TT 43: Superconducting Electronics: Qubits

Time: Wednesday 9:30–12:45 Location: CHE/0089

TT 43.1 Wed 9:30 CHE/0089

Analysis of Flux Noise in Charge Qubits — •Daniel Kruti and Roman-Pascal Riwar — Peter Grünberg Institute, Theoretical Nanoelectronics, Jülich Research Centre, Jülich, D-52425, Germany & Cologne University

Improving the lifetime of quantum information stored in superconducting qubits is a focal point of contemporary research. However, the modelling of time-dependent flux noise has long been based on simplified lumped-element approaches, neglecting details of the device layout and flux distribution. Building on a recently developed quantum geometric description of Faraday's law of induction, we provide an in-depth analysis of charge qubit relaxation and decoherence rates for various flux noise sources, such as surface spins and the surrounding qubit control hardware. Contrary to standard circuit theory, our treatment reveals that a circuit does not require flux-tunability (e.g. a dc-SQUID) in order to be affected by flux noise, as flux-induced relaxation persists in the single junction limit. We link relaxation and dephasing by a geometry-dependent form factor, allowing experimental 1/f flux noise spectra to be used for quantitative estimates. These suggest that, while surface spins are likely negligible for current qubit performances, far-field flux sources due to the surrounding hardware can, in principle, contribute significantly.

TT 43.2 Wed 9:45 CHE/0089

Observation of two-level systems in superconducting titanium-aluminum-nitride films — •Marius Frohn[1,2], Florian Mezger[1], Maximilian Kristen[1], Jan Nicolas Voss[1], Hannes Rotzinger[1,2], and Alexey Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruhe Institute for Technology (KIT), Germany — [2]Institute for Quantum Materials and Technologies (IQMT), Karlsruhe Institute for Technology (KIT), Germany

Thin films of disordered superconductors are currently the subject of extensive study due to their potential applications in modern quantum circuits and kinetic inductance detectors. While many materials are possible candidates, those with low microwave loss and a high degree of disorder are especially interesting for high impedance circuits. The disordered microscopic structure also favors the presence of intrinsic material defects, some of which behave as two-level systems (TLS)[1]. Found in dielectrics such as surface oxides or tunneling barriers, TLS are a significant source of electromagnetic loss, which limits the coherence of superconducting qubits. It has been recently proposed [2], that applied direct-currents in the disordered superconductors are influencing the observable TLS coupling, e.g. to a microwave resonator. We present microwave spectroscopy measurements of ultra-compact, high impedance resonators made from titanium-aluminium-nitride films. By applying electric fields, we observe TLS strongly interacting with the resonator modes.

[1] M. Kristen et al., Phys. Rev. Lett. 132, 217002 (2024)
[2] T. Liu et al., Phys. Rev. B 111, L180502 (2025)

TT 43.3 Wed 10:00 CHE/0089

Embedding Superconducting Quantum Circuits in a Millimeter-Wave Environment — •Jakob Lenschen[1], Sergei Masis[1], Jürgen Lisenfeld[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Institut für Quantenmaterialien and Technologie (IQMT), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany

Superconducting mm-wave quantum circuits operating at around 100 GHz offer many interesting new possibilities. Compared to microwave implementations, the higher photon energy and wider bandwidth enhance resilience to thermal fluctuations, and speed up qubit manipulations. However, mm-wave measurements at ultra-low temperatures are largely unexplored, and technical challenges demand alternative approaches [1]. The coherence and energy relaxation of superconducting quantum circuits is sensitive to a variety of loss mechanisms, e.g. interference with parasitic modes in the sample box and within the chip. Particular attention is required for mm-waves, as their wavelength is comparable to the dimensions of the dielectric substrate and many other structures in a conventional sample box. We have developed several approaches for coupling superconducting quantum circuits to waveguides, utilizing machined ridge gap waveguides and other techniques. In this presentation, we will discuss embedded superconducting mm-wave quantum chips, parasitic modes, and ways to inhibit or channel them out. We will compare our simulations with the experimental results.

[1] Lenschen et al., arXiv:2411.15058 (2024)

TT 43.4 Wed 10:15 CHE/0089

Niobium-based Josephson junctions for superconducting mm-wave qubits — •Urs Strobel[1], Benedict Rothmund[1], Jakob Lenschen[1], Jonas Kaemmerer[1], Lucas Radke[1], Sergei Masis[1], Jinji Luo-Hofmann[3], Danny Reuter[3], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), KIT, 76131 Karlsruhe, Germany — [2]Institut for Quantum Materials and Technologies (IQMT), KIT, 76131 Karlsruhe, Germany — [3]Fraunhofer-Institut für Elektronische Nanosysteme (ENAS), Chemnitz, Germany

Superconducting quantum circuits operating at millimeter-wave frequencies are an exciting area of research and offer the potential to maintain functionality at temperatures considerably higher than their widely studied centimeter-wave counterparts. The reduced wavelength allows for a smaller circuit footprint and faster qubit manipulation. Implementing such millimeter-wave qubits requires a superconductor with an energy gap above 100 GHz, which renders aluminum unsuitable. However, other conventional superconductors with larger gaps, such as niobium, are available with the technology to produce submicrometer Josephson junctions, key elements for superconducting quantum circuits.

To reduce dielectric losses, we use the low-loss substrate to eliminate extra dielectric layers present in classical niobium-based junction techniques [1]. We will present the concept, design constraints, and low-temperature characteristics. (2024)

[1] Patent pending DPO:02025132612.6 (2025)

TT 43.5 Wed 10:30 CHE/0089

fluxonium qubits inductively coupled to granular aluminum based readout resonators — •li-wei chang, asen Lyubenov georgiev, fabian kaap, christoph kissling, victor gaydamachenko, sergey lotkhov, mark bieler, and lukas grünhaupt — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

The fluxonium qubit is a specific type of superconducting qubit, which has garnered significant interest due to its coherence time in the millisecond range, high gate fidelities on the order of 99.9%, and a large anharmonicity up to several GHz. Recent years have also seen a surge in material studies related to this type of qubit, with a particular focus on high kinetic inductance materials such as granular aluminum (grAl). Three basic components form a fluxonium qubit: a Josephson junction, a capacitor, and a so-called superinductor with an impedance larger than the resistance quantum $R_Q = \frac{h}{4e^2}$. To enable dispersive readout, we employ a high-quality granular aluminum based readout resonator which is inductively coupled to the qubit through a shared inductor. Here, we present our methodology of qubit design, fabrication process and first experimental results.

TT 43.6 Wed 10:45 CHE/0089

Low-crosstalk modular flip-chip architecture with superconducting kinetic-inductively coupled flux-qubit-resonator circuits — •Sören Ihssen[1], Simon Geisert[1], Gabriel Jauma[2,3], Patrick Winkel[1,4,5], Martin Spiecker[1], Nicolas Zapata[1], Manuel Pino[2,7], Juan Jose Garcia-Ripoll[2], and Ioan M. Pop[1,6,8] — [1]IQMT, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute of Fundamental Physics IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain — [3]Applied Physics Department, Salamanca University, Salamanca 37008, Spain — [4]Departments of Applied Physics and Physics, Yale University, New Haven, CT 06520, USA — [5]Yale Quantum Institute, Yale University, New Haven, CT 06520, USA — [6]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [7]Nanotechnology Group, USAL-Nanolab, Salamanca University, Salamanca 37008, Spain — [8]Physics Institute 1, Stuttgart University, 70569 Stuttgart, Germany

We introduce a flip-chip architecture for arrays of coupled superconducting qubits in which each circuit component is placed inside its own microwave enclosure. Unlike conventional flip-chip designs, our qubit chips are electrically floating, enabling straightforward modular assembly of capacitively coupled elements while strongly suppressing microwave crosstalk. We demonstrate the architecture using a chain of three nearest-neighbor coupled generalized flux qubits, where the central qubit serves as a frequency-tunable coupler. This system achieves a transverse coupling on/off ratio of 50, zz-crosstalk of 0.7 kHz between resonant qubits, and >60 dB isolation between outer enclosures.

15 min. break

TT 43.7 Wed 11:15 CHE/0089

Investigation of tunable interactions between quarton flux qubits — •Hossam Tohamy[1], Alex Kreuzer[1], Thilo Krumrey[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]Institute for Quantum Materials and Technologies (IQMT), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Tunable qubits are useful in superconducting quantum processors because they enable high-performance quantum gates. Although transmon-based multiqubit systems are widely used in recent architectures, the quarton flux qubit [1] emerges as a promising alternative, offering a positive anharmonicity that is three to five times larger than in typical transmons. In this work, we present an experimental investigation of quarton flux qubits in a capacitively coupled multiqubit architecture. The qubit inductances are realized using a novel stacked-junction fabrication technology [2]. We performed microwave spectroscopy and time-domain measurements on coupled qubits, demonstrating tunable capacitive coupling between the qubits. We benchmarked the measured coupling strengths against analytical models and RF simulations and found good agreement.

[1] F. Yan et al., arXiv:2006.04130 (2020).
[2] A. Kreuzer et al., arXiv:2503.11437 (2025).

TT 43.8 Wed 11:30 CHE/0089

Improving performance of planar tantalum resonators and transmon qubits on silicon using advanced deposition techniques — Maciej W. Olszewski[1], Lingda Kong[2], •Simon Reinhardt[2], Daniel Tong[2], Shilling Du[3], Gabriele Di Gianluca[4], Haoran Lu[2], Saswata Roy[1], Aleksandra Biedron[5], David A. Muller[2], and Valla Fatemi[2] — [1]Department of Physics, Cornell University, USA — [2]School of Applied and Engineering Physics, Cornell University, USA — [3]Cornell NanoScale Facility, USA — [4]Department of Physics, University of Florida, USA — [5]NY Creates, USA

The cubic phase of tantalum is a very promising material for superconducting transmon qubits, due to its self-limiting surface oxide, low bulk losses, and low kinetic inductance.

We present a novel method of growing high-crystallinity tantalum films on silicon with magnetron sputtering, using a significantly lower substrate temperature than found in literature. Using coplanar waveguide resonators, we measure the losses and microwave performance of our films, achieving single photon quality factors above four million for resonators with gap size of 3-μm. We present first results on transmon qubits based on these low loss tantalum films.

Funding: This prototype was primarily supported by the Microelectronics Commons Program, a DoW initiative, under award number N00164-23-9-G061. Funding for shared facilities used in this prototype was provided by the Microelectronics Commons Program, a DoW initiative, under award number N00164-23-9-G061.

TT 43.9 Wed 11:45 CHE/0089

Microwave pulse shape optimization for enhanced spin excitation in a ^{31}P:^{28}Si ensemble coupled to a superconducting resonator — Patricia Oehrl[1,2], •Ana Strinic[1,2], Tahereh Sadat Parvini[1,2], and Hans Huebl[1,2,3] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

Phosphorus donors in silicon are considered as promising candidates for the realization of microwave quantum memories due to their electron spin transitions in the GHz regime with exceptionally long coherence times [1]. Here, we investigate the transduction of pulsed coherent microwave signals to spin excitations of a spin ensemble. This effectively pulsed electron spin resonance experiment uses a hybrid system consisting of a superconducting lumped-element microwave resonator coupled to a spin ensemble of phosphorus donors in isotopically engineered silicon. By modeling the system using an input-output formalism, we identify optimal pulse shapes and coupling parameters for enabling this excitation transfer. The understanding and optimization is of importance for the implementation of efficient quantum state storage protocols, which are of relevance for microwave quantum memory applications as well as quantum sensing.

[1] M. Steger et al., Science 336, 1280 (2012)

TT 43.10 Wed 12:00 CHE/0089

Quantum dynamics of two XY interacting PT-symmetric non-Hermitian qubits: enhancement of quantum annealing — •Yana Komissarova, Mikhail V. Fistul, and Ilya M. Eremin — Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum 44801, Germany

Quantum information processing devices enable the realization of analog quantum simulations, such as quantum annealing, and offer a promising route toward solving complex computational and combinatorial optimization problems. In this work, we introduce a new type of quantum information platform based on a network of interacting parity-time (PT) symmetric non-Hermitian qubits. The quantum dynamics of individual PT-symmetric non-Hermitian qubits have already been demonstrated experimentally using several approaches, including dilation schemes with digital coupling to an auxiliary qubit. These experiments carried out on a variety of platforms, such as NV centers, superconducting qubits, and superconducting and trapped-ion qutrits, have revealed exceptional points of different orders, as well as PT-symmetry-preserving and symmetry-breaking quantum states. A key next step is the investigation of coherent quantum dynamics in systems of interacting PT-symmetric non-Hermitian qubits. Here, we study both time-independent and time-dependent Hamiltonians relevant for quantum annealing in an exemplary two-qubit non-Hermitian network based on the XY model. We analyze the system in both PT-symmetric and PT-broken regimes to identify conditions that maximize the probability of reaching the ground state after quantum annealing.

TT 43.11 Wed 12:15 CHE/0089

Strongly interacting phases of spins and bosons in circuit QED — •Adrian Paul Misselwitz[1,2,3], Jacquelin Luneau[1,2,3], Enrico Di Benedetto[4], and Peter Rabl[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany — [4]Università degli Studi di Palermo, Dipartimento di Fisica e Chimica–Emilio Segrè, Via Archirafi 36, I-90123 Palermo, Italy

The scalability of superconducting circuit hardware is a promising route for the implementation and exploration of complex many-body systems. In this work, we study emerging phases of matter in a waveguide QED framework, arising from the interplay of competing forces of atom-bound state localization and Kerr-type photon-photon interactions. In addition, we extend our analysis to 1D flatband systems, map out the phase space and characterize the flatband states, which take on a unique form due to the nonlinear photonic dynamics of circuit QED.

TT 43.12 Wed 12:30 CHE/0089

Light-controlled transport across impurities in cavity quantum materials — Lukas Krieger[1], •Debashish Mondal[1,2], Ahana Chakraborty[3], and Peter P. Orth[1,2] — [1]Department of Physics, Saarland University, Campus, 66123 Saarbrücken, Germany — [2]Center for Quantum Technologies (QuTe), Saarland University, Campus, 66123 Saarbrücken, Germany — [3]Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803, USA

We investigate quantum materials placed inside optical cavities in the deep-strong and ultra-strong light-matter coupling regimes. In these regimes, standard perturbative techniques and aprroximation from quantum electrodynamics usch as rotating-wave approximation become unreliable. To address this challenge, we employ the asymptotic decoupling (AD) transformation, a unitary approach that shifts the minimal-coupling interaction to the renormalization of electronic mass and shift of the electronic position.

We examine how strong light-matter coupling affects electron scattering at the impurity site in a one dimensional system. We are analyzing these effects using both low-order perturbation theory and Green-function-based methods to capture higher-order scattering contributions. This work aims to build a framework for understanding scattering phenomena in cavity-embedded quantum materials and to guide future simulations and analytical studies in non-perturbative coupling regimes.