TT 39: Superconducting Electronics

Time: Wednesday 15:00–18:15 Location: HSZ 304

Invited Talk TT 39.1 Wed 15:00 HSZ 304

Sensing and control of MHz photons with microwave photon-pressure — Ines C. Rodrigues[1,2], Gary A. Steele[1], and •Daniel Bothner[1,3] — [1]Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands — [2]Department of Physics, ETH Zürich, Switzerland — [3]Physikalisches Institut, Center for Quantum Science (CQ) and LISA+, Universität Tübingen, Germany

Superconducting microwave circuits have emerged as one of the leading platforms for quantum information science and quantum sensing in the recent decade. In 2018, a new type of interaction between a superconducting microwave circuit and a low frequency (LF) circuit has been realized, so called photon-pressure coupling, which is the all-circuit analogue of the radiation-pressure interaction between a mechanical oscillator and an optical cavity in optomechanics. Since 2020, several milestone experiments with photon-pressure circuits have been reported, such as the interferometric thermometry of an LF circuit, the observation of parametric strong-coupling or sideband-cooling of an LF mode into its quantum groundstate. Quite recently, we have realized a series of experiments in these circuits, for which we add a strong parametric drive to the Kerr-nonlinear high-frequency mode. This approach allows for parametrically enhanced interaction strengths, for the observation of nonreciprocal heat flow and for the implementation of photon-pressure with a "negative mass" microwave mode that inverts dynamical backaction and sideband-cooling effects. In our presentation, we will give an overview of photon-pressure circuits, discuss the most recent developments and possible future directions.

TT 39.2 Wed 15:30 HSZ 304

Waveguide quantum electrodynamics in high impedance networks — •Miriam Resch[1], Ciprian Padurariu[1], Björn Kubala[1,2], Frank Grossmann[3], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [3]Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany

The emerging field of high impedance quantum circuits aims to exploit the extraordinary properties of high kinetic inductance materials, such as granular superconductors. The low propagation speed of electromagnetic excitations in such devices enables to strongly couple various types of qubits or resonators and waveguides. Theoretical description of such strongly coupled systems is challenging as the localized modes of the sub-unit couple to many waveguide modes simultaneously so that many common approximation schemes break down. Furthermore for a more realistic description of the system, Kerr nonlinearities are included in the model of the granular superconductor. To tackle this challenging regime in a numerically efficient way, we use the multi Davydov-Ansatz [1], where the wave function of the full system is described by a superposition of coherent states. As a first step we investigate how Kerr nonlinearities modify properties of qubit decay or readout, with the ultimate goal of identifying strong-coupling signatures in those observables, which are accessible to our experimental collaborators.

[1] M. Werther and F. Großmann, Phys. Rev. B **101**, 174315 (2020).

TT 39.3 Wed 15:45 HSZ 304

High-impedance resonators based on granular aluminum — •Mahya Khorramshahi, Martin Spiecker, Patrick Paluch, Nicolas Zapata, Ritika Dhundhwal, Ioan M. Pop, and Thomas Reisinger — Karlsruhe Institute of Technology, Germany

Superconductors with characteristic impedance larger than the resistance quantum are a valuable resource in superconducting circuits. They enable the design of protected qubits such as Fluxoniums or 0-pi qubits and can improve the coupling to small-dipole-moment objects, which may be useful for interfacing to spin-qubits, donor spins, etc. Here we present compact resonators in the lower GHz regime with a high characteristic impedance given by a high-kinetic-inductance material, namely granular aluminum, with spurious modes above 10GHz. We fabricated the resonators with an electron-beam lithography lift-off process, and we coupled them using a 50 Ohm coplanar waveguide architecture. Measurements performed in a dilution cryostat reveal that the resonators maintain high-quality factors in the single photon regime, a valuable resource for future quantum hardware implementations.

TT 39.4 Wed 16:00 HSZ 304

Surface acoustic wave resonators on thin film piezoelectric substrates for quantum acoustics — •Thomas Luschmann[1,2,3], Alexander Jung[1,2], Stephan Geprägs[1,2], Rudolf Gross[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Technische Universität München, TUM School of Natural Sciences, Physics Department, Garching, Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

Lithium Niobate (LNO) is a well established material for Surface Acoustic Wave (SAW) devices including resonators, delay lines and filters. Recently, multi-layer substrates based on LNO thin films have become commercially available. Here, we present a systematic study of the performance of SAW devices fabricated on LNO-on-Insulator (LNOI) and LNO-on-Silicon substrates and compare them to bulk LNO devices. Our study aims at applications of these substrates for quantum acoustics, i.e. the integration with superconducting circuits operating in the quantum regime. To this end, we design SAW resonators with a target frequency of 5 GHz and perform our experiments at millikelvin temperatures and microwave power levels corresponding to single photons or phonons. We investigate the device quality factors as a function of the excitation power and temperature and model the observed losses by the coupling of the resonator to a bath of two-level-systems (TLS). Our results suggest that SAW devices on thin film LNO on Silicon have sufficient performance to be used in future SAW based quantum acoustic devices.

TT 39.5 Wed 16:15 HSZ 304

Towards hybrid quantum systems coupling superconducting qubits to cold atoms — •Benedikt Wilde, Nicolas Albenge, Manuel Kaiser, Conny Glaser, Malte Reinschmidt, Andreas Günther, József Fortágh, Dieter Koelle, Reinhold Kleiner, and Daniel Bothner — Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, Universität Tübingen

Coupling superconducting quantum circuits to ultracold atom clouds promises the possibility of exploiting the advantages of both systems, enabling new advances in both fundamental research and potential technological applications. One can realize such a hybrid quantum system by using a superconducting microwave resonator that is simultaneously coupled to both sub-systems. While coupling superconducting resonators to superconducting qubits is state-of-the-art, several challenges arise when trying to couple cold atoms to the integrated circuit. These challenges include achieving the required microwave field homogeneity, engineering a sufficiently large interaction strength and keeping a high resonator quality factor despite environmental factors suitable to deteriorate the performance of superconducting circtuits, such as laser beams or magnetic atom traps. We present our recent developments and advances, discussing design considerations, simulations and intermediate results.

15 min. break

TT 39.6 Wed 16:45 HSZ 304

Parameter spread in Josephson traveling-wave parametric amplifiers: Vulnerabilities and tolerances — •Christoph Kissling, Victor Gaydamachenko, Fabian Kaap, Marat Khabipov, Ralf Dolata, Alexander B. Zorin, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Josephson traveling-wave parametric amplifiers (JTWPAs) hold great promise for wideband amplification of few-photon-level signals at microwave frequencies. These devices typically consist of thousands of nominally identical circuit elements, which are subject to fabrication variations. We analyse the effect of circuit parameter variation on the performance of a JTWPA using transient circuit simulations. Using this tool, we analyze two dispersion engineering concepts, resonant phase matching and periodic capacitance modulation, and compare their parameter spread tolerances. We identify circuit elements, which are critical concerning parameter spread, and explore ways to mitigate the impact of spread. Furthermore, we present the status of our practical implementation of rf-SQUID based JTWPAs and show experimental results.

TT 39.7 Wed 17:00 HSZ 304

Fabrication of low-loss Josephson parametric circuits — •Kedar E. Honasoge[1,2], Yuki Nojiri[1,2], Daniil E. Bazulin[1,2], Leon Koch[1,2], Thomas Luschmann[1,2], Niklas Bruckmoser[1,2], Maria-Teresa Handschuh[1], Florian Fesquet[1,2], Michael Renger[1,2], Fabian Kronowetter[1,2,4], Achim Marx[1], Rudolf Gross[1,2,3], and Kirill G. Fedorov[1,2] — [1]Walther-Meißner-Institut, 85748 Garching, Germany — [2]Physik- Department, Technische Universität München, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany — [4]Rohde & Schwarz GmbH, 81671 München, Germany

The emergence of quantum information processing with superconducting circuits has stimulated the development of various interest in Josephson parametric devices. The latter offer a wide range of applications ranging from quantum-limited amplification to the generation of entangled squeezed states of light. We fabricate low-loss devices by employing careful cleaning steps during the fabrication of the superconducting circuits. Upon optimization, we fabricate Josephson parametric devices with internal quality factors in excess of 10^5. We characterize bandwidth, gain, noise, dynamic range, and other properties of the realized devices. Based on these investigations, we derive useful criteria for the development of more intricate devices incorporating Josephson parametric circuits.

TT 39.8 Wed 17:15 HSZ 304

Nb SQUIDs patterned by He and Ne focused ion beams — •Simon Koch[1], Timur Griener[1], Simon Pfander[1], Julian Linek[1], Thomas Weimann[2], Reinhold Kleiner[1], Oliver Kieler[2], and Dieter Koelle[1] — [1]Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, Universität Tübingen, Germany — [2]Department Quantum Electronics, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

Nanopatterning of superconducting thin film structures with focused He or Ne ion beams (He/Ne-FIB) offers a flexible tool for creating constriction-type Josephson junctions (cJJs) which can be integrated into strongly miniaturized superconducting quantum interference devices (nanoSQUIDs) for magnetic sensing on the nanoscale. We present our attempts to use He/Ne-FIB for fabricating Nb cJJs and nanoSQUIDs which shall provide ultra-low noise and high spatial resolution for their application in scanning SQUID microscopy (SSM). Moreover, we address the possibility to implement multiterminal, multi-JJ SQUIDs that provide flexibility in SQUID readout. The nanoSQUIDs are designed as sensors for magnetic flux and dissipation. They shall be integrated on custom-made Si cantilevers, which will provide the possibility of simultaneous conventional topographic imaging by atomic force microscopy (AFM). We will discuss the status of this project and challenges that have to be met on the way to combine SSM and AFM on the nanoscale.

We acknowledge the European Commission under H2020 FET Open grant FIBsuperProbes (number 892427).

TT 39.9 Wed 17:30 HSZ 304

Synchronization in Josephson photonics devices in the presence of shot noise — Florian Höhe[1], Ciprian Padurariu[1], Brecht Donvil[1], Lukas Danner[1,2], Joachim Ankerhold[1], and •Björn Kubala[1,2] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

For many quantum sources the exploitation and characterization of their quantum properties, such as entanglement and squeezing, is hampered by phase instability. Josephson photonics devices, where microwave radiation is created by inelastic Cooper pair tunneling across a *dc-biased* Josephson junction 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. Intrinsic shot noise of the Josephson-photonics device inevitably diffuses the oscillators phase and requires an extension of classical synchronization theories to the quantum regime.
Performing multi-time scale perturbation theory we derive an effective Fokker-Plank equation for the phase to analyze quantum locking and synchronization in an Adler-type equation. Injection locking and synchronization lead to a narrowing of the photon emission statistics, while the shot noise induces phase slips.

[1] A. Peugeot et al., Phys. Rev. X 11, 031008 (2021).
[2] M. C. Cassidy et al., Science 355, 939 (2017).

TT 39.10 Wed 17:45 HSZ 304

Mitigating losses in NbTiN superconducting circuits under magnetic fields. — •Arne Bahr, Matteo Boselli, Benjamin Huard, and Audrey Bienfait — Laboratoire de Physique - École normale supérieure de Lyon, France

Quantum superconducting circuits enable quantum information processing as well as quantum sensing at microwave frequencies. One predominant factor limiting their performance is the presence of impurities creating microwave losses, triggering intense research effort for their identification and mitigation[1]. Here we probe these impurities in the context of using superconducting circuits under magnetic fields, which has application for coupling to other spin systems[2] and also detecting electron spin resonance (ESR) at the few spin levels[3].

We report continuous wave ESR measurements on spin impurities in resonators fabricated in NbTiN on a sapphire substrate. A simple etch through a resist layer process results in the presence of many spin impurities, preventing any ESR measurement near the spin 1/2 line. Following the characterization and identification of these spin signals, we improve our fabrication process to remove these spurious spin signals so that the resonators exhibit internal quality factors above $5 \cdot 10^5$ that remain constant up to 350 mT.

[1] N. P. de Leon et al., Science (2021)
[2] A. J. Landig et al., Nat. Com. (2019)
[3]V. Ranjan et al., Appl. Phys. Lett. (2020)

TT 39.11 Wed 18:00 HSZ 304

Pressure drop measurements and flow simulations of different regenerator fillings in a single stage GM-type pulse tube cryocooler — •Bernd Schmidt[1,2], Elias Eisenschmidt[1,3], Jack-André Schmidt[1,2], Jens Falter[1], Hardy Weisweiler[3], and André Schirmeisen[1,2] — [1]TransMIT-Center for Adaptive Cryotechnology and Sensors, Giessen, Germany — [2]Institute of Applied Physics, Justus-Liebig-University Giessen, Germany — [3]Technische Hochschule Mittelhessen, Friedberg, Germany

Although pulse tube cryocoolers (PTCs) reaching liquid Helium temperature were already presented in the 1990s[1], they are still subject to vivid development in many directions. Much of this development is done with the help of simulations and empirical values. A crucial part of a PTC is the regenerator, which is usually filled with multiple layers of porous materials with high heat capacity. These porous materials come in different shapes, mainly packed spheres and wire meshes.

In this talk we present measurements and simulations of pressure drop and gas flow through different regenerator fillings. We show the differences between the different kinds of fillings from the fluid mechanics point of view.

[1] C. Wang et al., Cryogenics, 37, 159 (1997)