TT 5: Poster Session: Superconductivity

Time: Monday 13:30–16:00 Location: P

TT 5.1 Mon 13:30 P

Proximity effects of superconducting Nb thin films on chiral magnetic substrates — •Julius Grefe[1], Rodrigo de Vasconcellos Lourenço[2], Philip Schröder[1], Jannis Willwater[1], Mauricio de Melo[3], Jochen Litterst[1], Stefan Süllow[1], and Dirk Menzel[1] — [1]Institut für Physik der Kondensierten Materie, TU Braunschweig, Germany — [2]Institut für Angewandte Physik, TU Braunschweig, Germany — [3]Departamento de Física, Universidade Estadual de Maringá, Brazil

Superconducting spin valves consisting only of a single magnetic layer and a thin superconducting film promise simple and compact devices in comparison to established GMR systems. Theory has suggested that the critical temperature T_C of a superconductor can be controlled via the proximity effect with a magnetic system exhibiting a non-collinear spin structure [1]. MnSi being a member of the noncentrosymmetric B20 structure shows helimagnetic spin order below $T_N = 29.5$ K and $B_{C1} = 100$ mT. In the related system $Fe_{1-x}Co_xSi$ the Néel-temperature can be tuned in a range of 0 K - 55 K by variation of the Co concentration. Superconducting Nb thin films have been deposited by molecular beam epitaxy on oriented monocrystalline substrates grown by the Triarc-Czochralski method. The surface quality of the substrates and the Nb films has been investigated by atomic force microscopy resulting in a surface roughness of approximately 2 nm.

[1] N. G. Pugach et al., Appl. Phys. Lett. **111**, 162601 (2017)

TT 5.2 Mon 13:30 P

Substrate enhanced superconductivity in layered materials — •Yann in 't Veld[1], Roelof Groenewald[2], Jan Berges[3], Stephan Haas[2], Mikhail Katsnelson[1], Tim Wehling[3], Ryotaro Arita[4], and Malte Rösner[1] — [1]Radboud University, Nijmegen, The Netherlands — [2]University of Southern Calidornia, Los Angeles, USA — [3]Universität Bremen, Bremen, Germany — [4]University of Tokyo, Tokyo, Japan

External dielectric screening can be used to efficiently tune the Coulomb interaction and plasmonic excitations in layered materials. At the same time, two-dimensional plasmons couple strongly to electrons due to their gapless square-root-like dispersion, which renders them particularly interesting for tunable superconductivity in layered materials. Here, we extend density functional theory for superconductors (SC-DFT) to account for both the full dynamic Coulomb interaction and phonon contributions in two dimensions. We apply this scheme to monolayer MoS_2 and find that external screening indeed strongly enhances the superconducting critical temperature in the low-doping regime.

TT 5.3 Mon 13:30 P

Relativistic first principles theory of Yu–Shiba–Rusinov states: Mn dimers on Nb(110) — •Bendegúz Nyári[1], András Lászlóffy[2], László Szunyogh[1], and Balázs Újfalussy[2] — [1]Budapest University of Technology and Economics, Budapest, Hungary — [2]Wigner RCP, ELKH, Budapest, Hungary

The local magnetic moments of magnetic impurities at superconducting surfaces break the Cooper pairs leading to the formation of localized bound states within the superconducting gap, called as Yu–Shina–Rusinov (YSR) states. In the present work we introduce an *ab initio* theory based on the Green's function embedding technique within the Korringa–Kohn-Rostoker method to solve the Bogoliubov–de Gennes equations for the impurities. We present a detailed study of a Mn adatom and various Mn dimers at the surface of Nb(110), as the building blocks of atomic chains expected to host Majorana zero modes. From the calculated local density of states (LDOS) the spatial distribution of the YSR states is determined and compared with scanning tunneling spectroscopy (STS) measurements. The dimers are calculated in several geometric and magnetic configurations, while also the effect of the spin-orbit coupling (SOC) is investigated. We also study the effect of a relative angle between the atomic spins on the YSR states, where we find that for certain values a zero bias peak can exist in some dimer geometries.

TT 5.4 Mon 13:30 P

Development of an ab initio Bogoliubov-de Gennes method with applications to Nb(110) — •Philipp Rüssmann and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany

Ab initio calculations based on density functional theory (DFT) play a major role in understanding and improving quantum materials. Recently, material platforms for topological superconductivity have attracted a lot of attention. Typically materials require a combination of topological insulator, superconductor and magnetic materials and are promising candidates for the realization of Majorana-based qubits.

In this work we present the Bogoliubov-de Gennes extension of the JuKKR code that is based on the all-electron full-potential relativistic Korringa-Kohn-Rostoker Green-function method (https://jukkr.fz-juelich.de). We demonstrate the features of our code using bulk Nb and Nb(110) surfaces as examples, discussing the importance of spin-orbit coupling and showing calculations of the superconducting gap through the layers of thin films of Nb(110). These calculations establish the computational technology that opens the doors to studying the interfaces of superconductors and topological materials and gain insights into the proximity effect and the interplay of the electronic structure in quantum materials from first-principles calculations.

We acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – Cluster of Excellence Matter and Light for Quantum Computing (ML4Q) EXC 2004/1 – 390534769.

TT 5.5 Mon 13:30 P

Impurities in inhomogeneous superconductors from Density Functional Theory — •David Antognini Silva, Philipp Rüssmann, and Stefan Blügel — Peter Grünberg Institute and Institute for Advanced Simulation, FZ Jülich and JARA, 52425 Jülich, Germany

As impurities in a given material can change the electronic properties of the pristine material and give rise to new unique behaviors, their study is crucial in material science. Very timely examples are impurities, atomic chains or nanostructures in superconductor heterostructures [1] where these defects can be instrumental to in-gap states or *e.g.* identifying Majorana modes in Yu-Shiba-Rusinov chains [2]. The relativistic full-potential Korringa-Kohn-Rostoker Green function (KKR-GF) method, used in the Density Functional Theory (DFT) framework, is particularly suited to perfectly embed impurities in materials. We extend the JuKKR code (https://jukkr.fz-juelich.de) by the Bogoliubov-de Gennes (BdG) formalism to treat inhomogeneous superconductors. In this poster we present an extension of the implementation to the impurity problem and present first results of magnetic impurities on superconductors.

This work was funded by the Deutsche Forschungsgemeinschaft (DFG) under Germany's Excellence Strategy - Cluster of Excellence Matter and Light for Quantum Computing (ML4Q) EXC 2004/1 - 390534769.

[1] Z. Yan, Phys. Rev. B **100**, 205406 (2019)
[2] L. Schneider *et al.*, Nat. Phys. (2021)

TT 5.6 Mon 13:30 P

Relativistic and non-relativistic Ginzburg-Landau models in two-dimensional curved films — •Igor Bogush[1,2] and Vladimir M. Fomin[2,3] — [1]Theoretical Physics, Faculty of Physics, Lomonosov Moscow State University, Leninskie Gory, Moscow, 119991, Russia — [2]Moldova State University, Chisinau MD-2009, Republic of Moldova — [3]Institute for Integrative Nanosciences, Leibniz IFW Dresden, D-01069 Dresden, Germany

Superconductor nanoarchitectures, including self-rolled films, are highly promising for advancements in nano- and meso-scale devices. Superconductivity strongly depends on the external magnetic field applied to thin films. Managing the profile of the magnetic field is a challenging technical problem. To get around this problem, one can give a complex shape to the film such that the normal component of the magnetic field has the desired profile. We solve relativistic and non-relativistic time-dependent Ginzburg-Landau models for two-dimensional curved manifolds by applying the tool of General Relativity, differential geometry. The arbitrary geometry opens the way to manipulate the effective normal component of the magnetic field to control the regions with normal or superconducting state and, as a consequence, to manage the superconducting properties of films, transitions between vortex-chain and phase-slip regimes. We describe numerically nontrivial vortex and phase-slip dynamics and topological transitions in cylindric films and membranes with a deep well.

The present work has been supported by the DFG project #FO 956/6-1 and by the COST Action CA16218 (NANOCOHYBRI).

TT 5.7 Mon 13:30 P

^{125}Te NMR studies of 1T-MoTe$_2$ under pressure -Towards superconductivity mediated by Weyl Fermions — •Takuto Fujii[1], Hiroshi Yasuoka[1], M.O. Ajeesh[1], Marcus Schmidt[1], Takeshi Mito[2], Michael Nicklas[1], Claudia Felser[1], Andrew Mackenzie[1], and Michael Baenitz[1] — [1]MPI for Chemical Physics of Solids, D-01187 Dresden, Germany — [2]School of Science, University of Hyogo Hyogo, Japan

1T-MoTe$_2$ is claimed to be one of the type-II Weyl semimetals, and has attracted much attention due to its exotic physical properties stemming from the topological (line nodal) band structure where the electron and hole pockets are touching at the E_F. One of the most preeminent features is the occurrence of superconductivity which is stabilized under pressure up to around T_c=7K. In order to understand the superconductivity, we have employed the ^{125}Te NMR technique under pressure (up to 2.17 GPa) and measured the NMR line profile and T_1, determining the Knight shift and low lying magnetic excitations. Using the same NMR tuning circuit, we have also measured the pressure and temperature (T) dependences of the resonant frequency, and extracted the T-dependence of the H_{c2}. The results are not in accord with simple WHH model, but are well fit to an empilical formula, $H_{c2}(T) = H_{c2}(0)[1-\frac{T}{T_c}]^{\alpha}$. By doing this, we obtained $H_{c2}(0)$=1.50T, T_c= 3.81K, and α=1.1 at 2.17 GPa. A superconducting signature has been observed in $K(T)$ and $1/T_1T(T)$ at around 2.5 K (2.17GPa). We present detailed NMR results and try to explore the superconductivity from the microscopic point of view.

TT 5.8 Mon 13:30 P

Critical current suppression via electrostatic field effect in epitaxial grown nanodevice — •Sohaila Z Noby, Roman Hartmann, Elke Scheer, and Angelo Di Bernardo — Physics department, Universität Konstanz, Germany

Quantum devices based on superconducting materials provide various technological applications, such as e.g. current limiters, electronic filters, routers, digital receivers, and photon detectors. Superconductors demonstrate unconventional pronounced performance under their critical temperatures in industrial electronic circuits in a comparison with semiconductors. However, controlling the electrical conductivity in nanoscale semiconductor devices considers as one of the cornerstones of such technology. This is attributed to the week screening effect, which allows the penetration of the electric field into a lower charge density semiconductor material. Although that phenomenon was believed that can not be realized in superconductor materials due to their higher charge density, which eliminate the field effect on the surface. Recent studies show that the strong electrostatic field can manipulate superconductor characteristics, which their origin still controversial between scientists. This effect has been seen in suppression of the critical current via the application of higher electrostatic field in different material. One such example is niobium (Nb), a well-established suitable elemental superconductor in circuit operation due to its highest critical temperature (~9.2K). In our study the mechanism of field effect, which introduced as a gate voltage, is being studied in a four-terminal nanowire device based on epitaxial grown Nb material.

TT 5.9 Mon 13:30 P

Unconventional Dynamical Scaling close to a Nematic Quantum Critical Point in FeSe$_{0.89}$S$_{0.11}$ — •Pascal Reiss[1,2], David Graf[3], Amir-Abbas Haghighirad[4], Thomas Vojta[5], and Amalia Coldea[1] — [1]Clarendon Laboratory, University of Oxford, UK — [2]MPI-FKF, Stuttgart, Germany — [3]NHMFL, Tallahassee, USA — [4]IQMT, Karlsruhe Institute of Technology, Germany — [5]Department of Physics, Missouri University of Science and Technology, USA

In the vicinity of quantum critical points, the interplay between electronic and structural order can lead to new and unconventional phases. Of particular interest is the electronic nematic order, with its predicted long-range interactions mediated through the lattices shear modes. Here, we first review the nature of the nematic QCP in FeSe$_{0.89}$S$_{0.11}$ under hydrostatic pressure. Then, we will demonstrate that the magnetoresistivity close to the QCP obeys a scaling relation over two decades in temperature with diverging critical exponents at low temperatures, in stark contrast to the usual ansatz using fixed exponents. We discuss our findings in the context of disconnected static and dynamic quantum fluctuations, a coupling between electronic and phononic modes, and topological changes of the Fermi surface. These lead to the emergence of an atypical non-zero energy scale at the QCP which strongly affects superconductivity. arXiv:2103.07991

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TT 5.10 Mon 13:30 P

Growth and characterisation of substitution variants of LaOFeAs single crystals — •Felix Anger[1], Christian Blum[1], Anja Wolter-Giraud[1], Sebastian Gass[1], Hans-Joachim Grafe[1], Saicharan Aswartham[1], Sabine Wurmehl[1,2], and Bernd Büchner[1,2] — [1]Leibniz Institute for Solid State and Materials Research, IFW, Dresden, Germany — [2]Institute of Solid State and Materials Physics, TU Dresden, Dresden, Germany

Facetted LaOFeAs single crystals with considerably growth in the crystallographic c direction were first reported by R. Kappenberger et al. [1]. The growth process takes place via diffusion in solid state, the so-called Solid State Crystal Growth (SSCG) method. The single crystals are grown from a polycrystalline matrix by the introduction of NaAs as a liquid phase to aid the crystallization process.1 Here, we present some additional experimental findings regarding growth temperature, initial microstructure and the role of NaAs for the growth. Furthermore, we are aiming to grow novel series of crystals of substitution variants as, e.g., Co-doped SmOFeAs and LaO1-xFxFeAs. The crystals were characterized regarding their composition, structure and magnetic properties.

[1] R. Kappenberger et al., Journal of Crystal Growth 483, 9-15 (2018)

TT 5.11 Mon 13:30 P

Anomalous softening of phonon-dispersion in the underdoped cuprate superconductors — •Saheli Sarkar[1,2], Maxence Grandadam[1], and Catherine Pépin[1] — [1]Institut de Physique Théorique, Gif-sur Yvette, France — [2]Current affiliation: Institut für QuantenMaterialien und Technologien, Karlsruhe Institute of Technology, Karlsruhe, Germany

Cuprate superconductors possess a complex phase diagram with various other phases like charge density wave (CDW) in the underdoped region. Interestingly, the CDW order has become fundamentally important due to growing evidences of its close relation to the pseudo-gap phase. One leading approach to unravel the relation, is to study the phonon-spectrum which couples to electronic degrees of freedom, thus leaving fingerprints associated with the electronic-structure. Several experiments have observed a softening of the phonon-dispersion in the underdoped cuprates at the CDW ordering wave vector, but only below the superconducting transition temperature. The phonon-softening in cuprates is considered ‘anomalous’ since it is in sharp contrast to the situation in metallic systems where such softening occurs for temperatures below the onset of CDW order. By employing a perturbative approach, we find that a complex interplay among the CDW order, superconductivity and a finite quasi-particle lifetime arising from an unusually connected thermal fluctuations of these orders, can explain the ‘anomalous’ nature of the phonon-softening, also giving good accounts for other features observed in recent inelastic-Xray scattering experiments.

TT 5.12 Mon 13:30 P

Enhanced Higgs oscillations in unconventional superconductors — •Matteo Puviani[1], Dirk Manske[1], and Rudi Hackl[2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Walther Meissner Institut, Bayerische Akademie der Wissenschaften, Garching, Germany

In superconductors the Anderson-Higgs mechanism allows for the existence of a collective amplitude (Higgs) mode which can couple to eV-light mainly in a non-linear Raman-like process. While the observed properties of the Higgs mode in clean, conventional, isotropic superconductors can be explained within a BCS picture, strong interaction effects with other modes in anisotropic d-wave superconductors are likely. In our work we have calculated the Raman contribution of the Higgs mode from a new perspective, including many-body Higgs oscillations effects and their consequences in steady-state Raman spectroscopy [1]. This solves the long-standing problem of the A1g symmetry Raman spectrum in d-wave superconductors [2]. In order to test our theory, we predicted the presence of measurable characteristic oscillations in THz quench-optical probe time-dependent reflectivity experiments[1,3].

[1] M. Puviani et al., arxiv: 2012.01922
[2] T.P. Devereaux et al., Phys. Rev. Lett. 72, 396 (1994)
[3] S. Nakamura et al., Phys. Rev. Lett. 122, 257001 (2019)

TT 5.13 Mon 13:30 P

Higgs mode mediated enhancement of interlayer transport in high-T_c cuprate superconductors — •Guido Homann[1], Jayson G. Cosme[1,2,3], Junichi Okamoto[4,5], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [3]National Institute of Physics, University of the Philippines, Diliman, Philippines — [4]Institute of Physics, University of Freiburg, Freiburg, Germany — [5]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Freiburg, Germany

We put forth a mechanism for enhancing the interlayer transport in cuprate superconductors, by optically driving plasmonic excitations along the c axis with a frequency that is blue-detuned from the Higgs frequency [1]. The plasmonic excitations induce a collective oscillation of the Higgs field which induces a parametric enhancement of the superconducting response, as we demonstrate with a minimal analytical model. Furthermore, we perform simulations of a particle-hole symmetric $U(1)$ lattice gauge theory and find good agreement with our analytical prediction. Our numerical results show that the Higgs mode mediated enhancement can be larger than 50%. We investigate how the renormalization of the interlayer coupling depends on the parameters of the optical field and discuss possible challenges brought by damping.

[1] G. Homann, J. G. Cosme, J. Okamoto, L. Mathey, Phys. Rev. B 103, 224503 (2021)

TT 5.14 Mon 13:30 P

Optimization of Sr_2RuO_4 thin films grown by pulsed laser deposition — •Priyana Puliyappara Babu, Roman Hartmann, Alfredo Spuri, Sohaila Zaghloul Nabi Mohammed, Elke Scheer, and Angelo Di Bernardo — University of Konstanz, 78457 Konstanz, Germany

Since its discovery in 1994, $Sr_2RuO_4$4 has been the subject of intensive studies aiming at shedding light on the nature of its superconducting order parameter (OP). Despite earlier reports suggesting an unconventional nature of the Sr_2RuO_4 superconductivity, conflicting results have been recently reported and a definitive conclusion about the superconducting OP symmetry has not been yet achieved. To address some of the open questions, it is crucial to fabricate superconducting devices based on high-quality superconducting thin films of Sr_2RuO_4. However, this task has proven challenging due the sensitivity of Sr_2RuO_4 to disorder and impurities. We have carried out a systematic study to optimize the transport properties of Sr_2RuO_4 thin films grown by pulsed laser deposition using Sr_3RuO_7 single crystals as the material source. Thin films with very low density of defects, high residual resistivity ratio (> 20) and fully metallic down to low temperatures have been grown. The growth parameters that can be further optimized to get fully superconducting thin films have also been identified.

TT 5.15 Mon 13:30 P

Spin torque in a Josephson junction between two superconducting magnetic impurity states — •Fabian Ziesel[1], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Superconducting tunneling between spin-polarized Yu-Shiba-Rusinov (YSR) impurity states can be realized using a functionalized mK-STM [1], which can be further developed as a local probe of electronic spins for spintronics applications. Here, we consider a Josephson junction containing two magnetic impurities and show that the Josephson current is spin-dependent and accompanied by a spin torque. The torque acts to align the two impurities either parallel or anti-parallel, depending on the parity of YSR states occupation.

Using standard Green's functions techniques, we derive the spin-torque and spin-current as function of the superconducting phase difference ϕ and the relative angle θ between the impurity spins, modeled as classical magnets. Our results are also relevant for recent realizations of double quantum dot superconducting junctions with YSR states [2]. Finally, we provide a discussion on spin dynamics with a possible relevance to spin chains that show topological superconductivity.

[1] H. Huang *et al.*, Nat. Phys. **16**, 1227 (2020)
[2] J.C.E. Saldaña *et al.*, Phys. Rev. Lett. **121**, 257701 (2018)

TT 5.16 Mon 13:30 P

Fluxoid dynamics in high impedance long Josephson junctions — •Micha Wildermuth[1], Lukas Powalla[1], Jan Nicolas Voss[1], Yannick Schön[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2,3] — [1]Institute of Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]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 soliton physics and allows to study highly nonlinear effects on a mesoscopic scale. We experimentally study the characteristics of a Josephson junction with electrodes having a large kinetic inductance fraction which provides an additional degree of freedom. The London penetration depth exceeds the stack thickness which results in an incomplete screening of magnetic fields and in fluxoids with an altered shape. We present transport measurements of long Josephson junctions with electrodes made from disordered oxidized aluminum showing current steps with and without external magnetic fields and the IV-characteristics resemble the Fiske and zero-field steps. Magnetic field dependent measurements also show a very similar behavior to conventional long Josephson junctions.

TT 5.17 Mon 13:30 P

Exponential speedup of incoherent tunneling via dissipation — •Dominik Maile[1,2,4], Sabine Andergassen[2], Wolfgang Belzig[1], and Gianluca Rastelli[3] — [1]Fachbereich Physik, Universität Konstanz — [2]Institut für Theoretische Physik and Center for Quantum Science, Universität Tübingen — [3]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento — [4]Institut für komplexe Quantensysteme, Universität Ulm

We study the escape rate of a particle in a metastable potential in the presence of a dissipative bath coupled to the momentum of the particle. Using the semiclassical bounce technique, we find that this rate is exponentially enhanced. In particular, the influence of momentum dissipation depends on the slope of the barrier that the particle is tunneling through. We investigate also the influence of dissipative baths coupled to the position, and to the momentum of the particle, respectively. In this case the rate exhibits a nonmonotonic behavior as a function of the dissipative coupling strengths. Remarkably, even in the presence of position dissipation, momentum dissipation can enhance exponentially the escape rate in a large range of the parameter space. Our theoretical findings can be directly tested in superconducting quantum circuits in which dissipative position and momentum interactions translate to dissipative phase or charge couplings. In particular, momentum/charge dissipation can be readily implemented simply using capacitances and resistances.

TT 5.18 Mon 13:30 P

Electron cooling by phonons in mesoscopic superconducting systems — •Danilo Nikolic[1], Denis M. Basko[2], and Wolfgang Belzig[1] — [1]Fachbereich Physik, Universität Konstanz, D-78467 Konstanz, Germany — [2]Université Grenoble Alpes and CNRS, LPMMC, 25 Rue des Martyrs, 38042 Grenoble, France

We investigate the electron-phonon cooling power in disordered electronic systems with a special focus on mesoscopic superconducting proximity structures. Employing the quasiclassical Keldysh Green's function method, we obtain a general expression for the cooling power perturbative in the electron-phonon coupling but valid for arbitrary electronic systems out of equilibrium. We apply our theory to several disordered electronic systems valid for an arbitrary relation between the thermal phonon wavelength and the electronic mean-free path due to impurity scattering. In addition to recovering the known results for bulk normal metals and BCS superconductors, we consider two experimentally relevant geometries of superconductor-normal-metal proximity contacts. Both structures feature a significantly suppressed cooling power at low temperatures related to the existence of a minigap in the quasiparticle spectrum. This improved isolation low cooling feature in combination with the high tunability makes such structures highly promising candidates for quantum calorimetry.

This project has received funding from the EU Horizon 2020 program (Marie Sklodowska-Curie action QuESTech 766025).

[1] D. Nikolić, D. M. Basko, W. Belzig, Phys. Rev. B **102**, 214514 (2020)

TT 5.19 Mon 13:30 P

Charge dynamics in quantum-circuit refrigeration: thermalization and microwave gain — •Hao Hsu and Gianluigi Catelani — JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, Jülich, Germany

Recently, a quantum circuit refrigerator (QCR) consisting of a voltage biased superconductor-insulator-normal metal-insulator-superconductor (SINIS) tunnel junction has been experimentally demonstrated to cool superconducting resonators [1] and theoretically predicted to reset superconducting qubits [2] fast and accurately. Here we derive a master equation for a QCR-two level system dynamics. We find that starting with a steady state charge distribution on the normal-metal island, thanks to slower charge relaxation rate than the bare qubit decoherence rate at the off mode and the QCR-induced qubit decay rate, it always remains in its steady state, thus validating the former-presented theory [2, 3]. Replacing the normal-metal island with a quantum dot, we find a voltage regime where the photon-assisted tunnelings serve as a pumping mechanism. Also using the master equation approach, we investigate the possible microwave gain application by coupling the quantum dot QCR to a resonator.

[1] K. Y. Tan et.al., Nat. Commun. 8 15189 (2017)
[2] H. Hsu et.al., Phys. Rev. B 101, 235422 (2020)
[3] M. Silveri et.al., Phys. Rev. B 96, 094524 (2017)

TT 5.20 Mon 13:30 P

Heat transport in quantum overdamped systems — •sadeq s. kadijani, thomas l. schmidt, massimiliano esposito, and nahuel freitas — Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg, Luxembourg

In classical and statistical physics, the overdamped limit of systems interacting with their environments is a very useful approximation allowing for the simplification of the Fokker-Plank equation in phase space to the Smoluchowski equation for the position variable alone. For quantum systems, the same limit leads to the quantum version of the Smoluchowski equation for systems in thermal equilibrium with only one thermal bath. However, to study the stochastic and quantum thermodynamics, one needs to deal with systems in a nonequilibrium situation where the quantum Smoluchowski equation is not valid anymore.

We are interested in studying the properties of the heat current in the overdamped limit where dissipation dominates. We obtain an analytical expression for the heat current between two overdamped quantum oscillators interacting with local thermal baths at different temperatures. The total heat current is split into classical and quantum contributions. We show how to evaluate both contributions by taking advantage of the timescale separation associated with the overdamped regime and without assuming the usual weak-coupling and Markovian approximations. We find that nontrivial quantum corrections survive even when the temperatures are high compared to the frequency scale relevant for the overdamped dynamics of the system.

TT 5.21 Mon 13:30 P

Emission of photon multiplets by a dc-biased superconducting circuit — •Björn Kubala[1,2], Gerbold Menard[3], Ambroise Peugeot[3], Ciprian Padurariu[2], Chloe Rolland[3], Zubair Iftikhar[3], Yuri Mukharsky[3], Carles Altimiras[3], Helene le Sueur[3], Philippe Joyez[3], Denis Vion[3], Patrice Roche[3], Daniel Esteve[3], Joachim Ankerhold[2], and Fabien Portier[3] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]ICQ and IQST, Ulm University, Germany — [3]SPEC, CEA Paris-Saclay, France

We show experimentally that a dc-biased Josephson junction in series with a high-impedance microwave resonator can emit up to $k = 6$ photons simultaneously for each Cooper pair tunneling through the junction. Our resonator is made of a simple micro-fabricated spiral coil that resonates at 4.4 GHz and reaches a 1.97 kΩ characteristic impedance, corresponding to an effective fine-structure constant, $\alpha \sim 1$. Measuring the second order correlation function of the emission from the resonator allows computing the Fano factor F of the emitted photons, found to coincide with the naive prediction $F = k$ in the weak driving regime. At higher emission, the feedback of the population of the resonator on the emission dynamics yields a non-monotonous behavior, hallmark of parametric transitions. Results are found in quantitative agreement with our theoretical predictions. This simple scheme highlights the ability of superconducting devices operating in the microwave domain to reach strong-coupling regimes of matter-light coupling inaccessible to conventional quantum optics experiments in the visible domain.

TT 5.22 Mon 13:30 P

Microwave photonics in High Kinetic Inductance Microstrip Networks — •Niklas Gaiser[1], Samuel Goldstein[2], Guy Pardo[2], Naftali Kirsh[2], Ciprian Padurariu[1], Björn Kubala[1,3], Nadav Katz[2], and Joachim Ankerhold[1] — [1]ICQ and IQST, University of Ulm, Ulm, Germany — [2]The Racah Institute of Physics, The Hebrew University of Jerusalem, Israel — [3]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Microwave photonics based on superconducting circuits is a promising candidate for many quantum-technological applications. Progress towards compact integrated photonics devices in the microwave regime, however, is constrained by their long wavelengths.

Here, we discuss a solution to these difficulties via compact networks of high-kinetic inductance microstrip waveguides and coupling wires with strongly reduced phase velocities experimentally realized in [1]. We describe, how the Kirchhoff equations of a periodic network map to a tight-binding model, which allows a description in term of Bloch waves and band structures, to explain experimental features. Furthermore, we present first steps towards exploiting versatility and unique properties of this new platform - compactness and reduced speed of light, strong nonlinear features, and band-structure design - to develop fundamental building blocks for integrated microwave photonics for technology applications and for exploring fundamental physics in such diverse areas as non-linear waves and topological lattice phases.

[1] S. Goldstein, G. Pardo, N. Kirsh, N. Gaiser, C. Padurariu, B. Kubala, J. Ankerhold, and N. Katz, arXiv:2106.15951

TT 5.23 Mon 13:30 P

Quantum Locking and Synchronization in Josephson Photonics Devices — •Florian Höhe[1], Lukas Danner[1,2], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Phase stability is an important characteristic of radiation sources. For quantum sources exploitation and characterization of many quantum properties, such as entanglement and squeezing, may be hampered by phase instability. Josephson photonics devices, where microwave radiation is created by inelastic Cooper pair tunneling across a *dc-biased* Josephson junction connected in-series with a microwave resonator are particularly vulnerable lacking the reference phase provided by an ac-drive. To counter this issue, sophisticated measurement schemes have been used in [1] to prove entanglement, while in [2] a weak ac-signal was put in to lock phase and frequency of the emission.

Here, we extend a recent classical theory [3] to describe locking and the synchronization of several Josephson-photonics devices to the quantum regime. Our description relies on linking the current shot-noise at a residual in-series resistor, which is crucial for phase diffusion, to the Full Counting Statistics of emitted radiation. From this full numerical description, phenomenological Adler-type equations for locking are derived to analyze quantum locking and synchronization.

[1] A. Peugeot et al., Phys. Rev. X 11, 031008 (2021).
[2] M. C. Cassidy et al., Science 355, 939 (2017).
[3] L. Danner et al., arXiv:2105.02564 (see also contribution here).

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Injection locking and synchronization in Josephson photonics devices — •Lukas Danner[1,2], Ciprian Padurariu[2], Joachim Ankerhold[2], and Björn Kubala[1,2] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]ICQ and IQST, Ulm University, Ulm, Germany

Injection locking can stabilize a source of radiation, leading to an efficient suppression of noise-induced spectral broadening and therefore, to a narrow spectrum. The technique is well established in laser physics, where a phenomenological description due to Adler is usually sufficient. Recently, locking experiments were performed in Josephson photonics devices, where microwave radiation is created by inelastic Cooper pair tunneling across a dc-biased Josephson junction connected in-series with a microwave resonator. An in-depth theory of locking for such devices however is lacking.

Here, we study injection locking in a typical Josephson photonics device where the environment consists of a single mode cavity, operated in the classical regime [1]. We show that an in-series resistance, however small, is an important ingredient in describing self-sustained Josephson oscillations and enables the locking region. We derive a dynamical equation describing locking, similar to an Adler equation, from the specific circuit equations. Phase slips due to noise are also studied. The synchronization of two Josephson photonics devices can be described by the Kuramoto model. For an extension of this classical analysis to the quantum regime, see the contribution by F. Höhe.

[1] L. Danner et al., arXiv:2105.02564 (submitted to PRB).

TT 5.25 Mon 13:30 P

Characterization of harmonic modes and parasitic resonances in multi-mode superconducting coplanar resonators — •Cenk Beydeda, Konstantin Nikolaou, Marius Tochtermann, Nikolaj G. Ebensperger, Gabriele Untereiner, Ahmed Farag, Philipp Karl, Monika Ubl, Harald Giessen, Martin Dressel, and Marc Scheffler — Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany

Planar superconducting microwave transmission line resonators can be operated at multiple harmonic resonance frequencies, which allows covering wide spectral regimes with high sensitivity, as is desired e.g. for cryogenic microwave spectroscopy. A common complication of such experiments is the presence of undesired "spurious" additional resonances. Identifying the nature of individual resonances ("designed" vs. "spurious") can become challenging for higher frequencies or if elements with unknown material properties are included, as is common for microwave spectroscopy. Here various experimental strategies are discussed to distinguish designed and spurious modes in a broad frequency range up to 20 GHz. These strategies include tracking resonance evolution as a function of temperature, magnetic field, and microwave power. It is also demonstrated that applying minute amounts of dielectric or ESR(electron spin resonance)-active materials on the resonator lead to characteristic signatures in the various resonance modes, which depend on the local strength of the electric or magnetic microwave fields.

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Josephson Optomechanics — •Surangana Sen Gupta[1], Björn Kubala[1,2], Ciprian Padurariu[1], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Optomechanics at optical frequencies typically uses sources of light in a classical state, e.g. coherent states from lasers, to control mechanical vibrations. Cavity optomechanics can also be realised in the microwave regime using superconducting cavities and Josephson junctions. Inelastic tunneling in a Josephson junction biased by a dc-voltage can provide a bright source of quantum states of light, that can then be used for optomechanics. Experiments [1] have shown that the nonlinearity of Josephson junctions allows for various photon creation processes including single photon and multi-photon resonances.

Here, we theoretically investigate an optomechanical system consisting of a single-mode superconducting cavity, which is parametrically driven by a dc-biased Josephson junction at the two-photon resonance, and a mechanical resonator. The optomechanical coupling is treated in the spirit of mean field where the cavity is deep in the quantum regime, while the mechanics is considered semi-classical. We show that squeezed microwaves lead to regimes of heating and cooling for the mechanics and identify their signatures in the spectrum. We contrast these signatures with those of conventional optomechanics.

[1] M. Hofheinz, F. Portier, Q. Baudouin, P. Joyez, D. Vion, P. Bertet, P. Roche, D. Esteve, Phys. Rev. Lett. **106**, 217005 (2011)

TT 5.27 Mon 13:30 P

Transmission spectra of the driven, dissipative Rabi model in the USC regime — •Luca Magazzu[1], Pol Forn-Diaz[2,3,4], and Milena Grifoni[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institut de Física d'Altes Energies (IFAE) — [3]The Barcelona Institute of Science and Technology (BIST), Bellaterra (Barcelona) 08193, Spain — [4]Qilimanjaro Quantum Tech SL, Barcelona, Spain

We present theoretical transmission spectra of a strongly driven, damped, flux qubit coupled to a dissipative resonator in the ultrastrong coupling regime. Such a qubit-oscillator system, described within a dissipative Rabi model, constitutes the building block of super-conducting circuit QED platforms. The addition of a strong drive allows one to characterize the system properties and study novel phenomena, leading to a better understanding and control of the qubit-oscillator system. The calculated transmission of a weak probe field quantifies the response of the qubit, in frequency domain, under the influence of the quantized resonator and of the strong microwave drive. We find distinctive features of the entangled driven qubit-resonator spectrum, namely resonant features and avoided crossings, modified by the presence of the dissipative environment. The magnitude, positions, and broadening of these features are determined by the interplay among qubit-oscillator detuning, the strength of their coupling, the driving amplitude, and the interaction with the heat bath. This work establishes the theoretical basis for future experiments in the driven ultrastrong coupling regime.

[1] arXiv:2104.14490 (2021)

TT 5.28 Mon 13:30 P

Probing the Density of States of Defects in Superconduncting Flux Qubits — •Benedikt Berlitz[1], Alexander Neumann[1], Alexey V. Ustinov[1,2,3], and Jürgen Lisenfeld[1] — [1]Physikalisches Institut Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany) — [2]National University of Science and Technology MISIS, Moscow, Russia — [3]Russian Quantum Center, Skolkovo, Moscow, Russia

Material defects forming two-level-systems (TLS) present a source of decoherence and unwanted degrees of freedom in superconducting quantum systems. Current theoretical models make different assumptions about the frequency dependence of the TLS' density-of-states (DOS). We intend to measure the TLS' DOS in a wide frequency range, spanning ~0.1 to 20 GHz, using widely tunable flux-qubits specifically designed as TLS-scanners. Measuring the DOS will enhance our understanding of the underlying physics of TLS in amorphous materials.

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Two-qubit gates between two transmons via parametrically driven coupling circuits — •Miriam Resch[1,2], Aneirin J. Baker[3], and Michael J. Hartmann[1,4] — [1]Physics Department, Friedrich-Alexander-University Erlangen Nürnberg, Germany — [2]ICQ and IQST, Ulm University, Germany — [3]Institute of Photonics and Quantum Sciences, Heriot-Watt University Edinburgh EH14 4AS, United Kingdom — [4]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

One important ingredient of quantum computation is the ability to implement gates that are efficient as well as precise to perform various operations on qubits. In the case of superconducting qubits, two-qubit gates can be implemented using a tunable coupler, where interaction terms in the Hamiltonian can be turned on and off. In this work we study the effective coupling of two transmon qubits through a coupler whose parameters are externally driven with a frequency ω_D. Depending on the drive frequency, the excitation number conserving interaction of an iSWAP gate, $\sigma_1^+\sigma_2^- + \sigma_1^-\sigma_2^+$, or the interaction of a bSWAP gate, $\sigma_1^+\sigma_2^+ + \sigma_1^-\sigma_2^-$, which does not conserve excitation numbers, can be created. Using an approach that considers the time dependent magnetic modulation of the coupler in a non-perturbative way, we find that the interaction of the bSWAP gate can be realized by driving the system with the average of the two qubit transition-frequencies. This result eliminates the demand for external drives at frequencies above 6 or 7 GHz for realizing interactions that break excitation number conservation and can thus realize bSWAP gates.

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Nuclear Spin Readout in a Cavity-Coupled Hybrid Quantum Dot-Donor System — •Jonas Mielke[1], Jason R. Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, Konstanz D-78457, Germany — [2]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

Nuclear spins show long coherence times and are well isolated from the environment, which are properties making them promising for quantum information applications. Here, we present a method for nuclear spin readout by probing the transmission of a microwave resonator. We consider a single electron in a silicon quantum dot-donor device interacting with a microwave resonator via the electric dipole coupling and subjected to a homogeneous magnetic field and a transverse magnetic field gradient. In our scenario, the electron spin interacts with a ^{31}P defect nuclear spin via the hyperfine interaction. We theoretically investigate the influence of the P nuclear spin state on the microwave transmission through the cavity and show that nuclear spin readout is feasible with current state-of-the-art devices. Moreover, we identify optimal readout points with strong signal contrast to facilitate the experimental implementation of nuclear spin readout.

TT 5.31 Mon 13:30 P

Bose condensation of squeezed light — •Klaus Morawetz — Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics-

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Light with an effective chemical potential and no mass is shown to possess a general phase-transition curve to Bose-Einstein condensation. This limiting density and temperature range is found by the diverging in-medium potential range of effective interaction. While usually the absorption and emission with Dye molecules is considered, here it is proposed that squeezing can create also such an effective chemical potential. The equivalence of squeezed light with a complex Bogoliubov transformation of interacting Bose system with finite lifetime is established with the help of which an effective gap is deduced. This gap phase creates a finite condensate in agreement with the general limiting density and temperature range. The phase diagram for condensation is presented due to squeezing and the appearance of two gaps is discussed.

[1] Phys. Rev. B 99 (2019) 205124

TT 5.32 Mon 13:30 P

Collisionless drag for a one-dimensional two-component Bose-Hubbard model — •Daniele Contessi[1,4], Donato Romito[2,3], Matteo Rizzi[4,5], and Alessio Recati[1,2] — [1]Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy — [2]INO-CNR BEC Center, 38123 Povo, Italy — [3]Mathematical Sciences, University of Southampton, Highfield, Southampton, SO17 1BJ, United Kingdom — [4]Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), 52425 Jülich, Germany — [5]Institute for Theoretical Physics, University of Cologne, D-50937 Köln, Germany

We theoretically investigate the elusive Andreev-Bashkin collisionless drag for a two-component one-dimensional Bose-Hubbard model on a ring. By means of Tensor Network algorithms, we calculate superfluid stiffness matrix as a function of the interactions and of the lattice filling. We focus on the region close to the so-called pair-superfluid phase, where we observe that the drag can become comparable with the total superfluid density. We elucidate the importance of the drag in determining the long-range behavior of the correlation functions and the spin speed of sound. In this way we are able to provide an expression for the spin Luttinger parameter K_S in terms of drag and the spin susceptibility. Our results are promising in view of implementing the system by using ultra-cold Bose mixtures trapped in deep optical lattices. Importantly the mesoscopicity of the system appears to favour a large drag, avoiding the Berezinskii-Kosterlitz-Thouless jump at the transition to the pair superfluid phase which would reduce the region where a large drag can be observed.