer thicknesses or even with*out Au on top of YBCO, and we discuss promising routes to further improve the performance of such YBCO nanoSQUDs.

TT 49.35 Wed 15:00 Poster D

Spectral properties of a SQUID-terminated tunable coplanar resonator at high microwave frequencies — •Sergey Lotkhov — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig Germany

An integrated superconducting circuit including a shunted Josephson junction as an irradiation source and a single-electron transistor as a photon detector (see, e.g., Ref. [1] for a similar setup), was implemented for an $in-situ$ study at $T = 15$ mK and up to $f \sim 100$ GHz of the transmission spectrum of a tunable high-frequency resonator. The resonator was composed of a sub-mm-long coplanar waveguide connected to a magnetic-flux-tunable Josephson interferometer (SQUID). All basic components were made of Aluminum in the same shadow-deposition cycle. The transistor was operated as a threshold-type detector utilizing photon-activated sequences of Cooper pair – Electron cotunneling cycles to produce the current signal. Varying the applied flux Φ_{ext} over multiple flux quanta Φ_0 demonstrated significant signal suppression within limited, frequency-dependent ranges centered around the frustration points $\Phi_{\text{ext}} = \Phi_0(n + 1/2)$. Sharp and almost flux independent geometric resonances were observed outside of the suppression ranges. The reported deep modulation of the transmitted signal is promising for application in fast frequency-selective propagation switches and microwave routing on-chip. The developed chip-scale spectrometric circuit provides an invaluable microwave tool for the point-of-use study of microscopic objects.

[1] B. Jalali-Jafari *etal.*, Appl. Sci. **6**, 35 (2016).

TT 49.36 Wed 15:00 Poster D

Experimental characterization of a wideband Josephson traveling-wave parametric amplifier — •Christoph Kissling, Marat Khabipov, Ralf Dolata, and Alexander B. Zorin — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

A Josephson traveling-wave parametric amplifier was developed and experimentally characterized. The amplifier consists of an array of N=1000-1500 RF-SQUIDs embedded in a coplanar transmission line. With a magnetic field bias, an optimal operation point ensuring a large quadratic and zero cubic nonlinearity in the current-phase relation of the SQUID can be set. Thus, the amplifier operates in a three-wave mixing regime, featuring large separation of pump and signal frequency, high bandwidth at a decent gain, and promisingly quantum-limited noise. The amplifier was realized in Niobium tri-layer technology with different circuit designs. The experimental results will be presented.

TT 49.37 Wed 15:00 Poster D

Dc-SQUID readout with high dynamic range and intrinsic frequency-domain multiplexing capability — •Daniel Richter, Andreas Fleischmann, Christian Enss, and Sebastian Kempf — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Dc superconducting quantum interference devices (dc-SQUIDs) are periodic flux-to-voltage converters whose linear flux range is rather small. For this reason, a flux locked loop (FLL) circuit is typically used to linearize the output signal. At the same time, FLL operation significantly increases the dynamic range if a linear relation between the input and output signal is crucial. However, the measurement of large signals while maintaining the excellent noise performance of SQUIDs sets high demands on the digitizer sampling the SQUID signal in terms of voltage resolution. Furthermore, FLL operation often sets a practical limit for the realization of massive multi-channel SQUID systems since feedback wires have to be routed to every SQUID.

In this contribution, we discuss a SQUID readout approach which relaxes the hardware requirements of a SQUID system while maintaining a linearized output signal and a large dynamic range. At the same time, it allows for reducing the number of wires within multi-channel SQUID systems due to its intrinsic frequency-domain multiplexing (FDM) capability. We introduce the basic concept of our readout approach and demonstrate that it yields a very high dynamic range. Furthermore, we demonstrate its intrinsic FDM-capability using a custom-made four channel multiplexer device.

TT 49.38 Wed 15:00 Poster D

Implementation of coherent cross junctions for superconducting quantum circuits — •Alexander Stehli[1], Hannes Rotzinger[1], Jan Brehm[1], Alexey V. Ustinov[1,2], and Martin Weides[1,3] — [1]Karlsruher Institut für Technologie, Karlsruhe, Deutschland — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia — [3]University of Glasgow, Glasgow, United Kingdom

Josephson tunnel junctions are the centerpiece of almost any superconducting quantum circuit. By harnessing their nonlinear current-phase relation it is possible to engineer various devices with quantum properties, including superconducting qubits. Typically, the Josephson tunnel junctions for these qubits are fabricated using shadow evaporation techniques. However, lately cross and overlap junctions have gained more and more attention. Compared to shadow mask techniques, neither an angle dependent metal deposition nor free-standing bridges or overlaps are needed. This comes at the cost of breaking the vacuum during fabrication, but simplifies their integration in multi-layered circuits, and on larger substrates. Their implementation in coherent quantum circuits has been demonstrated in a recent work [1]. In this work, we implement cross junctions with superconducting transmon qubits and evaluate qubit coherence properties.

[1] Wu *et al.*, Appl. Phys. Lett. **111**, 032602 (2017)

TT 49.39 Wed 15:00 Poster D

Design of a granular aluminium fluxonium qubit with phonon traps — •Alexandru Ionita[1], Martin Spiecker[1], Lukas Grünhaupt[1], Daria Gusenkova[1], and Ioan Pop[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany

Fluxonium qubits employing the high kinetic inductance of granular aluminum (grAl) have recently been implemented, demonstrating state of the art coherence. One of the main sources of decoherence can be attributed to non-equilibrium quasiparticles (QPs) inside the grAl superinductance of the qubit. The generation of QPs can be partially traced back to bursts of phonons in the sapphire substrate, of yet unknown origin, which are followed by a slow QP population decay on a characteristic time-scale of 1 second. We present a grAl fluxonium design in a 2D-environment with phonon traps filling the entire waver, potentially decreasing the number of quasiparticle bursts.

TT 49.40 Wed 15:00 Poster D

Cryogenic microwave attenuators — •Julian Ferrero[1], Fabio Henriques[1], Lukas Grünhaupt[1], and Ioan Pop[1,2] — [1]Physikalisches Institut, Karlsruhe Institue of Technology, 76131 Karlsruhe, Germany — [2]Institute of Nanotechnology, Karlsruhe Institue of Technology, 76344 Eggenstein-Leopoldshafen, Germany

Qubits in cavities show an effective temperature higher than the base temperature of the cryostat due to RF heating from the input line. Usually control and input pulses are thermalized using multiple wideband resistive attenuators fixed at the different cryostat stages.

The dissipated power causes heating in the attenuators. Since the qubit-cavity system is directly connected to the attenuator fixed at the 20 mK stage, any self-heating of the device will have a strong impact on the qubit performance.

In order to adress this problem, we develop fast thermalizing cryogenic attenuators. We present finite element simulations of the thermal and electromagnetic characteristics of the devices based on a low temperature heat transport model.

TT 49.41 Wed 15:00 Poster D

Josephson vortices in a high kinetic inductive environment — •Lukas Powalla[1], Micha Wildermuth[1], Jan Nicolas Voss[1], Yannick Schön[1], Hannes Rotzinger[1], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia

The dynamics of Josephson vortices in long Josephson junctions is a well-known example of solitons in physics and allows to study highly nonlinear effects on a mesoscopic scale. A possible path to approach a quantum limit of soliton propagation is to study the Josephson vortices in an environment with high kinetic inductance. We experimentally study long Josephson junctions with electrodes having a large fraction of high kinetic inductance. The kinetic inductance of the electrodes is expected to strongly reduce the Josephson penetration depth and leads to nonlocal electrodynamics of vortices in the junction.

We will present transport measurements of long Josephson junctions with electrodes made from disordered oxidized aluminium and evaluate the influence of high kinetic inductance on the vortex properties.

TT 49.42 Wed 15:00 Poster D

Vortex dynamics in nanoscale Josephson junction parallel arrays — •Micha Wildermuth[1], Amadeus Dieter[1], Lukas Powalla[1], Jan Nicolas Voss[1], Yannick Schön[1], Hannes Rotzinger[1], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

A periodic arrangement of Josephson junctions is a toy model to experimentally study topological excitations in spatially modulated systems, e.g., dislocations in crystals, domain walls in various condensed matter systems, and dynamics of nonlinear lattices. Quantum limit for such lattices can be achieved by using ultra-small junctions, with their charging energy being on the order of Josephson energy. Using both ultra-small Josephson tunnel junctions and additional kinetic inductances in the array loops, we approach the quantum regime for both plasma oscillations and Josephson vortices and accompanied the interplay of charges and fluxoids in the array. Here, charge and magnetic flux become quantum-mechanical conjugated variables, wherefore the dynamics of spatially localized fluxoids entail local phase slips and concomitant charge quantum transfer across the junctions.

We present transport measurement of discrete parallel arrays of nanoscale Josephson junctions, observe appealing novel features in the current-voltage characteristics and compare them with the theoretical models.

TT 49.43 Wed 15:00 Poster D

Time resolved quantum sensing of microwave frequencies and fields with transmons — •Maximilian Kristen[1], Andre Schneider[1], Alexander Stehli[1], Tim Wolz[1], Alexey V. Ustinov[1,2], and Martin Weides[1,3] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia — [3]University of Glasgow, Glasgow, UK

Within the last years, quantum sensing has become a steadily growing field of research leading to numerous new technologies. For instance, it was recently demonstrated that off-resonant anharmonic quantum systems, e.g., transmon qubits, work as sensors for extremely weak microwave signals which are usually not measurable with conventional room-temperature electronics due to thermal background noise. However, these spectroscopic proof of principle experiments offered limited precision for reasonable data acquisition times [1]. In this work, we explore the opportunities provided by time resolved measurements. Using Ramsey fringes, we determine the shift of the first and second qubit transition induced by the applied microwave signal. This allows us to infer amplitude and frequency of this signal with a precision of a few MHz. From numerical simulations of the system we find that perturbative treatment of the transmon Hamiltonian yields insufficient results for the sensing scheme at this level of precision. Finally, we discuss the implementation of a phase estimation algorithm, enabling us to further increase the sensitivity and speed of our sensor.

[1] A.Schneider et al., Phys. Rev. A 97, 062334 (2018)

TT 49.44 Wed 15:00 Poster D

Implementing an inductively shunted transmon qubit with tunable transverse and longitudinal coupling — •Daria Gusenkova[1], Nataliya Maleeva[1], Sebastian T. Skacel[1,2], Martin Spiecker[1], Lukas Grünhaupt[1], Susanne Richer[3], David DiVincenzo[3], and Ioan M. Pop[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany — [3]JARA Institute for Quantum Information, RWTH Aachen University, Germany

The longitudinal qubit-resonator coupling is a prospective alternative to the commonly used transverse coupling scheme. The longitudinal interaction does not lead to the entanglement of qubit and resonator states. In addition to the advantage of a purely QND readout, it allows to build a scalable architecture with strictly local interactions.

We present first results towards the implementation of an inductively shunted transmon qubit with tunable transverse and longitudinal coupling to an embedded harmonic mode. The inductive shunt acts as a coupler and it combines Josephson junction arrays with compact, linear, low-loss inductances, making use of the high kinetic inductance of granular aluminum.

Besides overcoming fabrication challenges, originating from strict requirements on the circuit parameters, the main goal is to suppress phase slips in the JJ array, which prevent tuning to the pure longitudinal coupling regime.

TT 49.45 Wed 15:00 Poster D

Quantization of non-reciprocal, singular superconducting circuits — •Martin Rymarz[1,2] and David DiVincenzo[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [2]Peter Grünberg Institut: Theoretical Nanoelectronics, Research Center Jülich, D-52425 Jülich, Germany

Non-reciprocal circuit elements play an essential role for the practical realization of a solid-state quantum computer, independent of the chosen implementation. For that matter, non-reciprocal circuit elements often constitute the interface between the quantum and classical description of an electrical network.

In electrical network theory, the gyrator proposed by Tellegen in 1948 is considered to be the most fundamental non-reciprocal circuit element. The miniaturization of the actual device allows for the description of the gyrator within the lumped element model.

We propose a possible incorporation of the gyrator into circuit Quantum Electrodynamics using node fluxes. In theory effective descriptions of circuits involving gyrators can easily result in singular Lagrangians, which cannot be transformed to the corresponding Hamiltonian using the Legendre transformation since they describe constrained systems. For this reason, a generalization to the quantization of non-reciprocal, singular circuits will be presented, giving rise to physically as well as mathematically interesting models such as the Hofstadter Hamiltonian promising an implementation of the GKP code.

TT 49.46 Wed 15:00 Poster D

Gauge dependence of the two-level approximation in circuit QED — •Marco Roth[1,2], David DiVincenzo[1,2], and Fabian Hassler[1] — [1]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [2]JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, 52428 Jülich, Germany

The Rabi model describes a qubit coupled to a single bosonic degree of freedom. In circuit QED, the qubit is usually obtained by projecting an anharmonic oscillator onto its two lowest eigenstates. This two-level approximation breaks the gauge invariance of the full-system Hamiltonian and results in gauge dependent Rabi models. Although the gauge invariance can be restored by block-diagonalizing the full Hamiltonian prior to the projection, this approach yields a strongly dressed model which lacks the physical interpretability of the Rabi model. We thus perform the block diagonalization perturbatively and investigate the gauge-related effects on different qubits. We find that in many cases, one can find a gauge that requires only a small number of perturbative terms to achieve good agreement between approximated and full Hamiltonian.

TT 49.47 Wed 15:00 Poster D

Calibrating the Individual Properties in Coupled Nonlinear Resonators — •Qi-Ming Chen[1,2], Michael Fischer[1,2,3], Frank Deppe[1,2,3], Michael Renger[1,2], Stefan Pogorzalek[1,2], Edwar Xie[1,2,3], Kirill G. Fedorov[1,2], Achim Marx[1], 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

Precise and effective control of the properties of the individual items in a coupled system is crucial to the study of quantum information and quantum simulation. In a system composed of coupled nonlinear resonators, the tunability of resonance frequency and nonlinearity attracts most interests since it leads to different regimes with significantly different physics. Here we report the local control of two capacitively coupled nonlinear microwave resonators in the driven-dissipative regime. Following calibration, both the frequency and the nonlinearity of the individual resonators can be controlled effectively. The ability to control the local properties of coupled nonlinear resonators paves the way for applications in quantum information and quantum simulation in the future.

We acknowledge support by the German Research Foundation through FE 1564/1-1 and the Excellence Cluster MCQST, the Elite Network of Bavaria through the program ExQM, and the European Union via the Quantum Flagship project QMiCS (Grant No 820505).

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Helimagnons meet circuit quantum electrodynamics — •Mohammad T. Amawi[1,2], Philip Schmidt[1,2,3], Aisha Aqeel[2], Christian Back[2,3], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Germany — [2]Physik-Departement, Technische Universität München, Garching, Germany — [3]Nanosystems Initiative Munich, München, Germany

A wealth of hybrid quantum systems is discussed in the context of converting quantum information between various frequency domains, such as from microwave to optical frequencies. Besides conversion concepts based on opto-mechanics or electromechanics, the strong coupling regime of spin excitations interacting with microwave resonators offers an alternative pathway to this goal.

We present a hybrid system consisting of tunable resonators and a helimagnonic mode . The tunable resonator is a superconducting coplanar microwave resonator shunted to ground via a dc-SQUID. Thus the resonator is frequency tunable using a magnetic field bias. At low temperatures and close to zero magnetic field helimagnetic modes form in Cu_2OSeO_3 (CSO) crystals, as the system orders magnetically in a helical spin structure. We investigate the magnetization dynamics of the CSO as millikelvin temperatures using broadband techniques and present initial results regarding the coupling of CSO to flux-tunable microwave resonators.

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Comparison of superconducting microwave resonators for electron paramagnetic resonance at low tempertures — •Andreas Faltermeier[1,2], Stefan Weichselbaumer[1,2], Matthias Althammer[1,2], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany — [3]Nanosystems Inititative Munich, München, Germany

Superconducting coplanar microwave resonators are used for various applications, ranging from sensitive radiation detectors to photon storage units required for quantum information processing. All applications rely on a careful tailoring of the resonator. We investigate superconducting microwave resonators made from niobium nitride and niobium grown by ultra-high vacuum sputter deposition with the aim of pursuing electron paramagnetic resonance (EPR) spectroscopy. The geometric layout of our resonator is based on coplanar lumped element design, which guaranatees small mode volumes and large filling factors. Moreover, these resonators have typically ultra-high quality factors. Together, this results in an improved spin sensitivity compared to conventional EPR resonators. We quantitatively compare the performance of the resonator properties for Nb and NbN including the impact of the kinetic inductance. Furthermore, we compare between experimental results with numerical simulations.

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Entropic measures in propagating quantum microwaves — •Robert Neagu[1,2], Kirill G. Fedorov[1,2], Stefan Pogorzalek[1,2], Qi-Ming Chen[1,2], Michael Fischer[1,2,3], Michael Renger[1,2], 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

Classical information theory is a useful tool to describe the communication, storage, and processing of classical information by exploiting the Shannon entropy. In quantum information theory, similar tasks can be achieved for quantum system by utilizing the von Neumann entropy. Furthermore, quantum correlations lead to additional intriguing effects which can be utilized in various protocols. We experimentally investigate two-mode squeezed (TMS) microwave states as a source of such nonclassical correlations and characterize the latter in terms of different entropic measures. Additionally, we realize a fundamental quantum communication protocol by employing the TMS states and a feedforward. Finally, we relate this quantum communication protocol to an extension of the one-time pad to the quantum regime and investigate the security of the protocol using entropic measures.

We acknowledge support by the German Research Foundation through FE 1564/1-1 and the Excellence Cluster MCQST, the Elite Network of Bavaria through the program ExQM, and the European Union via the Quantum Flagship project QMiCS (Grant No 820505).