TT 54: Quantum Coherence and Quantum Information Systems II

Time: Thursday 15:00–17:45 Location: HSZ 304

TT 54.1 Thu 15:00 HSZ 304

Dominant materials losses in superconducting circuits based on tantalum thin films — •Ritika Dhundhwal[1], Haoran Duan[2], Dirk Fuchs[1], Alexander Welle[3], Mahya Khorramshahi[1], Jasmin Aghassi-Hagmann[2], Ioan M. Pop[1], and Thomas Reisinger[1] — [1]Institut für Quantenmaterialien und technologien — [2]Institut für Nanotechnologie — [3]Institut für Funktionelle Grenzflächen, Karlsruher Institut für Technologie

Superconducting quantum circuits are a promising hardware platform in the fields of quantum computing and detection. To improve their performance, exploring new materials is highly relevant. One promising candidate material is tantalum (Ta), which was recently shown to improve transmon qubit lifetimes[1]. However, the understanding of the dominant loss mechanisms related to Ta is limited. Here, we present a study of losses in epitaxial Ta films deposited using magnetron sputtering, with the aim of relating basic material properties to loss mechanisms. A variation in the deposition parameters (mainly substrate temperature) leads to structurally different films. We characterized these using high-resolution X-ray diffraction, Time-of-Flight secondary-ion mass spectrometry, scanning electron microscopy and superconducting transition temperature measurements. We fabricated lumped element resonators from the films and measured their quality factors as a function of photon number and temperature. In addition, we vary the energy participation ratio of Ta metal-substrate interface to find the dominant loss mechanism.

[1] A. P. M. Place *et al.*, Nat. Commun. 12, 1779 (2021)

TT 54.2 Thu 15:15 HSZ 304

Many body localization of 2D transmon arrays with a quasi-periodic potential and perturbative Walsh-Hadamard coefficients — •Evangelos Varvelis and David DiVincenzo — JARA, Aachen, Germany

Recently it has been shown that transmon qubit architectures experience a phase transition between many body localized and quantum chaotic. It is crucial for quantum computation that the system remains in the localized regime, yet the most common way to achieve this relies on random disorder. Here we propose a quasi-periodic potential as a substitute for random disorder, with the purpose of localizing a 2D transmon array. We demonstrate, using the Walsh-Hadamard diagnostic, that the quasiperiodic potential is more effective at achieving localization. In order to study the localizing properties of our new potential for experimentally relevant system sizes, we develop a many-body perturbation theory whose computational cost scales only with the non-interacting system dimensions.

TT 54.3 Thu 15:30 HSZ 304

Linear response for pseudo-Hermitian Hamiltonian systems: Application to PT-symmetric qubits — •Mikhail V. Fistul, Leander Tetling, and Ilya M. Eremin — Ruhr-Universität Bochum, Bochum Germany

We develop the linear response theory formulation suitable for application to various *pseudo-Hermitian Hamiltonian* systems. The analytical expressions for the generalized temporal quantum-mechanical correlation function and the time-dependent dynamic susceptibility, $\chi(t)$, are derived [1].

We apply our results to two PT-symmetric non-Hermitian quantum systems: a single qubit and two unbiased/biased qubits coupled by the exchange interaction. For both systems we identify PT-symmetry unbroken and broken quantum phases and quantum phase transitions between them. The temporal oscillations of the dynamic susceptibility of the qubits polarization, $\chi(t)$, relate to *ac* induced transitions between different eigenstates, and we analyze the dependencies of the oscillations frequency and the amplitude on the gain/loss parameter γ and the interaction strength g.

Studying the time dependence of $\chi(t)$ we observe different types of oscillations, i.e., undamped, heavily damped and amplified ones, related to the transitions between eigenstates with broken (unbroken) PT-symmetry. These predictions can be verified in the microwave transmission experiments.

[1] L. Tetling, M. V. Fistul, and I. M. Eremin, Phys. Rev. B **106**, 134511 (2022).

TT 54.4 Thu 15:45 HSZ 304

High kinetic inductance microstrip networks for integrated quantum information devices — •Niklas Gaiser[1], Ciprian Padurariu[1], Björn Kubala[1,2], Nadav Katz[3], and Joachim Ankerhold[1] — [1]ICQ and IQST, University of Ulm, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [3]The Racah Institute of Physics, The Hebrew University of Jerusalem, Israel

Modern superconducting quantum information devices integrate qubits and readout resonators into complex microwave circuits. Efficient qubit operation and fast readout require relatively strong coupling. This, however, can compromise the qubit lifetime due to spontaneous emission through the resonator. An elegant solution is provided by a Purcell filter, an added circuit element that suppresses transmission at the qubit frequency.

Here, we present a theoretical proposal for circuit architectures that realize qubit readout with Purcell filters, utilizing the highly versatile platform of high-kinetic inductance microstrip networks experimentally realized in [1]. The strongly reduced phase velocities in such materials allow compact filter designs that can be integrated on-chip. We describe band-structure design techniques to build an efficient Purcell filter and provide quantitative estimations for the suppression of unwanted relaxation channels.

[1] S. Goldstein, G. Pardo, N. Kirsh, N. Gaiser, C. Padurariu, B. Kubala, J. Ankerhold, and N. Katz, New J. Phys. 24 023022 (2022)

TT 54.5 Thu 16:00 HSZ 304

Microwave radiation emitted by a phase qubit — •Surangana Sengupta[1], Ciprian Padurariu[1], Bjoern Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Germany — [2]German Aerospace Center (DLR), Ulm, Germany

Josephson photonics devices consist of a DC-biased Josephson junction in series with a superconducting microwave cavity and are promising sources of bright quantum states of microwave radiation. Such devices realize the regime of strong-coupling circuit quantum electrodynamics, when the effective fine structure constant of the circuit approaches unity. In this case, multi-photon downconversion processes, where one tunnelling Cooper pair emits k photons in the cavity ($k \leq 6$), have been observed [1].

Here, we propose a new regime for Josephson photonics devices, where both the inductive as well as the capacitive behavior of the Josephson junction is taken into account [2]. Thereby, the Josephson phase is treated as an electronic degree of freedom, characterized by the plasma frequency of the junction, that is independent of the photonic degree of freedom, described by the phase of the cavity. We present a preliminary study of the coupled photonic and electronic dynamics, discuss the nature of the coupling and present a detailed comparison to conventional Josephson photonics dynamics. As an example, we focus on the case when the Josephson junction is operated as a phase qubit and study the resulting statistics of radiation emitted in the cavity.

[1] G. C. Ménard *et al.*, Phys. Rev. X **12**, 021006 (2022)
[2] C. Yan *et al.*, Nat. Electron. **4**, 885-892 (2021)

15 min. break

TT 54.6 Thu 16:30 HSZ 304

Heat transport and rectification in an ultrastrongly-coupled qubit-resonator system — •Luca Magazzu[1], Milena Grifoni[1], and Elisabetta Paladino[2] — [1]Regensburg University — [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, and 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, and F. Taddei, New J. Phys. 24, 035001 (2022)

TT 54.7 Thu 16:45 HSZ 304

Qubit reset using frequency modulation by AC Stark effect — •Jami Rönkkö, Vasilii Sevriuk, Antti Vepsäläinen, and Fabian Marxer — IQM Quantum Computers, Espoo, Finland

We present a theory for an unconditional reset scheme utilizing qubit's frequency modulation by AC Stark effect and a coupled lossy resonator. In AC Stark effect, off-resonant microwave drive shifts the frequency of a qubit without causing strong Rabi oscillations. Modulating the frequency of this drive creates sidebands around the qubit frequency. By setting the modulation frequency equal to the difference between the qubit and resonator frequencies, one of the sidebands becomes resonant with the resonator frequency. This leads to the transfer of the qubit excitation to the lossy resonator, resulting in a qubit reset. With typical parameters, the reset is achieved in only tens of nanoseconds

TT 54.8 Thu 17:00 HSZ 304

Fabrication of a superconducting transmission line in a planar design on a spin-doped crystalline membrane — •Georg Mair[1,2], Ana Strinic[1,2,3], Niklas Bruckmoser[1,2], Michael Stanger[1], Andreas Erb[1,2], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85747 Garching, Germany — [2]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology, 80799 Munich, Germany

Scaling up the density of superconducting qubits on a chip is reaching its limits, and a supplementing microwave quantum memory is a promising way to enhance the computing power [1]. Rare-earth doped crystals are potential candidates to realize such microwave quantum memories, due to the long coherence times of their spin states [2]. For efficient operation, one needs to have precise control over the distribution of strength and orientation of the oscillating magnetic field inside the sample. Here, we introduce a novel, planar superconducting transmission line design based on a thin crystalline $CaWO_4$ membrane. The transmission line is designed to exhibit high transmission in the range of $1-8\,$GHz, i.e. the frequency range of the hyperfine transitions of the rare-earth ions in near-zero external magnetic field. Fabrication techniques are explained and transmission spectra recorded at cryogenic temperatures are discussed.

[1] É. Gouzien and N. Sangouard, Phys. Rev. Lett. **127**, 140503 (2021)
[2] N. Kukharchyk et al. New J. Phys. **20**, 023044 (2018)

TT 54.9 Thu 17:15 HSZ 304

Quantum state storage in spin ensembles — •Patricia Oehrl[1,2], Julian Franz[1,2], Manuel Müller[1,2], Nadezhda Kukharchyk[1,2,3], 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]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [3]Munich Center for Quantum Science and Technologies (MCQST), Munich, Germany

The storage of quantum states is considered as a key element for successful realization of a multimode quantum network, enabling various applications, such as secure communication and distributed quantum computing [1]. In order to allow for connection of multiple quantum nodes without frequency conversion, several requirements have to be met, such as frequency compatibility and connectability between chosen quantum systems. As superconducting quantum circuits 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 show experimental results toward the storage of quantum states and their retrieval based on Hahn-echo type pulse sequences.

We acknowledge financial support from the Federal Ministry of Education and Research of Germany (project number 16KISQ036).

[1] M. Pompili et al., Science 372, 6539 (2021)
[2] M. Steger et al., Science 336, 1280 (2012)

TT 54.10 Thu 17:30 HSZ 304

Broadband electron spin resonance spectroscopy of rare earth spin ensembles at mK temperatures — •Ana Strinic[1,2,3], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[2,1,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bavarian Academy of Sciences, Garching, Germany — [3]Munich Center for Quantum Science and Technologies, Munich, Germany

Rare earth spin ensembles exhibit spin coherence times in the millisecond range and possess transitions at microwave frequencies [1,2]. These properties make them attractive candidates for realizing microwave quantum memories, which can be directly interfaced with superconducting quantum processors. In principle, there are two options for the implementation of spin-based quantum memories: (i) coupling them to resonators, or (ii) interfacing them with an open transmission line. In particular, the latter is considered for multi-modal concepts or the storage of information based on atomic frequency comb protocols. In this work we characterize the electron spin resonance Hamiltonian of an ^{167}Er spin ensemble in a $^{7}LiYF_4$ host crystal at mK temperatures using a broadband microwave spectroscopy approach. We find good agreement with published g and hyperfine tensors, which is key for the implementation of microwave quantum memory schemes at low magnetic fields.

[1] P.-Y. Li et al., Phys. Rev. Appl. 13, 024080 (2020)
[2] A. Ortu et al., Nat. Mater. 17, 671 (2018)