Quantum Science and Technology
Room 304 - Session QS2-MoA

Surfaces, Interfaces, Defects, and Microwave Loss in Superconducting Devices

Moderators: Suman Bhaumik, TEL Technology Center, America, LLC, **Drew Rebar**, Pacific Northwest National Laboratory, **Preetha Sarkar**, Brookhaven National Laboratory

4:00pm **QS2-MoA-11 Control of Defects and Interfaces for High–Coherence Superconducting Qubits***, **Peter Sushko**,* Pacific Northwest National Laboratory **INVITED**

Superconducting qubits have advanced rapidly, yet coherence and device-to-device reproducibility remain limited by material imperfections concentrated at surfaces, buried interfaces, and ultrathin native surface oxides. These regions occupy a small fraction of the device volume, yet can dominate loss via two-level systems associated with defects located there. I will highlight materials science challenges that must be addressed to enable scalable superconducting quantum processors, emphasizing the need for precise synthesis and tightly controlled processing of films and interfaces that form qubits and their circuit elements.

We will cover a few examples of how the combined input from high-resolution microscopic and spectroscopic techniques, together with ab initio simulations, has provided mechanistic, atomic-level insights into the processes leading to the formation of these interfaces and their properties. First, we discuss an atomistic picture of Ta surface oxidation and the formation of a semi-ordered TaO_{1-x} suboxide at the boundary between the amorphous Ta_2O_5 and metallic Ta. Building on this mechanistic understanding, we demonstrate a materials-by-design strategy to suppress Ta oxidation using a reactive Mg and noble-metal capping layers. Beyond free surfaces, we discuss the Ta/sapphire interfacial layer and show that sapphire surface termination prior to Ta deposition controls the heterojunction structure, Ta film orientation, and likely the density of grain boundaries and defect traps in the Ta film. Extending these concepts to Nb, we show how controllable processing can deliberately re-engineer oxides, producing thinner, smoother Nb oxides and improving resistance to oxygen exchange/diffusion. Experiments and simulations together indicate that hydrogen segregates to the oxide/metal interface and can migrate during oxide evolution. Finally, we present a scalable passivation strategy for qubit-grade Nb that uses encapsulation and show how structural characterization and ab initio simulations elucidate the mechanisms of atomic rearrangement and stabilization that suppress oxide formation.

Overall, improving coherence and yield requires atomic-level insight to enable predictive control of oxidation, intermixing, and impurity-induced effects, thereby transforming native interfaces into engineered, reproducible materials systems.

4:30pm **QS2-MoA-13 Microscopic Impact of Sapphire Preparation on Losses in Superconducting Tantalum Thin Films***, **Aswin Kumar Anbalagan**, Hyeongjun Koh,* Brookhaven National Laboratory*; Suhas Ganjam,* Yale University*; Ruoshui Li, Daniel Olds,* Brookhaven National Laboratory*; Vesna Stanic,* IBM T. J. Watson Research Center*; Jean-Jordan Sweet,* IBM TJ Watson Research Center*; ChenYu Zhao, Shuoyuan Huang,* Brookhaven National Laboratory*; Jinhyun Cho,* Stony Brook University/Brookhaven National Laboratory*; Ananya Chattaraj, Kim Kisslinger, Sooyeon Hwang, Steven L. Hulbert,* Brookhaven National Laboratory*; Luigi Frunzio, Robert J. Schoelkopf,* Yale University*; Mingzhao Liu, Judith Yang, Andrew L. Walter, Andi M. Barbour,* Brookhaven National Laboratory

Understanding the microscopic origins of dielectric loss in superconducting quantum devices is essential for improving qubit coherence and scalable production. Here, we investigate the relationship between crystalline ordering, interfacial structure, and superconducting loss in tantalum (Ta) thin films deposited on c-plane sapphire substrates prepared using edge-fed film growth (EFG) and heat exchange method (HEM) sapphire. HEM sapphire substrates were chemically cleaned and selectively annealed at 1200 °C in an oxygen-rich environment prior to high-temperature Ta deposition by DC magnetron sputtering. Superconducting measurements reveal that Ta films grown on non-annealed EFG sapphire exhibit lower surface loss factors, higher residual resistivity ratio (RRR), and sharper superconducting transitions compared to annealed HEM sapphire, despite the care taken to fabricate HEM samples with stronger epitaxial ordering that may be conventionally anticipated to improve superconducting performance. Synchrotron X-ray diffraction (XRD) and X-ray reflectivity (XRR) measurements reveal differences in epitaxial ordering, rotational disorder, and interfacial oxide layers. Using four-dimensional scanning transmission electron microscopy (4D-STEM), Ta grown on both EFG- and HEM-samples were found to exhibit single crystallinity with (111)Ta || (0001) sapphire orientation. However, the HEM-annealed sample contains ~100 nm-wide secondary grains associated with local epitaxial breakdown driven by elastic strain relaxation, whereas the EFG-non-annealed sample shows gradual in-plane lattice rotation without secondary grain formation, suggesting strain accommodation through lattice curvature. Altogether, these results suggest that sapphire surface preparation, substrate homogeneity, and interface chemistry strongly influence microwave loss in superconducting Ta devices and highlight the need for further optimization of sapphire processing and early-stage film growth conditions.

4:45pm **QS2-MoA-14 A Comparative Study of Niobium Superconducting Resonators on Silicon and 4H-Silicon Carbide Substrates***, Marcelo Velasco Forest, **Joseph Falvo**,* Quantum Collaborative Research Corps & Department of Physics, University of Maryland, College Park*; Kiana Reed,* Department of Physics and Astronomy, University of California, Irvine*; Ivan Lainez, Kasra Sardashti,* Quantum Collaborative Research Corps & Department of Physics, University of Maryland, College Park

Energy loss from two-level systems (TLS) at metal–dielectric and substrate interfaces continues to limit coherence in superconducting quantum circuits. We investigate whether substrate selection and surface preparation can suppress TLS-related loss by comparing niobium (Nb) coplanar-waveguide resonators fabricated on silicon (Si) and 4H-silicon carbide (SiC). Nb films (~150 nm) are deposited by DC magnetron sputtering using a standardized baseline process. Substrate preparation spans a controlled matrix of ex-situ and in-situ treatments, including solvent sonication, O_2 plasma, piranha clean, and HF clean by dip and vapor methods.

TLS-related losses and the effects of different preparation methods were determined from fitting resonator complex transmission, S_{21}, to well-tested theoretical models. We will report a comparison of Si and SiC under identical deposition conditions, as well as the surface preparation procedure that yields the lowest losses for each substrate. The primary outcome is a ranked set of substrate/preparation combinations that maximize single-photon internal quality factor and minimize inferred TLS-related loss.

5:00pm **QS2-MoA-15 A Comparative Study of the Properties of Sputter Deposited Platinum Silicide Thin Films of Varying Thicknesses for Scalable Superconducting Quantum Devices***, **Soorya Suresh Babu**, Ananya Chattaraj, Aswin Anbalagan,* Brookhaven National Laboratory*; Mingzhao Liu,* Brookhaven National Laboratory and State University of New York at Stony Brook*; Charles Black, Tharanga Nanayakkara, Andi Barbour,* Brookhaven National Laboratory

Josephson junction-based superconducting quantum circuits are a strong platform for quantum computing, and materials compatible with standard CMOS processing would allow large-scale manufacturing of quantum devices in semiconductor fabs. Transition metal silicides are promising in this regard, and platinum silicide is of particular interest for its long superconducting coherence length (~80 nm at 0 K), thermal and chemical stability, and established use in silicon foundries as .

We report the electrical and structural characterization of PtSi thin films 2-10 nm thick, formed by room temperature RF sputter deposition of platinum in an argon plasma onto high-resistivity Si(100) substrates, followed by silicidation via rapid thermal processing at 600 °C in forming gas for 120s. Transport measurements down to 400 mK show that Tc decreases from 0.9 to 0.7 K and RRR decreases from 1.9 to 1.4 as thickness is reduced. SEM and AFM confirm that the films remain continuous, with roughness increasing as thickness decreases.X-ray reflectivity (XRR) performed at the National Synchrotron Light Source II provides further detail about film thickness, density, and interfacial roughness, confirming formation of the PtSi phase rather than Pt_2Si. These results establish how the superconducting and structural properties of PtSi evolve across this thickness range and identify the films best suited to constriction Josephson junctions and microwave resonators.

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