TT 58: Superconductivity: Qubits 2

Time: Thursday 15:00–18:30 Location: Theater

TT 58.1 Thu 15:00 Theater

Observation and stabilization of photonic Fock states in a hot radio-frequency resonator — Mario F. Gely[1], •Christian Dickel[1], Marios Kounalakis[1], Jacob Dalle[1], Remy Vatre[1], Brian Baker[2], Mark D. Jenkins[1], and Gary A. Steele[1] — [1]Kavli Institut of Nanoscience, Delft University of Technology, The Netherlands — [2]Department of Physics and Astronomy, Northwestern University, United States of America

Detecting weak radio-frequency electromagnetic fields plays a crucial role in a wide range of fields, from radio astronomy to nuclear magnetic resonance imaging. In quantum mechanics, the ultimate limit of a weak field is a single-photon. Detecting and manipulating single-photons at megahertz frequencies present a challenge as, even at millikelvin temperatures, thermal fluctuations are significant. Here, we use a superconducting transmon qubit to directly observe photon-number splitting of the transition frequency due to a megahertz electrical resonator. Using the qubit, we achieve quantum control over thermal photons, sideband cooling the system and stabilizing photonic Fock states. Releasing the resonator from our control, we directly observe its re-thermalization with nanosecond resolution. Extending circuit quantum electrodynamics to a new regime, we enable the exploration of thermodynamics with photon-number resolution and allow interfacing quantum circuits with megahertz systems, for example, electromechanical oscillators.

TT 58.2 Thu 15:15 Theater

Al based microwave resonators in the clean and dirty limit — •Karthik Bharadwaj[1,2], Farshad Foroughi[1,2], Remy Dassonneville[1,2], Luca Planat[1,2], Sebastien Leger[1,2], Jovian Delaforce[1,2], Valdmir Milchakov[1,2], Cecile Naud[1], Olivier Buisson[1], Nicolas Roch[1], and Wiebke Hasch-Guichard[1,2] — [1]Univ. Grenoble Alpes, F-38000 Grenoble France — [2]Institut Neel, CNRS, F-38000 Grenoble France

Resonators have become a very important part superconducting Circuit QED. And they are an excellent candidate to understand the dissipation sources in qubit systems. We present a comparative experimental study of the internal quality factor of Al based microwave resonators. Microwave resonators with a typical frequency of 4GHz have been fabricated with different film thicknesses. We have developed a new fabrication technique to fabricate microwave resonators having a film thickness of around 6microns. For these film thicknesses Al turns into a clean type 1 superconductor. The behavior of the internal quality factor as a function of applied microwave power is discussed as well as the limiting dissipation mechanism of each resonator.

TT 58.3 Thu 15:30 Theater

Quantum-correlated photons generated by non-local electron transport — •Felicitas Hellbach[1], Wolfgang Belzig[1], Fabian Pauly[2,1], and Gianluca Rastelli[1] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz — [2]OIST Graduate University, Onna-son, Okinawa 904-0395, Japan

Since the realization of high-quality superconducting microwave cavities, one can envisage the possibility to investigate the coherent interaction of light and matter [1]. We study a parallel double quantum dot device operating as single-electron splitter interferometer, with each dot coupled to a local photon cavity. We explore how quantum correlation and entanglement between the two cavities is generated by the coherent transport of a single electron passing simultaneous through the two different dots. We calculate the covariance of the cavity occupations by use of a diagrammatic perturbative expansion (Keldysh Green's functions) to the fourth order in the dot-cavity interaction strength, taking into account vertex diagrams. In this way, we demonstrate the creation of entanglement by showing that the Cauchy-Schwarz inequality can be violated.

[1] A. Stockklauser et. al., Phys. Rev. X **7**, 011030 (2017),
X. Mi et al., Science **355**, 156-158 (2017),
J. J. Viennot et. al., Science **349**, 408-411 (2015)

TT 58.4 Thu 15:45 Theater

Thermal Engineering for Superconducting Microwave Circuits — •Matti Partanen[1,2], Jan Goetz[1], Kuan Yen Tan[1], Shumpei Masuda[1], Russell E. Lake[1,3], Joonas Govenius[1], Matti Silveri[1,4], Máté Jenei[1], Kassius Kohvakka[1], Vasilii Sevriuk[1], Roope Kokkoniemi[1], Joni Ikonen[1], Dibyendu Hazra[1], Eric Hyyppä[1], Leif Grönberg[5], Juha Hassel[5], Slawomir Simbierowicz[5], Visa Vesterinen[1,5], Jani Tuorila[1,4,6], Tapio Ala-Nissila[6,7,8], and Mikko Möttönen[1] — [1]QCD Labs, Aalto University, Finland — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Germany — [3]National Institute of Standards and Technology, Boulder, Colorado, USA — [4]Research Unit of Nano and Molecular Systems, University of Oulu, Finland — [5]VTT Technical Research Centre of Finland Ltd, Finland — [6]MSP group, Aalto University, Finland — [7]Departments of Mathematical Sciences and Physics, Loughborough University, United Kingdom — [8]Department of Physics, Brown University, Providence, Rhode Island, USA

Circuit quantum electrodynamics is a versatile architecture for various experiments in fundamental physics, as well as for different applications. Since excess heat is a substantial source of errors in cryogenic devices, it is of vital importance to evacuate heat. Here, we present our experimental results on optimized energy transfer between two resonators, and discuss photon absorption and emission techniques. We utilize photon-assisted electron tunneling through hybrid tunnel junctions coupled to resonators, and a heat sink based on a resistor in a flux-tunable resonator.

TT 58.5 Thu 16:00 Theater

Observation of dissipation driven geometric phase in superconducting microwave resonators — •Vasilii Sevriuk[1], Kuan Tan[1], Shumpei Masuda[1,2], Arto Viitanen[1], Mate Jenei[1], Matti Partanen[1], Matti Silveri[1,3], Jan Goetz[1], Eric Hyyppä[1], Leif Grönberg[4], and Mikko Möttönen[1] — [1]QCD Labs, Department of Applied Physics, Aalto University, Espoo, Finland — [2]Collage of Liberal Arts and Sciences, Tokyo Medical and Dental University, Ichikawa, Japan — [3]Research Unit of Nano and Molecular Systems, University of Oulu, Finland — [4]VTT Technical Research Centre of Finland, QFT Center of Excellence, Espoo, Finland

We recently introduced quantum-circuit refrigerator (QCR) [1] which gives possibility to tune dissipation of superconducting circuits. In this work we present an experiment in which coplanar waveguide resonator is capacitively coupled to a QCR on the one end, and to the transmission line on the other end. Coupled to the microwave resonator, QCR creates topologically nontrivial parameter space for the transmission line input-output relationship. In this work we utilize this feature to create a dynamical geometrical phase in a probe signal reflected from the superconducting resonator. Here we present our observation of this effect in a form of an additional tone, created by a frequency shift of the probe signal.

[1] K. Y. Tan, et al., Nat. Commun. 8, 15189 (2017)

TT 58.6 Thu 16:15 Theater

Metallic, superconducting and insulating low-temperature transport properties of disordered nanowires — •Jan Nicolas Voss[1], Yannick Schön[1], Micha Wildermuth[1], Lukas Powalla[1], Hannes Rotzinger[1], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

Lithographically fabricated nanowires are a promising alternative to Josephson tunnel junctions as a nonlinear element in superconducting quantum circuits. They potentially offer low intrinsic loss, high impedance, and low fabrication requirements. In the superconducting regime, a key requirement is a high kinetic inductance stemming from a low normal state conductance. Our nanowire material of choice is disordered oxidized aluminum, which, depending on the implanted oxygen impurities, allows for implementing a wide range of resistivities. Microscopically the material forms a natural, disordered network of nanometer-sized aluminum grains that are separated by thin aluminum-oxide barriers. Given this nanoscale morphology, the transport at very low temperatures ranges from insulating to superconducting depending on the resistance of the wires. We will present experimental results on nanowires with a length ranging from 50 nm up to 1000 nm and a width of about 20 nm and compare the measured data with theoretical predictions.

TT 58.7 Thu 16:30 Theater

Rabi-oscillations in disordered superconducting nanowire qubit — •Yannick Schön[1], Jan Nicolas Voss[1], Micha Wildermuth[1], Andre Schneider[1], Martin Weides[1], Hannes Rotzinger[1], and Alexey V. Ustinov[1,2] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow 119049, Russia

At feature sizes of nanometer scale, superconducting wires made from a material with high normal state resistance show a pronounced nonlinear microwave response.

Our material of choice, granular aluminum oxide, is a new material for superconducting quantum circuits which features not only a very high kinetic inductance but also microwave resonators with high quality factors. Microscopically, it can be described as a disordered network of nano-scale aluminum grains, coupled via the Josephson effect.

We demonstrate a new type of superconducting quantum circuit, using capacitively shunted granular aluminum nanowires embedded as nonlinear circuit element. We present circuit characterization in microwave response measurements featuring Rabi-oscillations and measure state life times in the μs range.

15 min. break.

TT 58.8 Thu 17:00 Theater

Investigating a Superconducting Quantum Metamaterial in a Waveguide — •Jan David Brehm[1], Tim Wolz[1], Alexander Stehli[1], Hannes Rotzinger[1], and Alexey V. Ustinov[1,2] — [1]Karlsruhe Institute of Technology, Institute of Physics, Karlsruhe, Germany — [2]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia

Quantum metamaterials extend the idea of classical metamaterials to a regime where the quantum coherence of the meta-atoms exceeds the typical time of a wave propagation through the medium. In recent works, it was proposed that this regime gives rise to various collective light-matter interaction effects such as self-induced transparency, quasi-superradiant phase transitions and lasing. Here, we investigate a one-dimensional quantum material which consists of an array of 80 transmon qubits coupled to a continuum of light modes of a coplanar waveguide. Since specific frequency control of the individual qubits is at the current stage of technology not feasible, we rely on strong qubit-waveguide coupling and optimizing the parameter spread by improving the circuit fabrication techniques, to reduce disorder in the metamaterial. Our qubit-based material exhibits a broad engineered bandgap, which is significantly larger than a single qubit linewidth. Beside detailed spectroscopic characterization we will present first experimental results on the time-resolved transmission of short microwave pulses through the metamterial.

TT 58.9 Thu 17:15 Theater

Phonon traps to reduce the quasiparticle density in superconducting circuits — •Francesco Valenti[1,2], Fabio Henriques[1], Maria Martinez[3,4], Lukas Grünhaupt[1], Daria Gusenkova[1], Julian Ferrero[1], Sebastian T. Skacel[5], Nataliya Maleeva[1], Alexey V. Ustinov[1,6], and Ioan M. Pop[1,5] — [1]Physikalisches Institut, Karlsruhe Institue of Technology, 76131 Karlsruhe, Germany — [2]Institute for Data Processing and Electronics, Karlsruhe Institue of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [3]Laboratorio de Física Nuclear y Astropartículas, Universidad de Zaragoza, C/ Pedro Cerbuna 12, 50009 Zaragoza, Spain — [4]Fundacíon ARAID, Av. de Ranillas 1D, 50018 Zaragoza, Spain — [5]Institute of Nanotechnology, Karlsruhe Institue of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [6]Russian Quantum Center, National University of Science and Technology MISIS, 119049 Moscow, Russia

Out of equilibrium quasiparticles (QPs) are a main source of dissipation and noise in superconducting circuits, and pinpointing their origin and decreasing their density remain outstanding tasks. The generation-recombination processes of QPs link their dynamics to the phonon dynamics of the circuit + substrate ensemble. We demonstrate that surrounding granular aluminum resonators with lower gapped aluminum islands increases the internal quality factors of the resonators in the single photon regime, suppresses the noise, and reduces the rate of observed QP generation events. The aluminum islands are positioned far enough from the resonators to be electromagnetically decoupled, and we attribute the decrease in dissipation and noise to phonon trapping.

TT 58.10 Thu 17:30 Theater

Efficient quasiparticle traps with low dissipation through gap engineering — •Roman-Pascal Riwar and Gianluigi Catelani — JARA Institute for Quantum Information (PGI-11), Forschungszentrum Jülich, Germany

Quasiparticles represent an intrinsic source of perturbation for superconducting qubits, leading to both dissipation of the qubit energy and dephasing. Recently, it has been shown that normal-metal traps may efficiently reduce the quasiparticle population and improve the qubit lifetime, provided the trap surpasses a certain characteristic size. Moreover, while the trap itself introduces new relaxation mechanisms, these perturbations should not hamper with state-of-the-art transmon qubits – under the condition that the traps are not placed too close to extremal positions where electric fields are high. Here, we study a different type of trap, realized through gap engineering. We find that the gap-engineered traps relax the remaining constraints imposed by normal metal traps. Firstly, the characteristic trap size, above which the trap is efficient, is reduced with respect to normal metal traps, such that here, strong traps are possible in smaller devices. Secondly, the relaxation caused by the trap is now greatly reduced, providing more flexibility in trap placement. The latter point is of particular importance, since for efficient protection from quasiparticles, the traps ideally should be placed close to the active parts of the qubit device, where electric fields are typically high.

TT 58.11 Thu 17:45 Theater

Single-spin relaxation in Si quantum dots induced by spin-valley coupling — •Amin Hosseinkhani and Guido Burkard — Department of Physics, University of Konstanz, D-78464 Konstanz, Germany

The spin of isolated electrons in Silicon quantum dot heterostructures is a promising candidate for quantum information processing. While silicon offers weak spin-orbit coupling and nuclear-spin free isotopes, the valley degree of freedom in silicon couples to spin and therefore can degrade the qubit performance by opening a relaxation channel. We have developed the theory of qubit relaxation induced by spin-valley coupling. In this talk, we will discuss the results of our theory for single qubit relaxation in an applied magnetic field and compare our results with experimental findings.

TT 58.12 Thu 18:00 Theater

Towards single-shot readout of NV centers in diamond by low-temperature spin-to-charge conversion — •Dominik M. Irber[1], Michael Kieschnick[2], Jan Meijer[2], and Friedemann Reinhard[1] — [1]TU München, Walter Schottky Institut und Physik-Department, Am Coulombwall 4, 85748 München — [2]Felix-Bloch-Institut für Festkörperphysik Abteilung Nukleare Festkörperphysik, Linnéstraße 5, 04103 Leipzig

We present our recent progress in implementing an improved readout scheme for the nitrogen-vacancy (NV) center's spin-state combining resonant excitation at low temperature with spin-to-charge conversion. Resonant excitation exploits that the optical excitation spectrum at low temperature has sufficiently narrow linewidths to selectively address the spin-sublevels. In combination with a second laser pulse, a spin-to-charge conversion protocol can be implemented, where the NV center is spin-selectively excited and converted to different charge-states. These are more stable than the initial spin-state and can currently be read-out with near single-shot fidelity.

Compared to the state-of-the-art readout, this work promises to accelerate readout by a factor of up to 100. Besides, laser power in the optical regime can be reduced by orders of magnitude. This reduces the risk of photodamage for future sensing experiments with biological samples.

TT 58.13 Thu 18:15 Theater

Topological Frequency Pump with a Decohering Qubit — •Matthias Droth and David Carpentier — École Normale Supérieure de Lyon, 69007 Lyon, France

The underlying topological order of a physical device can lead to very robust phenomena. The most prominent example is the quantum Hall effect where measurement of the quantized transverse conductance σ_{xy} yields the conductance quantum e^2/h with high accuracy [1,2]. We study topological protection in a system with a driven quantum bit that features a topological phase in frequency space. A recent theoretical work proposed to realize an analog of the half Bernevig-Hughes-Zhang (BHZ) model – which realizes a quantum Hall effect – in the frequency domain by driving periodically a quantum spin, leading to an effective time dependent Hamiltonian [3,4].

It is known that for such a realization of the half-BHZ model, the power transfer rate between the frequency drives, $P_{1\to 2}$, takes the role of σ_{xy} as the quantized and topologically protected quantity [4]. Here, we investigate the robustness of this quantization in a realistic setup that involves a decohering qubit.

[1] K. v. Klitzing *et al.*, Phys. Rev. Lett. **45**, 494 (1980)
[2] M. H. Freedman *et al.*, Bull. Amer. Math. Soc. **40**, 31 (2003) Ch. Nayak *et al.*, Rev. Mod. Phys. **80**, 1083 (2008)
[3] B. A. Bernevig *et al.*, Science **314**, 1757 (2006).
[4] I. Martin *et al.*, Phys. Rev. X **7**, 041008 (2017).