DY 36: Quantum Coherence and Quantum Information Systems (joint session TT/DY)

Time: Thursday 9:30–12:30 Location: H22

DY 36.1 Thu 9:30 H22

Design of a granular aluminum Fluxonium qubit in a coplanar waveguide architecture — •Patrick Paluch, Martin Spiecker, Nicolas Gosling, Alexandru Ionita, Simon Günzler, Daria Gusenkova, Dennis Rieger, Ivan Takmakov, Francesco Valenti, Patrick Winkel, Wolfgang Wernsdorfer, and Ioan-Mihai Pop — Karlsruhe Institute of Technology

Fluxonium qubits are often embedded in rectangular waveguides which dilute the electric field and favor high coherence [1,2]. However, this configuration complicates in-situ flux gates and multi-qubit experiments. Here, we present a fluxonium qubit placed in a coplanar waveguide architecture with an integrated fast-flux coil, surrounded by a normal metal ground plane. The superinductor is made out of granular aluminum (grAl) [3] and the use of a comparably large silver ground plane potentially decreases the number of quasiparticles in the system via phonon trapping [4].

[1] Pop et al., Nature 508, 369 (2014)
[2] Somoroff et al., arXiv:2103.08578 (2021)
[3] Grünhaupt et al., Nat. Mater. 18, 816 (2019)
[4] Henriques et al., Appl. Phys. Lett. 115, 212601 (2019)

DY 36.2 Thu 9:45 H22

Gralmonium: Granular aluminum nano-junction Fluxonium qubit — •Dennis Rieger, Simon Günzler, Martin Spiecker, Patrick Paluch, Patrick Winkel, Lothar Hahn, Judith K. Hohmann, Andreas Bacher, Wolfgang Wernsdorfer, and Ioan M. Pop — Karlsruhe Institute of Technology, Germany

Mesoscopic Josephson junctions (JJs), consisting of overlapping superconducting electrodes separated by a nanometer thin oxide layer, provide a precious source of nonlinearity for superconducting quantum circuits and are at the heart of state-of-the-art qubits, such as the transmon and fluxonium. Here, we show that in a fluxonium qubit the role of the JJ can also be played by a lithographically defined, self-structured granular aluminum (grAl) nano-junction: a superconductor-insulator-superconductor (SIS) JJ obtained in a single layer, zero-angle evaporation. The measured spectrum of the resulting qubit, which we nickname gralmonium, is indistinguishable from the one of a standard fluxonium qubit. Remarkably, the lack of a mesoscopic parallel plate capacitor gives rise to an intrinsically large grAl nano-junction charging energy in the range of $10 - 100\,\mathrm{GHz}$, comparable to its Josephson energy E_J. We measure average energy relaxation times of $T_1 = 10\,\mu\mathrm{s}$ and Hahn echo coherence times of $T_2^{\mathrm{echo}} = 9\mu\mathrm{s}$. The exponential sensitivity of the gralmonium to the E_J of the grAl nano-junction provides a highly susceptible detector. Indeed, we observe spontaneous jumps of the value of E_J on timescales from milliseconds to days, which offer a powerful diagnostics tool for microscopic defects in superconducting materials.

DY 36.3 Thu 10:00 H22

Quantum dynamics of disordered arrays of interacting superconducting qubits: Signatures of quantum collective states — Mikhail Fistul, •Oliver Neyenhuys, Antonia Bocaz, and Ilya Eremin — Theoretische Physik III, Ruhr-Universität Bochum, Bochum 44801, Germany

We study theoretically the collective quantum dynamics occurring in various interacting superconducting qubits arrays (SQAs) in the presence of a spread of individual qubit frequencies. The interaction is provided by mutual inductive coupling between adjacent qubits (short-range Ising interaction) or inductive coupling to a low-dissipative resonator (long-range exchange interaction). In the absence of interaction the Fourier transform of the temporal correlation function of the total polarization (z-projection of the total spin), i.e. the dynamic susceptibility $C(\omega)$, demonstrates a set of sharp small magnitude resonances corresponding to the transitions of individual superconducting qubits. We show that even a weak interaction between qubits can overcome the disorder with a simultaneous formation of the collective excited states. This collective behavior manifests itself by a single large resonance in $C(\omega)$. In the presence of a weak non-resonant microwave photon field in the low-dissipative resonator, the positions of dominant resonances depend on the number of photons, i.e. the collective ac Stark effect. Coupling of an SQA to the transmission line allows a straightforward experimental access of the collective states in microwave transmission experiments and, at the same time, to employ SQAs as sensitive single-photon detectors.

DY 36.4 Thu 10:15 H22

Heat transport and rectification in an ultrastrongly-coupled qubit-resonator system — •Luca Magazzu[1], Milena Grifoni[1], and Elisabetta Paladino[2] — [1]University of Regensburg — [2]University of Catania

Inspired by the recent experimental developments in the field of heat transport in the quantum regime, we consider a flux qubit coupled to a superconducting resonator as a composite open quantum system. The two elements of this open quantum Rabi system interact with two heat baths held at different temperatures. At the steady state, a heat current is established which is the result of photon exchanges between the system and the baths. Due to the geometry of the setup, the coupling to the heat baths is asymmetric. In turn this entails the presence of a preferred direction for the heat current, to a degree quantified by the heat rectification.

We calculate the heat current and rectification in different coupling regimes and considering a periodic driving applied to the qubit. The rectification displays the signatures of multi-photon processes that occur when the qubit-resonator coupling enters the nonperturbative regime

[1] A. Ronzani et al., Nat. Phys. 14, 991 (2018)
[2] J. Senior, A. Gubaydullin, B. Karimi, J. T. Peltonen, J. Ankerhold, J. P. Pekola, Commun. Phys. 3, 40 (2020)
[3] B. Bhandari, P. Andrea Erdman, R. Fazio, E. Paladino, and F. Taddei. Phys. Rev. B 103, 155434 (2021)
[4] L. Tesser, B. Bhandari, P. A. Erdman, R. Fazio, E. Paladino, F. Taddei, New J. Phys. 24, 035001 (2022)

DY 36.5 Thu 10:30 H22

Probing the coherence of superconducting Fluxmon qubits — •Benedikt Berlitz, Alexander Neumann, Alexander Bilmes, Jürgen Lisenfeld, and Alexey V. Ustinov — Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

The Fluxmon qubit combines a transmission line resonator with a DC-SQUID and offers wide control over the circuit's potential energy via two independently applied bias flux channels. This allows one to operate the qubit as a phase or flux qubit, provides means for fast single-shot qubit readout, and offers a path to characterize decoherence due to surface spins and tunneling defects in a wide frequency range. We will review the Fluxmon qubit design and fabrication, and present measurements of its potential energy landscape which demonstrate single- and double well qubit physics. Our time-resolved measurements confirm that the Fluxmon qubit's performance is strongly limited by microscopic sources of decoherence, which might render it a suitable detector for defect spectroscopy applications.

DY 36.6 Thu 10:45 H22

Mapping the positions of individual material defects in superconducting transmon qubits — •Alexander K. Händel, Benedikt Berlitz, Alexander Bilmes, Jürgen Lisenfeld, and Alexey V. Ustinov — Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

In superconducting quantum bits, material defects at the surface of circuit electrodes and the substrate constitute a major source of decoherence. In our experiment, we detect individual defects with a transmon qubit while tuning their resonance frequencies with applied static electric fields. We fabricated samples that feature on-chip gate electrodes that are placed close to the qubit island. By measuring the coupling strength of each detected defect to various electrodes, we are able to deduce the defect's position on the qubit chip. Our goal is to create two-dimensional maps of defect distribution over qubit electrodes. This will help to identify circuit components which contain majority of coherence-breaking defects and improve fabrication methods towards more coherent qubits.

15 min. break

DY 36.7 Thu 11:15 H22

Quantum memory based on spin donors in silicon — •Patricia

Oehrl[1,2], Julian Franz[1,2], Florian Fesquet[1,2], Nadezhda Kukharchyk[1,2], Kirill G. Fedorov[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]Munich Center for Quantum Science and Technologies (MCQST), Germany

Quantum memories are considered as key elements for the successful realization of quantum communication [1]. In order to allow for the connection of several quantum nodes into a quantum network without frequency conversion, several requirements have to be met such as frequency compatibility and connectability to the quantum system of choice. As superconducting quantum processors operate in the microwave regime, solid-state spin ensembles with their exceptional coherence times are promising candidates [2]. Here, we present a hybrid system consisting of a superconducting lumped-element microwave resonator coupled to a phosphorus donor electron spin ensemble hosted in isotopically engineered silicon. We present experimental results on the storage of coherent microwave states and their retrieval using a Hahn-echo type pulse sequence. In detail, we discuss the impact of the resonator design, the classical storage times and outline strategies towards storing quantum signals.

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[1] H. J. Kimble, Nature **453**, 1023 (2008)
[2] C. Gezes *et al.*, Phys. Rev. X **4**, 021049 (2014)

DY 36.8 Thu 11:30 H22

Crystal electric field effects in yttrium orthosilicate doped with paramagnetic rare-earth ions — •Tim Hofmann, Andreas Bauer, Fabian Kessler, and Christian Pfleiderer — Chair for the Topology of Correlated Systems, Department of Physics, Technical University of Munich, Germany

Monoclinic yttrium orthosilicate Y_2SiO_5 doped with several ten ppm of rare-earth ions, such as Er^{3+}, Yb^{3+}, or Nd^{3+}, represents a candidate material for optical applications in quantum information technology. The amount of dopants directly influences key properties, such as the linewidth or the coherence time, and in turn precise control on the doping levels is essential. The quantitative determination of doping on ppm level is challenging when using conventional characterization techniques. Here, we report the magnetic characterization of rare-earth doped yttrium orthosilicate single crystals. We infer information from magnetization measurements at low temperatures down to 2 K for magnetic fields up to 14 T applied along the optical axes b, $D1$, and $D2$, exhibiting paramagnetic contributions characteristic of rare-earth ions. Distinct crystalline anisotropy and the substitution of yttrium on two magnetically inequivalent sites is observed, indicating the importance of crystal electric field effects for both the fundamental characterization and potential applications in quantum information technology.

DY 36.9 Thu 11:45 H22

Synchronized coherent charge oscillations in coupled double quantum dots — •Eric Kleinherbers[1], Philipp Stegmann[2], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, 47057 Duisburg, Germany — [2]Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

We study coherent charge oscillations in double quantum dots tunnel-coupled to metallic leads [1]. If two such systems are coupled by Coulomb interaction, there are in total six (instead of only two) oscillation modes of the entangled system with interaction-dependent oscillation frequencies. By tuning the bias voltage, one can engineer decoherence such that only one of the six modes, in which the charge oscillations in both double quantum dots become synchronized in antiphase, is singled out. We suggest to use waiting-time distributions and the $g^{(2)}$-correlation function to detect the common frequency and the phase locking.

[1] E. Kleinherbers et al., Phys. Rev. B 104, 165304 (2021)

DY 36.10 Thu 12:00 H22

Electrically driven spin resonance with bichromatic driving — •Zoltán György[1], András Pályi[2], and Gábor Széchenyi[1] — [1]Institute of Physics, Eötvös University, H-1117 Budapest, Hungary — [2]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics, H-1111 Budapest, Hungary

Electrically driven spin resonance (EDSR) is an established tool for controlling semiconductor spin qubits. Here, we theoretically study a frequency-mixing variant of EDSR, where two driving tones with different drive frequencies are applied, and the resonance condition connects the spin Larmor frequency with the sum of the two drive frequencies. Focusing on flopping-mode operation, we calculate the parameter dependence of the Rabi frequency and the Bloch-Siegert shift. A shared-control spin qubit architecture could benefit from this bichromatic EDSR scheme, as it enables simultaneous single-qubit gates.

DY 36.11 Thu 12:15 H22

Cavity-mediated superconductor-ferromagnet interaction — Andreas T. G. Janssønn, •Henning G. Hugdal, Arne Brataas, and Sol H. Jacobsen — Center for Quantum Spintronics, Department of Physics, NTNU, Norwegian University of Science and Technology, Trondheim, Norway

We present a microscopic theoretical analysis of interactions between a ferromagnet (FM) and superconductor (SC) mediated by photons in a cavity. This facilitates interactions over macroscopic distances, in contrast with extensively researched FM-SC proximity systems, and ensures there is no interfacial suppression of their respective order parameters. The spatial separation between the materials also means the FM and SC may be held at different temperatures, and has potential applications as a bridge in spintronic-superconducting circuitry. Specifically, we deduce the anisotropy field induced across the FM due to the presence of the SC when the system is subjected to a symmetry-breaking external field. Other quantities such as renormalized dispersion relations can also be deduced. The model is a modification and quantum mechanical extension of the principle presented in Janssøn et al. PRB 102, 180506(R) (2020).