Quantum Information Science Focus Topic
Room 302 - Session QS+AP+EM+MN+NS+SS-ThM

Systems and Devices for Quantum Computing

Moderators: Vivekananda Adiga, IBM, T.J. Watson Research Center, **Kathy-Anne Soderberg**, Air Force Research Laboratory

8:00am **QS+AP+EM+MN+NS+SS-ThM-1 Effects of Environmental Radioactivity on Superconducting Qubits***, L. Cardani, **Ambra Mariani**,* Istituto Nazionale di Fisica Nucleare, Italy **INVITED**

Environmental radioactivity was recently discovered as a potential limit for superconducting quantum bits.

We review recent works proving that ionizing radiation lowers the coherence of singe qubits and induces correlated errors in qubits arrays. We also present preliminary studies showing that operating qubits in a low-radioactivity environment improves their performance. These results fuelled the interest of several European and US groups in further investigating and mitigating radioactivity for next-generation quantum processors.

Using radioactivity measurements and simulations, we estimated the separate contribution of “far” radioactive sources (cosmic rays and laboratory radioactivity) and close materials contamination (chip holder, magnetic shield, …) on a typical chip, focussing on a qubit prototype developed within the SQMS center. We present such contributions and discuss the possibility of mitigating them in "standard" qubit laboratories or, eventually, in deep underground facilities.

8:40am **QS+AP+EM+MN+NS+SS-ThM-3 Dynamics of a Dispersively Coupled Transmon in the Presence of Noise from the Control Line***, **Antti Vaaranta**,* Bluefors Oy, Finland*; M. Cattaneo,* University of Helsinki, Italy*; R. Lake,* Bluefors Oy

In this talk we present theoretical results from a complete description of transmon qubit dynamics in the presence of noise introduced by an impedance-matched resistor (50 Ohm) that is embedded in the qubit control line, acting as a noise source [1]. We derive a model to calculate the qubit decoherence rate due to the noise emanating from this noise source [2]. The resistor is treated, using the Caldeira-Leggett model, as an infinite collection of harmonic LC-oscillators making it a bosonic bath [3]. To obtain the qubit time evolution affected by this remote bath, we start with the microscopic derivation of the Lindblad master equation using the dispersive Jaynes-Cummings Hamiltonian with added inductive coupling to the bath. To solve the resulting master equation, we transform it into a block diagonal form by exploiting its underlying symmetries following Ref. 4. The block diagonalization method reveals that the long time decoherence rate is given by the slowest decaying eigenmode of the Liouvillian superoperator. Moreover, when the readout resonator is in the equilibrium thermal state, the rate of exponential decoherence of the qubit is almost exactly exponential for all times with the predicted rate given by the slowest decaying eigenmode. We also study how the decoherence rate depends on the temperature of the noise source and explore the strong and weak dispersive coupling regimes. The model captures the often used dispersive strong limit approximation of the qubit decoherence rate being linearly proportional to the number of thermal photons in the readout resonator. However, in the dispersive weak limit we predict remarkably better decoherence rates. The model parameters are completely determined by the values of the circuit components, allowing for the exact study of the dynamics on the level of each individual circuit element.

[1] S. Simbierowicz et al., Rev. Sci. Instrum. 92, 034708 (2021).

[2] A. Vaaranta, Study of environmental effects on a dispersive transmon qubit, MSc thesis, Univ. of Helsinki, (2022).

[3] M. Cattaneo and G. Paraoanu, Adv. Quantum Technol. 2100054 (2021).

[4] M. Cattaneo et al., Phys. Rev. A 101, 042108 (2020).

9:00am **QS+AP+EM+MN+NS+SS-ThM-4 Accurate Microwave Characterization for Superconducting Quantum Technology***, **Slawomir Simbierowicz**,* Bluefors Oy, Finland

Recent breakthroughs in quantum technology have highlighted a need for methods for accurate characterization of cryogenic microwave devices at millikelvin temperatures. In this two-part talk, I will highlight recent progress on microwave measurements at the quantum device reference plane including: (1) system noise characterization of amplifier chains, and (2) calibrated S-parameters of qubit drive line components.In the first part, I will discuss an impedance-matched variable temperature noise source which can be installed in a coaxial line of a cryostat. Using the method of hot/cold source with many input noise temperature points, the system noise temperatures of qubit readout amplifier cascades can be determined. I present measurement results in terms of added noise in Kelvins or photons from a four-wave (4WM) mixing traveling wave parametric amplifier (TWPA) [1], a Josephson parametric amplifier [2], 3WM TWPA, and high electron mobility transistor amplifiers [1].In the second part of the talk, I will present measurements of the 1-port S-parameters of qubit drive line components using a data-based short-open-load calibration at a temperature of 30 mK [3]. The measurement enables us to model systematic errors in qubit state preparation due to non-idealities in qubit control lines such as impedance mismatch. We model the results using a master equation simulation of all XY gates performed on a single qubit. Our work directly addresses the gap between electrical engineering parameters of individual measurement components and performance of the quantum device itself.

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[1] Slawomir Simbierowicz, Visa Vesterinen, Joshua Milem, Aleksi Lintunen, Mika Oksanen, Leif Roschier, Leif Grönberg, Juha Hassel, David Gunnarsson, and Russell E. Lake, "Characterizing cryogenic amplifiers with a matched temperature-variable noise source", Rev. Sci. Instr. **92**, 034708 (2021)

[2] Mustafa Bal et al., “Overlap junctions for superconducting quantum electronics and amplifiers”, Appl. Phys. Lett. **118**, 112601 (2021)

[3] Slawomir Simbierowicz, Volodymyr Y. Monarkha, Suren Singh, Nizar Messaoudi, Philip Krantz, and Russell E. Lake, "Microwave calibration of qubit drive line components at millikelvin temperatures", Appl. Phys. Lett. **120**, 054004 (2022)

9:20am **QS+AP+EM+MN+NS+SS-ThM-5 Improving Qubit Performance Through Engineering of the Substrate-Josephson Junction Interface***, **Cameron Kopas**, H. Cansizoglu, R. Cochrane, B. Ercan,* Rigetti Computing*; D. Goronzy, C. Torres-Castanedo,* Northwestern University*; J. Oh,* Ames Laboratory*; A. Murthy,* Fermi Lab*; E. Lachman,* Rigetti Computing*; A. Romanenko, A. Grassellino,* Fermi Lab*; M. Kramer, L. Zhou,* Ames Laboratory*; M. Bedzyk,* Northwestern University*; J. Mutus,* Rigetti Computing*; M. Hersam,* Northwestern University*; K. Yadavalli,* Rigetti Computing **INVITED**

The performance of a superconducting qubit is often limited by dissipation and two-level systems (TLS) losses. The dominant sources of these losses are believed to come from interfaces and surfaces, likely as a result of fabrication processes, materials, or atmospheric exposure. We show that certain chemical surface treatments can be used to modify the silicon surface before Josephson junction deposition, reducing the number of strongly-coupled TLS, and improving T1. While identifying specific microscopic sources for loss and TLS is still an open question, targeted characterization of test structures will show which physical changes correlate with performance improvements. We report chemical, structural, and low-temperature microwave characterization of superconducting qubits and films fabricated with different Si surface treatments.

11:00am **QS+AP+EM+MN+NS+SS-ThM-10 Design and Optimal Control of Superconducting Qubits to Achieve Quantum Speed Limits***, **Meenakshi Singh**,* Colorado School of Mines, USA **INVITED**

Fast two-qubit entangling gates are essential for quantum computers with finite coherence times. The finite interaction strength between qubits introduces a theoretical speed limit on the speed of these two-qubit entangling gates. This speed limit has been analytically found only for a two-qubit system under the assumption of negligible single qubit gate times. Here, we demonstrate such a speed limit experimentally using optimal control on two superconducting transmon qubits with a fixed capacitive coupling and finite single qubit gate times. Furthermore, we investigate the effect of additional couplings on the speed limit, both through introduction of an ancillary qubit as well as through utilization of higher transmon energy states. Finally, we discuss the generalization to many qubit systems where properly leveraging all available couplings can provide dramatic speedups.

11:40am **QS+AP+EM+MN+NS+SS-ThM-12 Atomic Scale Processing for Quantum Computing**, ***Harm Knoops,*** Oxford Instruments Plasma Technology, Netherlands **INVITED**

With the increasing technological readiness of quantum technology (QT) the field has to start focussing on scalable fabrication methods for quantum bits (qubits) and quantum circuits. This contribution will focus on the enabling role atomic scale processing (ASP) methods such as atomic layer deposition (ALD) and atomic layer etching could play in scaling of QT. The main focus will relate to superconducting qubits and processing of superconducting nanolayers.

Superconducting nanolayers (metals, metal-nitrides) are required for various roles in QT including use in resonators, single-photon detectors, and interconnects.[1] The electrical contacts needed to control the qubits will require non-planar connectivity using superconducting interconnects.[2]Adequate routes for fabrication of planar superconducting layers exist, but for 3D interconnects or through-silicon vias (TSVs), the excellent conformality of ALD nanolayers could be essential. Although for resonators conformality is not a challenge, ALD's thickness control and uniformity should allow high-quality resonators with low spread in properties. For these superconducting nanolayers, metal-nitride compounds have been identified as particularly promising since they exhibit limited surface oxidation (compared to pure metals such as Nb), combined with relatively high critical temperature (T_c) for superconductivity (e.g., as compared to Al). Despite the challenges that the synthesis of high-quality nitrides pose, plasma ALD has demonstrated the capability to deposit high-quality nitrides (e.g., low O content, high electrical conductivity).[3] Furthermore, substrate-biased plasma-ALD offers unique opportunities to obtain and tune high-quality nitrides.[4] For removal of surface oxides or smoothing of resonator surfaces and interfaces, approaches combining ALD and ALE could be of interest.[5] Both ALD and ALE are envisaged to be key tools to allow scaling of these devices and advance the QT field.

References

1. Giustino et al., *J. Phys. Mater.***3**, 042006 (2021)
2. Kjaergaard et al., *Annu. Rev. Condens. Matter Phys.***11**, 369 (2020)
3. Knoops et al., *J. Vac. Sci. Technol. A***37**, 030902 (2019)
4. Faraz et al., *ACS Appl. Mater. Interfaces***10**, 13158 (2018)
5. Chittock et al, *Appl. Phys. Lett.* **117**, 162107 (2020)

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