Quantum Science and Technology
Room 304 - Session QS-MoM

Qubit Modalities I — Hybrid Superconducting–Semiconducting Quantum Devices

Moderators: Dr. Aranya Goswami, Nokia Labs, **Dr. Dave Pappas**, Rigetti Computing

10:00am **QS-MoM-1 Quantum Devices based on Sn-InAs Nanowire Josephson Junctions***, **Sergey Frolov,*** University of Pittsburgh **INVITED**

I will discuss superconducting qubits and parametric amplifiers based on hybrid superconductor-semiconductor Josephson junctions. The basic physics of these platforms is fairly understood and non-controversial. The bigger circuits tend to use similar materials, such as aluminum. It is a great superconductor for device applications. But similar qubits can also be made out of different materials which come with larger gaps, stronger spin-orbit interaction, electrical and not magnetic tunability and other nominal advantages. We are working on unexplored materials for those, namely Sn-based InAs nanowire Josephson junctions. Of course new materials are less mature as device platforms, but trying to make them perform can offer valuable lessons and expand our understanding of what works and why. Our InAs-Sn transmonos have reached a T1 relaxation time of 27 microseconds, and T2 dephasing times of 18 microseconds. We also report reduced nonlinearity beyond the short junction limit due to higher-order Josephson harmonics. Our parametric amplifiers operate both in the four-wave mixing mode as well as in the three-wave mixing mode, driven by the unconventional Josephson relation. We also demonstrate Andreev qubits based on nanowires, including the spectroscopy of a perfectly transmitting Majorana-like Andreev bound state.

10:30am **QS-MoM-3 Transport Study of SQUID Devices on Ge Quantum Well for Protected Superconducting Qubit***, **Shukai Liu,** Adhilsha Parachikunnumal, Joshua Thompson, Kasra Sardashti,* University of Maryland College Park

Superconductor-semiconductor (super-semi) hybrid Josephson junctions (JJs)emerged as a promising platform for a protected superconducting qubit with a π-periodic potential in phase. The π-periodic potential is achieved by leveraging the non-sinusoidal current-phase relation (CPR) of the super-semi JJs and the phase interference between JJs in a SQUID loop. In this talk, we share our progress toward realizing a moderately-protected superconducting qubit based on super-semi JJs realized on a Ge quantum well(QW), which promises a high baseline coherence from not only the parity protection but also the high- purity Si substrate. We focus on the transport measurement of SQUID devices on Ge QW to extract the current-phase relation at half-integer flux quanta, aiming to optimize the device parameters for qubit protection against both depolarization and dephasing.

10:45am **QS-MoM-4 Characterizing single and double quantum dots with quenched charging energy in semiconductor PbTe nanowires***, **Seth Byard**, Maksim Gomanko,* University of Pittsburgh*; Tongxie Zhang, Shixiong Zhang,* Indiana University Bloomington*; Sergey Frolov,* University of Pittsburgh

PbTe is a IV-VI narrow-bandgap semiconductor with potential utility for novel topological or spin qubits. One of PbTe's most notable characteristics is its large static dielectric constant, which exceeds 1000 at cryogenic temperatures and thus results in quenched charging energy in hosted quantum dots (QDs). Here we present our findings from transport measurements of QD systems defined electrostatically in PbTe nanowire devices and examine the implications of these results for our ongoing development of PbTe spin qubits.Our samples display large and highly anisotropic spin-orbit interaction (SOI) strengths and effective Landé g-factors, both of which are generally desirable properties for spin qubits. We characterize these anisotropies through the use of an externally applied magnetic field with variable angle. We discuss our analysis and interpretation of these data, focusing on how they relate to PbTe's rocksalt crystal structure.We additionally report the definition and control of double quantum dots in such systems. We find charge stability diagrams distinguished by the spin degeneracy of all transport resonances at zero magnetic field. We show the fourfold splitting of high-bias triangles in an applied magnetic field to illustrate the lifting of spin degeneracy via the Zeeman effect. We also identify patterns of transport resonances within these high-bias triangles and discuss their possible physical origins.

11:00am **QS-MoM-5 Sn–Inas Nanowire Josephson Parametric Amplifiers as Probes of Hybrid Junction Nonlinearity***, **Amritesh Sharma**, Amrita Purkayastha,* University of Pittsburgh, USA*; Param Patel,* Yale University*; Subhayan Sinha, Shreyas Asodekar,* University of Pittsburgh, USA*; An-Hsi Chen,* Grenoble-INP/CNRS, France*; Connor Dempsey,* University of California Santa Barbara*; Kun Zuo,* University of Sydney, Australia*; Chris Palmstrom,* University of California at Santa Barbara*; Moira Hocevar,* Grenoble-INP/CNRS, France*; Michael Hatridge,* Yale University*; Sergey Frolov,* University of Pittsburgh, USA

Hybrid semiconducting Josephson junctions, where proximity-induced superconductivity in a spin–orbit-coupled nanowire can be tuned by gate voltage and magnetic field, offer a rich platform to explore nonlinear quantum dynamics beyond what conventional Josephson tunnel junctions provide. We embed single Sn-InAs nanowire Josephson junctions carrying supercurrents of order 0.5 μA into NbTiN coplanar waveguide resonators to realize Josephson parametric amplifiers (JPAs) and probe the junction's intrinsic nonlinearity in a controlled microwave environment. The intrinsic quartic (Kerr) nonlinearity drives a four-wave mixing process yielding up to 20 dB of parametric gain in reflection, building on our prior demonstration of nanowire-based transmon qubits[1,2] and further establishing Sn-InAs nanowire junctions as effective nonlinear circuit elements at microwave frequencies.

Beyond amplification, we use the parametric response as a sensitive probe of how electrostatic gating, which tunes the resonant frequency by hundreds of MHz, and applied magnetic field modify the junction's nonlinear character. In select devices, we observe signatures of Kerr coefficient suppression and three-wave mixing, pointing to the activation of nonlinear terms beyond the standard quartic nonlinearity. These observations are consistent with higher-order or odd-order contributions expected when strong spin–orbit coupling and time-reversal symmetry breaking lift the constraints that ordinarily confine conventional Al/AlOx junctions to purely four-wave mixing processes [3]. These results establish the Sn-InAs nanowire JPA as both a functional quantum amplifier and a spectroscopic tool for studying field- and gate-tunable nonlinearity in hybrid Josephson systems.

References:

[1] A. Purkayastha et al., *Nano Lett.* 26, 2074 (2026).
[2] A. Purkayastha et al., arXiv:2603.26895 (2026).
[3] T. Reza et al., *SciPost Phys.* 20, 089 (2026).

11:15am **QS-MoM-6 Optimizing Ge/SiGe Quantum Well Interfaces for Low-Noise Spin Qubits via Surface Passivation***, **Iris Boateng**, Rebika Makaju, Giovanni Franco-Rivera, Kasra Sardashti,* Quantum Collaborative Research Corps & Department of Physics, University of Maryland, College Park MD, USA

Silicon-Germanium (SiGe) heterostructures are one of the leading platforms for semiconductor-based spin qubits. In silicon-based heterostructures, quantum dots (QDs) are defined electrostatically by lithographically patterned surface gates, allowing the confinement of a few electrons or holes and the manipulation of their spin degree of freedom for quantum information processing. However, a critical challenge in fabricating low-noise Ge/SiGe quantum dots is controlling the interface between the semiconductor and the high-κ gate dielectric, such as Al_2O_3. Imperfections at this boundary, primarily driven by the formation of unstable Ge-O bonds, lead to a high density of interface traps (D_{it}) [1]. These charge traps act as prominent sources of electrical noise, degrading device tune-up reliability and coherence [2]. In this work, we explore a systematic series of pre-deposition surface passivation methods designed to mitigate these interfacial defects and minimize D_{it}. We investigate a range of in-situ and ex-situ chemical treatments applied prior to atomic layer deposition (ALD). These protocols are specifically targeted at suppressing the formation of deleterious Germanium suboxides and promoting stable, stoichiometric bonding across the semiconductor-dielectric boundary. To evaluate the physical and chemical efficacy of these varying passivation techniques, X-ray photoelectron spectroscopy (XPS) is utilized to meticulously characterize the Silicon and Germanium chemical specie concentrations after each processing step. By correlating these chemical depth profiles with frequency dependent capacitance-voltage (C-V) measurements performed on Metal-Oxide-Semiconductor Capacitor (MOSCAP) devices, our aim is to establish a deterministic link between the targeted interface chemistry and the resulting electrical trap density. Ultimately, this comparative analysis aims to identify optimal interface engineering protocols, providing a clear pathway for the fabrication of highly stable, low-noise quantum dot devices for semiconducting based quantum computing architectures.

References:

[1] Duygu, K. et al. Microelectronic Engineering 88, 3428-3431 (2011).

[2] Leonardo, M. et al. Commun. Mater. 5, 151 (2024).

11:30am **QS-MoM-7 A Rapidly Iterable, Materials-Agnostic Platform for Correlating Loss in Superconducting Qubits*, Mihir Pendharkar,*** Stanford University **INVITED**

Most superconducting qubits use Josephson junctions made by angled evaporation, which ties the device to a narrow set of materials and processes. I will share our group's work on a junction approach that loosens these constraints. By decoupling junction synthesis from device geometry — the essence of a trilayer architecture — the junction becomes a designer element whose materials, barrier, and layering are chosen deliberately and iterated rapidly. The approach is, in a useful sense, materials-agnostic, since it accommodates many material systems; yet that same freedom makes it deeply materials-focused, turning the junction stack into a controlled experimental variable. It also extends naturally across qubit geometries, from transmons to mergemons and beyond, and supports industry-scalable practices such as lift-off-free junction fabrication.

I will delve into the novel junction materials this approach makes accessible and how they push qubit operation toward higher frequencies and temperatures than conventional devices reach. From there I will turn to what synchrotron x-ray techniques uncover about a working junction — the buried interfaces, disorder, and composition that define its true nature within the qubit and that electrical measurements leave hidden. Threading these together is a fast loop — design a junction, build it, measure it, resolve its structure — through which we aim to draw direct, microscopic correlations between materials and the sources of loss in superconducting qubits.

Quantum Science and Technology
Room 304 - Session QS1-MoA

Scalable Superconducting Qubits, Materials, and Integration

Moderators: Dr. Ekta Bhatia, NY CREATES, **Dr. Aswin Anbalagan**, Brookhaven National Laboratory

1:30pm **QS1-MoA-1 Towards Scalable, Available, and Capable Superconducting Qubits***, **Valla Fatemi**,* Cornell University **INVITED**

In this seminar, I will present our team's recent efforts in developing high-performance superconducting qubits. Topics will include improving performance and processing windows of base layer films made from niobium and tantalum on silicon substrates. Particularly, this effort includes a reduction of the substrate temperature well into the back-end-of-the-line process window via use of krypton as a sputtering gas. Transmon qubits with a twenty-micron capacitor gap made from these films exhibit quality factors exceeding fifteen million (coherence times up to 1 millisecond), demonstrating their performance with processing that is compatible with a greater number of tools. Additionally, I will highlight high-performance qubits made with Josephson junctions formed by a resist-free fabrication method and our efforts to make high-performance qubit fabrication more broadly available through developing standard process flows at the Cornell Nanoscale Facility.

This prototype was partially supported by the Microelectronics Commons Program, a DoW initiative, under award number N00164-23-9-G061. Partial 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.

2:00pm **QS1-MoA-3 Barrier Height Engineering at V3Si-Si Interfaces for Quantum Device Applications***, **Preetha Sarkar,*** Brookhaven National Laboratory*; Zhujun Huang, Ting Cao, Charles Marcus,* University of Washington*; Charles Black, Mingzhao Liu,* Brookhaven National Laboratory

The superconducting A15 phase of vanadium silicide (V_3Si) is a promising candidate for quantum device applications. V_3Si-Si based Josephson junctions can be used to fabricate voltage-controlled transmon qubits, also known as gatemons. Apart from higher temperatures of operation due to the higher T_c (~ 17 K) of V_3Si, these superconductor-insulator-superconductor type gatemons are also expected to have longer coherent times. Because V_3Si is almost perfectly lattice-matched to Si, fabrication of these qubits is compatible with existing CMOS technology.

In order to realize V_3Si-based gatemons, it is crucial to understand how the V_3S-Si Schottky barrier height is tuned by the carrier density in silicon. In this talk, I report a method for reproducibly synthesizing superconducting vanadium silicide on Si substrates at various levels of doping and a systemic temperature-dependent transport study to determine the V_3S-Si Schottky barrier height. It is observed that, as compared to undoped Si, doping increases the barrier transparency by reducing both barrier height and width. Interestingly, n-type doping in Si lowers the barrier height more than p-type doping. We also demonstrate a gate-voltage tunable V_3Si-Si-V_3Si based superconducting field effect transistor.

These results evidence that V_3Si is a suitable platform for realizing voltage-based Josephson field effect transistors (JoFETs) and can have a significant broader impact not only in the field of semiconductor-based quantum computing research but also in the development of novel energy-efficient microelectronics.

2:15pm **QS1-MoA-4 Transition Metal Silicides: A New Class of Material Candidates for Superconducting Quantum Circuit Applications***, **Mingzhao Liu,*** Brookhaven National Laboratory **INVITED**

For future superconducting qubits development, implementations that are compatible with silicon-based microelectronics (e.g., CMOS), have the best outlook to enable rapid scale-up and high levels of device uniformity and reliability. This vision takes advantage of the vast knowledge obtained from studying transition metal (TM) silicides as gate and low-resistance interconnect materials in CMOS implementations, and that many TM silicides, such as CoSi2, PtSi, and V3Si, are superconductors. The talk will feature the thin film material synthesis and characterization of several superconducting TM silicides that have transition temperatures ranging from just below 1 K to above 10 K. By using standard nanolithography techniques, these TMSi thin films can be turned into relevant quantum information devices, such as Josephson weak links and microwave resonators. In particular I will discuss the application of PtSi, a B31 noble metal silicide that has superior chemical stability and long superconducting coherence length (~100 nm), for application in constriction-type, co-planar Josephson junctions.

2:45pm **QS1-MoA-6 Niobium Air Bridge Fabrication and Characterization for Superconducting Quantum Devices***, **Colin Myers**, Haozhi Wang, Eli Bader,* University of Maryland, College Park*; Ben Palmer,* Laboratory for Physical Sciences*; Kasra Sardashti,* University of Maryland, College Park

Operation of superconducting qubits at high frequencies and elevated temperatures requires materials with larger superconducting gaps, not only for Josephson junctions but also for surrounding circuit elements such as airbridges and crossovers. This motivates the development of airbridge fabrication using high-gap materials such as niobium (Nb). However, sub-micron Nb airbridges are challenging to realize due to the combined demands of fine lithographic definition, mechanical stability, clean interfaces, and robust Nb deposition. In particular, internal stress, morphology, step coverage, and process compatibility must be carefully controlled to obtain continuous and reliable suspended bridge structures. In this talk, we compare different methods of Nb airbridge fabrication, including two-photon and grayscale lithography. We will also discuss the DC and microwave performance and loss characterizations of various devices, including suspended wires and superconducting resonators.

3:00pm **QS1-MoA-7 Scalable Quantum Computation with Integrated Superconducting Electronics***, **Igor Vernik**, Caleb Jordan, Aaron Somoroff, Luigi Di Palma, Alex Kirichenko, Kan-Ting Tsai, Meng-Ju Yu, Jason Walter, Adam Weis, Chris Checkley, Oleg Mukhanov, Daniel Yohannes, Shu-Jen Han,* SEEQC **INVITED**

As quantum computing processors continue to increase in size, there is growing interest in developing cryogenic electronics to address the challenges associated with conventional brute-force approaches to system scaling. Single Flux Quantum (SFQ) technology, implemented using a multilayer niobium (Nb) process and adapted for operation near quantum processors at millikelvin temperatures, offers a promising alternative to remote, bulky, and power-hungry room-temperature electronics. SEEQC's digital quantum management approach places energy-efficient SFQ (ERSFQ) circuits in close proximity to qubits within a multi-chip module (MCM) featuring tightly controlled inter-chip spacing. This architecture enables extremely low power dissipation, compatible with the limited cooling capacity of a typical dilution refrigerator, while maintaining high processing speeds and low error rates. In this presentation, we describe our multilayer fabrication and MCM assembly processes. We demonstrate that, by deploying digital ERSFQ circuitry in close proximity to qubits at millikelvin temperature, all essential functions required to operate a full-stack quantum computer can be realized, including digital qubit charge control, magnetic flux control, and qubit readout.

3:30pm **QS1-MoA-9 Thermal Laser Evaporation of Superconducting Nb Films***, **Yifei Yan**, David Catherall, Finley Donachie, Austin Minnich,* California Institute of Technology

Niobium thin films are widely used in superconducting electronics and quantum devices, where film thickness, microstructure, and interfaces strongly influence superconducting properties. Despite mature deposition techniques such as sputtering, evaporative techniques are attractive because their near-equilibrium growth enables improved control over film phase and microstructure. However, conventional evaporation approach is limited for refractory elements such as Nb due to the high temperatures required to reach sufficient vapor pressure. Thermal laser evaporation (TLE) addresses this by using localized laser heating with almost arbitrary power density to reach any desired evaporation temperatures. Here, we report the deposition of Nb thin films using a home-built TLE system, in which a continuous-wave 1kW laser (1070nm) is focused onto a Nb target under ultrahigh vacuum to generate an evaporation flux. We examine the thickness-dependent superconducting transition behavior of the films by physical property measurement system (PPMS). Structural, chemical, and surface morphological properties are characterized using x-ray diffraction (XRD), x-ray photoelectron spectroscopy (XPS), and atomic force microscopy (AFM).

Quantum Science and Technology
Room 304 - Session QS2-MoA

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

Moderators: Dr. Suman Bhaumik, TEL Technology Center, America, LLC, **Dr. Drew Rebar**, Pacific Northwest National Laboratory, **Dr. 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 Engineering the α-Ta/Sapphire Heterostructure: Phase Diagrams, Single-Crystal Growth, and Interface-to-Oxide Characterization for Next-Generation Quantum Devices***, **Joseph Perry Corbett**,* Miami University Ohio

Superconducting qubits are one of the leading candidates for quantum computers capable of surpassing modern supercomputers on specific problems, with steady progress over the last 20 years increasing both quantum state lifetimes and qubit counts. The recent demonstration of α-Ta thin film qubits with coherence times of 0.5 ms, alongside the well-recognized impetus in the QISE community for fundamental materials science on the insulator/superconductor heterostructure, motivates the work presented here. We perform a comprehensive multi-faceted investigation of sputter-grown Ta thin films on sapphire, integrating studies of phase selectivity, single-crystal epitaxy, and thickness-dependent microstructure alongside first-principles calculations of interfacial energetics and surface oxidation. Phase diagrams constructed for DC magnetron sputtering on c-plane Al_2O_3 (with oxygen partial pressure spanning 5.5×10^{-11} to 2.23×10^{-4} Torr and substrate temperatures from 300 to 900 °C) demonstrate that elevated temperatures exclusively stabilize α-Ta while increased oxygen at low temperatures drives single-phase β-Ta formation, with mixed α/β coexistence at intermediate conditions; complementary measurements resolve phase-dependent surface morphologies and work function values relevant to superconducting performance. Sputter epitaxy at 650 °C followed by UHV annealing at 1000 °C yields single-crystal α-Ta in multiple orientations on c- and a-plane sapphire, as confirmed by XRD pole figures, rocking curves, asymmetric scans, and XRR modeling. Thickness-resolved characterization from 2 to 250 nm identifies three structurally distinct regions (a 0.88 nm pseudomorphic interface, a bulk α-Ta(111) film with terrace widths saturating near 150 nm, and a self-limiting 2.25 nm amorphous oxide), and Van der Pauw transport reveals a superconducting Tc that increases smoothly from 2.9 K at 7.5 nm to 4.2 K at 269 nm, consistent with universal thickness scaling. Complementary DFT calculations rationalize the Ta-rich thermodynamic stability of α-Ta/Al_2O_3 interfaces (with mixed ionic/covalent Ta–O bonding and no oxygen interdiffusion into the film) and the emergence of amorphous TaO once the Ta:O ratio exceeds 1:1. Together, these results provide a quantitative roadmap for phase-selective, orientation-controlled, thickness-tuned α-Ta growth on sapphire for next-generation superconducting qubit platforms.

5:00pm **QS2-MoA-15 Mitigating Vortex Losses in Tantalum Superconducting Resonators Through Defect Landscape Engineering***, **Rohin Tangirala**, Chaman Gupta,* University of Washington*; Benjamin Palmer,* Laboratory for Physical Sciences, University of Maryland*; Yongqiang Wang,* Los Alamos National Laboratory*; Serena Eley,* University of Washington

Tantalum (Ta) has recently emerged as a low-loss material for superconducting circuits, due to its stable native oxide with fewer two-level system (TLS) defects that may cause dissipation and decoherence. Stray and applied magnetic fields can introduce additional energy losses due to the motion of Abrikosov vortices, especially in clean-limit tantalum films. To mitigate this loss channel, we intentionally introduce defects through proton irradiation and lithographically-defined antidots into tantalum superconducting resonators to engineer the vortex pinning landscape and control vortex dynamics. We characterize device performance across a range of applied magnetic fields and conditions relevant to superconducting qubit operation, including single-photon power levels and millikelvin temperatures, in order to quantify losses arising from vortices and explore design considerations for increasing the performance of tantalum resonators under magnetic fields. This may enable the integration of magnetic-field-resilient tantalum resonators into superconducting and hybrid quantum systems.

5:15pm **QS2-MoA-16 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.

5:30pm **QS2-MoA-17 Spectroscopy of Two-Level-System Defects via Multilevel Relaxation in a Fixed-Frequency Transmon***, **Tanay Roy**, Xinyuan You, David van Zanten, Francesco Crisa, Sabrina Garattoni, Shaojiang Zhu, Anna Grassellino, Alexander Romanenko,* Fermi Lab

Temporal fluctuations in the coherence of superconducting transmon qubits are widely believed to originate from two-level system (TLS) defects coupled to the qubit. Existing TLS spectroscopy techniques typically rely on qubit frequency tunability or AC-Stark-based approaches, which can introduce additional complexity and offer limited bandwidth. Here, we demonstrate an alternative method for TLS spectroscopy based on monitoring the relaxation dynamics of multiple excited states in a fixed-frequency transmon [1]. By analyzing temporal correlations between multilevel decay processes, we identify signatures of TLS defects that are detuned by more than 100 MHz from the qubit transition yet still significantly impact coherence. Our results establish multilevel relaxation spectroscopy as a simple and broadly applicable technique for probing defect-induced noise in superconducting qubits without requiring flux tunability[1] https://arxiv.org/abs/2602.11127This work was supported by the U.S. Department of Energy, Office of Science, National Quantum Information Science Research Centers, Superconducting Quantum Materials and Systems Center (SQMS), under Contract No. 89243024CSC000002. Fermilab is operated by Fermi Forward Discovery Group, LLC under Contract No. 89243024CSC000002 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

2D Materials
Room 304 - Session 2D+QS-TuM

Novel Quantum 2D Materials

Moderators: Fei Yao, University at Buffalo, **Roland Kawakami**, The Ohio State University

11:00am **2D+QS-TuM-13 Watching 2D Materials Form: Real-Time Atomic-Scale Visualization of TMD Growth and Crystallization Pathways***, **Raymond Unocic**, Prajakta Prabhune, Aidan Cotton,* North Carolina State University*; Caitlin Obrero,* Stanford University*; Suman Jaiswal, Masoud Mahjouri-Samani,* Auburn University*; Kyungnam Kang, Kai Xiao,* Oak Ridge National Laboratory **INVITED**

Achieving control over 2D material functional properties requires direct insight into the dynamic pathways that drive nucleation, crystallization, and growth. Aberration-corrected scanning transmission electron microscopy (STEM), coupled with in situ capabilities, has emerged as a powerful platform that can be used to directly observe these processes with atomic-scale spatial resolution and under a range of synthesis conditions. In this work, we investigate thermolysis-driven growth and pulsed laser deposition (PLD)-derived amorphous-to-crystalline transformations for 2D transition metal dichalcogenides (TMDs). Using MEMS based heating microchips, controlled heating experiments were performed to directly visualize the evolution of amorphous precursor phases into crystalline layered structures, revealing the atomic-scale pathways governing growth and phase evolution. By systematically varying thermal conditions and electron dose, we aimed to establish correlations between processing parameters and the resulting kinetic and energetic landscapes that dictate crystallization behavior. To further uncover hidden relationships within the transformation dynamics, we employ data analytics and machine learning approaches to quantify atomic trajectories and to identify transient states. The direct observation of these transformations provides unprecedented insight into the role of local structural rearrangements and transient intermediate states in governing the evolution of final material architectures. These findings establish a foundation for predictive synthesis strategies and enable atomic-scale control over TMD growth pathways.

11:30am **2D+QS-TuM-15 Airgap-Mediated Remote Epitaxial Control of Bandgap Opening in Bilayer Silicene on Semiconductor Substrates***, **Kumar Vishal**,* Wright University

Bilayer silicene (BLSi) is a promising silicon-compatible 2D material for future nanoelectronic channels, but practical bandgap engineering requires simultaneous strain retention, substrate interaction control, and release from growth templates. We use first-principles density functional theory to model epitaxial and remote-epitaxial BLSi on lattice-mismatched semiconductor substrates, with emphasis on Ga- and Sb-terminated GaSb surfaces. Substrate-induced biaxial tensile strain is used to flatten and electronically activate BLSi, while the BLSi/substrate separation is varied to emulate an airgap interlayer that suppresses direct chemical bonding.The calculations reveal three interaction regimes governed by optimized interface spacing, surface termination, electron transfer, and residual buckling. For Ga-terminated GaSb, direct epitaxy relaxes to a strongly bonded interface at Δd0 = 0.817 Å, producing a 112 meV bandgap but limiting transferability. Increasing the spacing creates a metastable remote-epitaxial regime at Δd0 ≈ 2.6–2.9 Å, where electron density at the interface drops below 0.075 Å^-3 and the bandgap becomes tunable in the 20–30 meV range. At larger spacing, interfacial charge transfer becomes negligible and BLSi approaches the strained free-standing limit near 57–59 meV. For Sb-terminated GaSb, the weaker Si-Sb interaction enables a wider practical tuning window: an airgap of approximately 3.0–4.3 Å gradually opens the BLSi bandgap from near zero to 57 meV while maintaining a weakly coupled, releasable interface.These results show that an atomically controlled airgap can function as a passive remote-epitaxial layer, preserving lattice-mismatch strain while preventing irreversible covalent bonding. The approach offers a low-complexity route for tuning bilayer silicene electronic structure and for integrating strain-engineered 2D silicon materials with scalable semiconductor device processing.The technical details above are grounded in your uploaded paper, including the DFT modeling, GaSb_Ga/GaSb_Sb comparison, three interface-spacing regimes, electron-density reduction, and tunable bandgap results.

11:45am **2D+QS-TuM-16 Synthesis and Characterization of Two-Dimensional Indium Gallium Nitride (2d $In_xGa_{1-x}N$) via Graphene Encapsulation***, **Krishnan Mekkanamkulam Ananthanarayanan**, Soukyoon Kim, Md Farhan, Nutifafa Y. Doumon, Adri van Duin, Joshua Robinson,* The Pennsylvania State University

Group-III nitrides are widely explored semiconducting material for optoelectronics including light-emitting diodes (LEDs), photodetectors, solar cells and lasers; however, quantum applications such as single photon emitters, tunnel junctions and quantum sensors remain unrealized. Atomically thin two-dimensional (2D) nitrides are predicted to have large tunable bandgap than the bulk counterpart via quantum confinement with electronic and optical properties for wide spectrum of applications such as deep UV light emitters, single photon sources and other optoelectronic devices. First-principles calculations predict 2D $In_xGa_{1-x}N$ to possess a tunable bandgap ranging from 1.7 to 4.1 eV depending on the composition. However, experimental realization of large area 2D nitrides growth other than hBN remains elusive due to 3D growth induced by surface energy constraints. Graphene encapsulation has paved the way for realization of MOCVD growth of 2D GaN_x (E_g≈5eV), InN_x (E_g≈2eV) and AlN_x (E_g≈9eV). The significant limitation in the MOCVD growth of 2D nitrides via graphene encapsulation is the 3D island formation on top of graphene and small domain growth. In this study, we have synthesized large-area 2D $In_xGa_{1-x}N$ by intercalation of 2D In_xGa_{1-x} alloy at the interface of EG/SiC using confinement heteroepitaxy (CHet) and followed by ammonolysis to intercalate nitrogen to counter the 3D island formation. The high energy interface between epitaxial graphene (EG) and silicon carbide (SiC) efficiently stabilizes the metal and other compounds into confined 2D crystalline form. The intercalation of tunable 2D In_xGa_{1-x} metal alloy composition by changing the relative elemental composition of the precursor using CHet technique have been previously demonstrated. XPS, cross sectional transmission electron microscopy (TEM), energy dispersive X-ray spectroscopy (EDS) and AES mapping provides evidence of ~100 μm^2 2D $In_xGa_{1-x}N$ at the EG/SiC interface and determine the III-alloy nitride composition. The electron energy loss spectroscopy (EELS) and UV-vis spectroscopy extract the energy bandgap of 2D $In_xGa_{1-x}N$ with varying alloy compositions. The vertical transport measurements of the heterostructure are carried out using conductive atomic force microscopy (C-AFM) using a conductive SiC substrate. Scanning electron microscopy (SEM) and AFM validate the reduced 3D island formation. The surface morphology of 2D III-nitride consists of graphene wrinkles, tears and nitrogen trapped bubbles formed underneath the EG. We combine the study with ReaxFF reactive molecular dynamics simulations to elucidate the mechanism of graphene bubbles formation and the role of EG, In and Ga.

Quantum Science and Technology
Room 304 - Session QS-TuM

Quantum Sensing, Simulation, and Emerging Quantum Applications

Moderators: Dr. Suman Bhaumik, TEL Technology Center, America, LLC, **Dr. Walid Redjem**, University at Albany State University of New York, **Dr. Simon Seymour**, UIUC

8:00am **QS-TuM-1 Opportunities for Quantum Sensing and Computing for Energy and Infrastructure Security Applications***, **Hari P. Paudel**, Yuhua Duan,* National Energy Technology Laboratory **INVITED**

Quantum information science (QIS) harnesses quantum mechanics to solve problems that are beyond the reach of traditional methods and devices. The rapid advances of quantum sensing and computing are creating promising pathways to improve energy production, distribution, and consumption, and minimizing security challenges. However, applying emerging technologies in quantum information science to real-world systems remains challenging. The National Energy Technology (NETL) is actively leveraging both experimental and computational tools to strengthen the nation’s energy and security competitiveness.

This presentation will highlight recent advances in quantum sensing for energy and infrastructure security applications. Examples of mineral detection and exploration will be discussed, and possibilities for the deployment of quantum tools will be examined. The presentation will also showcase opportunities for materials chemistry and complex optimization problems in areas such as energy storage, fluid dynamics, and grid operations. This presentation will review quantum simulations of ground state and vibrational properties of small molecules, benchmarking current algorithms against qubit counts, basis sizes, and memory demands. The presentation will conclude by identifying high-value application pathways for addressing major challenges in the energy sector.

8:30am **QS-TuM-3 Can NISQ-era Quantum Computing drive the design of new DFT Functionals?*, Simon Seymour*,** *Andre Schleife,* University of Illinois, Urbana-Champaign

This work aims at comparing the epistemic uncertainty stemming from the lack of knowledge on the universal functional to the various uncertainty sources inherent to NISQ era quantum computing (QC). Three variational quantum subroutines with varying degrees of Quantum ErrorMitigations are implemented to estimate the total energies of quantum chemistry systems. Notably, one of the subroutines is novel and uses a Riemannian preconditioned Crank-Nicolson Markov Chain Monte-Carlo solver to infer the 2-Reduced Density Matrix (2RDM) of chemistry systems from sparse shadow tomography data. This construction was motivated to bypass both the limited quantum computational resources as well as to improve the scaling of previous 2RDM solvers based on Semi-Definite Programming. Finally, a dual Bayesian-Bootstrapping framework is established to identify the relevant sources of uncertainty within the QC workflow. This will help find strategies for improving QC performance and further the development of 2RDM tomography whose data we hope can eventually be used in the training stage of new Exchange-Correlation functionals.

8:45am **QS-TuM-4 Linearly Uncoupled Silicon Photonic Cavities for Quantum State Generation*, Prabha Prasad Nair,*** University at Albany-SUNY

Quantum sensing leverages quantum mechanical resources to surpass classical limits of measurement precision. A key pathway is the use of squeezed states of light, which suppress quantum noise below the shot-noise limit and enable enhanced sensitivity in low-signal environments. In this work, we investigate the integration of squeezed light within silicon photonic circuits as a scalable platform for quantum-enhanced sensing. By embedding nonlinear optical processes into CMOS-compatible waveguides, we outline strategies for the on-chip generation and manipulation of squeezed states. To address the challenges associated with state-of-the-art squeezed-state generation, we propose a novel architecture consisting of two ring resonator cavities coupled through a Mach–Zehnder interferometer, enabling enhanced stability and control.

In addition to their applications in sensing, squeezed states play a crucial role in continuous-variable (CV) quantum information processing, underpinning protocols for universal quantum computation, quantum teleportation, quantum error correction, quantum secret sharing, and quantum key distribution. By combining compact nonlinear waveguides, interferometric architectures, and low-loss photonic integration, this work establishes a pathway toward fully integrated quantum sensors with sub-shot-noise performance, while simultaneously contributing to the broader development of scalable CV quantum technologies.

Our theoretical modeling and circuit-level simulations demonstrate the potential for significant noise reduction and improved detection sensitivity across applications such as biosensing, navigation, and precision metrology. This work lays the foundation for the experimental realization of integrated squeezed-light sources, advancing the development of compact, high-performance quantum sensors for real-world applications.

9:00am **QS-TuM-5 High Precision Fiber-Integrated Micro-Optics for Quantum Photonic Interfaces*, Raman Kumar*,** *Sebastian Will,* Brookhaven National Laboratory

Scalable quantum photonic technologies require efficient light matter interfaces that are compact, alignment stable, and compatible with optical fiber infrastructure. Here, we report the nanofabrication of high precision micro-optical elements directly on the end facets of single mode fibers. Our approach is based on focused ion beam nano-machining, enabling a new class of fiber integrated quantum photonic components. We fabricate and characterize multiple classes of fiber-integrated optics, including micro-concave and micro-convex spherical elements, spiral phase plates, and axicons, using focused-ion beam (FIB) to define three-dimensional optical profiles directly on the fiber core [1].

Precise alignment to the guided optical mode is achieved by selectively etching the fiber facet, which reveals the doped core as an alignment marker before FIB machining. Atomic force microscopy shows that the spherical surfaces achieve subwavelength form accuracy. Surface roughness analysis further shows no measurable degradation after optimized FIB processing, with roughness remaining in the sub nanometer range establishing quantum grade optical performance.

Optical characterization with visible laser illumination confirms the intended functionality of the fabricated elements. Axial imaging demonstrates fiber-integrated focusing from spherical micro-optics with radii of curvature in the range of hundreds of microns, while Mach-Zehnder interferometry verifies the azimuthal and radial phase structures generated by spiral and axicon fibers, respectively. The resulting far field patterns and interferometric signatures confirm deterministic phase control.

These results establish FIB-fabricated fiber micro-optics as a compact, alignment free, and quantum-grade platform for quantum photonic interfaces, with applications in fiber coupled atom cavity QED, and structured light generation for high dimensional quantum information processing.

<u>References:</u>

[1] Kumar, R., & Will, S., “High precision micro-optical elements on fiber facets via focused-ion beam machining.” *arXiv:2604.18426* (2026).

9:15am **QS-TuM-6 The Role of QED-C in Growing the Quantum Industry*, Sebastian Engelmann,*** QEDC, United States Minor Outlying Islands (the)

The Quantum Industry has gathered lots of interest and is on track to surpass 3B market size by 2028. While many advances in the scientific community are highlighted, commercial success is still not a given.

In the US, an Industry led consortium called QED-C has formed, which collects input from industry, academia and Government agencies. I will introducte QED-C, its mission and services to its members. In particular I will showcase the emerging Technologies TAC (technical advisory committee) and our recent activites.

In this talk I would like to highlight the items that are important for community, specifically what QED-C is doing in regards to testbeds, standards and foundry pathways.

9:30am **QS-TuM-7 Rejuvenating Photonic Quantum Sensing by Replacing Traditional Beamsplitters with Higher-Dimensional Gauge-Invariant Multiports*, Alexander Sergienko,*** Boston University **INVITED**

Photonics quantum sensors are among the central areas of quantum technologies. The optical Michelson or Mach-Zehnder interferometers are core elements of many photonics sensors. Introducing entangled and noise-squeezed quantum states in such interferometers boosts their sensitivity and resolution beyond classical limits. The original resolution of all conventional Michelson or Mach-Zehnder interferometers is limited by the maximum attainable slope of the intensity interference pattern as a function of the phase shift. The (cos^2) shape of all existing interferograms is determined by the physical properties of the optical beamsplitter - a traditional device that introduces an optical superposition and governs the operation of many known optical devices.

We introduced a novel concept of higher-dimensional gauge-invariant multiports. The directionally unbiased four-port Grover coin can be considered a higher-dimensional generalization of beam splitters, in which inputs to the four available ports have equal probability of exiting any of the four ports, including back reflection. *This offers direct access to a greater number of degrees of freedom* [1] (Fig.1).

We demonstrated that traditional interferometers acquire novel features and offer a dramatically ***enhanced resolution in phase measurement when directionally unbiased Grover multi-ports replace traditional beam splitters*** (Fig. 2). We demonstrated experimentally that the Grover-based counterpart of the conventional Michelson interferometer can substantially improve the phase measurement resolution due to a new feature of increasing the intensity-phase slope by 10X÷20X times instead of a traditional (cos^2) profile limited to 1 (Fig. 3). This converts any Michelson or Mach-Zehnder interferometer into a super-resolution sensor [2,3].

This novel approach dramatically elevates the baseline for optical interferometric measurements, even before quantum states of light are involved, thereby rejuvenating the field of high-resolution sensing. The introduction of quantum light (such as entangled or squeezed states) into new Grover-Mach-Zehnder or Grover-Michelson interferometers will increase the photonic measurement resolution even further.

[1] C. R. Schwarze, A. D. Manni, David S. Simon, A. Ndao, and A. V. Sergienko ''Next-Generation Interferometry with Gauge-Invariant Linear Optical Scatterers, '' Metrology, **v. 5**, 5040065 (2025).

[2] C. R. Schwarze, D. S. Simon, and A. V. Sergienko, Phys. Rev. A 106, 052615 (2023).

[3] C. R. Schwarze, D. S. Simon, A. D. Manni, A. Ndao, and A. V. Sergienko, ''Experimental demonstration of a Grover-Michelson interferometer'', Optics Express, v.32, p. 34116-34127 (2024).

Quantum Science and Technology
Room Ballroom A - Session QS-ThP

Quantum Science and Technology Poster Session

QS-ThP-1 from Quantum Device Output to Governed Compute Continuation: A Runtime Architecture for Heterogeneous Scientific Workflows, ***Thomas Porter,*** ACGEOS

The Issue:

Emerging quantum-enabled devices, including quantum computers, photonic devices, neuromorphic, superconducting, spin, and advanced microelectronic platforms, are increasingly presented as peer elements in heterogeneous computing scientific workflows. However, the boundary between experimental device output and runtime compute continuation remains creates isolation. Device configuration, execution conditions, telemetry, logs, uncertainty, AI/ML probability interpretation, and returned results are often handled through separate files, scripts, instruments, schedulers, or manual processes, limiting reproducibility and cross-platform comparison. Quantum computers are treated as stand-alone devices.

Presenting a solution:

This poster conceptually presents ACGEOS, a governed runtime orchestration architecture for integrating quantum-enabled devices into auditable heterogeneous workflows. The model treats each task, device, configuration, telemetry record, result, and continuation state as an identifiable object. A portable governed container, the .polyp , preserves the original request, device setup, execution context, telemetry, logs, error state, and returned data. A Binding Object Layer record links expected execution to actual returned state, allowing the workflow to continue without losing provenance.

Innovation:

A central feature is a triplet return model from the quantum-device integration:

1. un-edited quantum result preserved as a .polyp , the original evidence package,
2. a BOL-bound result returned to the compute runtime for deterministic workflow continuation, and
3. an AI/ML evaluation sidecar used for confidence scoring, anomaly detection, repeatability assessment, or interpretation of probabilistic device behavior. In this model, AI/ML does not replace the governed result of record; it becomes an attached evaluation layer.

The proposed architecture is intended for future testbeds where quantum, photonic, neuromorphic, GPU, CPU, and instrument-class devices must participate in reproducible scientific workflows. The goal is to provide a systems-level bridge between device performance, experimental evidence, and compute continuation, supporting scalability, reliability, and translation of emerging quantum technologies into practical research and engineering environments.

QS-ThP-2 Josephson Effect at the Atomic Scale with High Energy Resolution and Microwave Irradiation, ***Soumyaranjan Jhankar,*** *Christian Ast,* Max Planck Institute for Solid State Research, Germany

The Josephson effect is a fundamental phenomenon of a superconductor-insulator-superconductor (SIS) junction. The Josephson current encodes information about the Cooper pair condensate, and its spectral features can be exploited as a benchmark for the energy resolution of the system. Understanding the Josephson effect at the atomic level is directly relevant to superconducting devices such as SQUIDs and to emerging quantum technologies.

Using a low temperature scanning tunneling microscope (STM) with a superconducting tip and sample, it can be investigated at the atomic scale. In this work, we report high resolution STM measurements with a microwave source at the SIS junction. We have achieved an energy resolution of 9 μeV at 1.09 K, representing the lowest benchmark value reported at this temperature so far and on par with state-of-the-art mK systems.

Microwave irradiation allows the study of microscopic phenomena, including subgap bound states (e.g., Yu–Shiba–Rusinov states), tunneling processes such as Cooper pair and quasiparticle tunneling, and resonant processes such as electron paramagnetic resonance. This motivates us to study SIS junctions under microwave irradiation, where the energies of tunneling particles are varied non-adiabatically, giving rise to replica features in the differential conductance spectra and in the Josephson current–voltage characteristics. These features serve as a signature of quantum interference at the atomic scale.

QS-ThP-3 TOF-SIMS Depth Profiling of Tantalum Deposited with Ar and Kr Sputter Gas, ***Aleksandra Biedron,*** *Vidya Kaushik,* NY Creates*; Maciej Olszewski, Lingda Kong, Simon Reinhardt, Daniel Tong, Xinyi Du,* Cornell University*; Gabriele Di Gianluca,* University of Florida*; Haoran Lu, Saswata Roy, Luojia Zhang, David Muller, Valla Fatemi,* Cornell University

Tantalum (Ta) is an attractive material for superconducting applications, and optimizing deposition conditions could improve compatibility with standard semiconductor processes. Ta is typically deposited on silicon at high temperature with argon (Ar) gas. This work examines how changing the sputter gas from Ar to krypton (Kr) promotes growth of high-quality Ta films at lower substrate temperatures. The Ta films were characterized with a variety of surface analysis techniques, including depth profiling with Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS). Changes in the morphology and structure of Kr sputtered films were observed, as compared to ones deposited using conventional Ar gas. The results from SIMS and other thin film analysis were in agreement and complemented by cryogenic microwave and qubit performance data. We therefore promote Kr as a superior process gas for scalable deposition of Ta films for superconducting qubit applications. [1]Reference: [1] arXiv:2601.20091 [quant-ph]; https://doi.org/10.48550/arXiv.2601.20091

QS-ThP-4 A High-Yield "Baseline" Fabrication Recipe for Superconducting Resonators and Qubits at Cornell Nanoscale Facility, ***Xinyi Du,*** *Maciej Olszewski, Simon Simon Reinhardt, Lingda Kong, Gabriele Gianluca, Ron Olson, Valla Fatemi,* Cornell University

The reliable scaling of superconducting quantum processors depends heavily on the reproducibility and yield of the underlying micro- and nanofabrication processes. As quantum computing research expands, open user facilities play a critical role in providing standardized, high-quality fabrication baselines that democratize hardware developmentand prototyping. In this work, we present a user-facility-compatible fabrication flow for coplanar waveguide (CPW) resonators and planar transmon qubits, developed using the equipment at the Cornell NanoScale Facility (CNF).

This baseline methodology focuses on process optimization to maximize device yield, establish a reliable foundation for quantum coherence, and improve overall fabrication efficiency. A primary challenge in planar qubit fabrication is mitigating Two-Level System (TLS) losses arising from interfacial defects and fabrication residues, a step that traditionally relies on labor-intensive processing. To address this, our process flow incorporates a streamlined wet chemical treatment protocol. This optimized approach significantly reduces hands-on effort while effectively minimizing polymer and oxide residues at critical material interfaces, providing an easier fabrication route that ensures no degradation of feature resolution or device quality.

We characterize the efficiency of this baseline flow through comprehensive room-temperature metrology, followed by cryogenic microwave measurements. The presentation details the step-by-step cleanroom recipe, emphasizing the correlation between our refined wet processing and the resulting quantum metrics. This baseline provides the broader materials for quantum information science community with a reliable approach to consistently achieve high-yield quantum hardware.

QS-ThP-5 Learning-Guided Variational Quantum Eigensolver with Circuit-Aware Parameterization and Post-Processing, ***Yan Li,*** Penn State University

Variational quantum eigensolver (VQE) methods provide a promising hybrid quantum-classical framework for estimating low-energy states of complex Hamiltonian systems on near-term quantum devices. However, practical VQE performance is often limited by the strong dependence of the optimization landscape on circuit structure, parameter initialization, measurement noise, and the quality of classical post-processing. This work develops a learning-guided VQE workflow that integrates circuit-aware characterization, machine-learning-assisted parameter prediction, and classical post-processing to improve convergence and solution quality. First, the variational circuit is analyzed to identify structural features that influence the energy landscape and parameter sensitivity, enabling a more informed design of the ansatz and search space. Second, machine learning models are trained to predict promising initial parameters or parameter-update directions from Hamiltonian features and prior optimization data, reducing the reliance on random initialization and repeated classical optimization. Third, post-processing techniques are applied to refine measured quantum outputs, mitigate sampling effects, and improve the physical interpretability of the resulting eigenstate estimates. The proposed framework is demonstrated through representative Hamiltonian problems relevant to quantum simulation and energy-system optimization. Results show that incorporating circuit-informed learning and post-processing can accelerate convergence, reduce optimization variability, and enhance the reliability of VQE under realistic measurement constraints. This study highlights the potential of combining quantum circuit analysis, data-driven parameter learning, and classical refinement to make variational quantum algorithms more scalable and robust for near-term quantum science and technology applications.

QS-ThP-6 Scanning-Tunneling-Microscope-Defined Josephson Junctions as a Local Platform for Qubit-Relevant Phase Dynamics*, **Robertus Elbertse,** Dengyu Yang,* NIST-Gaithersburg*; Fabian Natterer,* ETH Zürich, Switzerland*; Joseph Stroscio,* NIST-Gaithersburg

Superconducting qubits rely on the controlled dynamics of the Josephson phase across weak links, yet the microscopic relationship between junction structure, dissipation, electromagnetic environment, and phase coherence remains difficult to access directly. Scanning tunneling microscopy provides an unusual route to this problem: the tunnel junction itself can act as a local, continuously tunable Josephson junction between superconducting electrodes. Unlike lithographically defined devices, an STM-defined junction allows the critical current, normal-state resistance, capacitance, and local atomic environment to be varied in situ while preserving cryogenic operation and microwave access.

Here we develop STM-defined Josephson junctions as a platform for exploring qubit-relevant superconducting phase dynamics. Using superconducting tips and samples, we characterize Josephson coupling as a function of junction conductance, material parameters, and engineered microwave environment. We examine signatures associated with phase fluctuations, junction switching, and the crossover toward regimes where the junction potential becomes sufficiently nonlinear and isolated to support phase-qubit-like dynamics. Even when operated below the threshold for a fully realized qubit, this approach provides direct access to the ingredients that govern superconducting weak-link behavior: local structure, dissipation, impedance, and noise. The resulting platform bridges atomic-scale superconducting spectroscopy and circuit-level Josephson physics, offering a flexible route toward local studies of superconducting quantum devices.

QS-ThP-7 Structure-Transport Relationships of Epitaxial Superconducting Nitride Films*, Evangeline Beeching, Sabin Regmi, Amey Khanolkar, Ahmed Wasif Mustakim, Volodymyr Buturlim, Zach Cresswell, Kevin Vallejo,* Idaho National Laboratory*; Robert Makin,* Western Michigan University*; Krzysztof Gofryk,* Idaho National Laboratory*; **Brelon May,*** Montana State University

The high tunability of semiconductor platforms has enabled them to be leveraged for various technologies and applications. The aspects of superconductivity can also be engineered to have specific targets. Recent efforts surrounding superconducting films for quantum systems have largely focused on achieving higher critical temperatures. However, as consensus is reached surrounding the importance of defects in quantum systems there is increasing interest in elucidating and controlling other mechanisms and resulting parameters. Understanding how synthesis parameters influence structural disorder at various length scales and their impact on the physical properties is a complex problem. This work will look into aspects of disorder ranging from the atomic scale to longer range inhomogeneities in the crystalline lattice and the relationships with electrical transport.

We will discuss the deposition of epitaxial superconducting ZrN by molecular beam epitaxy, the separate roles of atomic and crystalline disorder, and relationships between synthesis parameters and resulting structural and physical properties. The use of various substrates and orientations allows for insight into the effects of lattice mismatch and the preferential growth directions. Under the conditions investigated, rocksalt ZrN appears to prefer formation along the (001) direction but (111) oriented inclusions are observed when the temperature is too low. There is a complex relationship between synthesis parameters and resulting short range (atomic scale) and long range (crystalline lattice) order, as measured by detailed X-ray diffraction. The resulting structure shows tunability of electrical transport and optical properties, which can both range from metallic to dielectric. A broad generalization shows that samples deposited at elevated temperatures were more metallic and have higher superconducting transitions. However, other properties change in unintuitive ways, which can be explained by the non-monotonic changes in the atomic scale disorder. This work integrating superconducting films with known semiconductor platforms provides an avenue for the pursuit of (001) oriented heterostructures for superconducting or optical quantum applications.

QS-ThP-8 High Purity CaO thin films for quantum information science*, **Jake DeChiara,*** Pennsylvania State University*; Bonnie Lin,* MIT*; Amirehsan Alizadeh, Edo Waks,* University of Maryland College Park*; James LeBeau,* MIT*; Saeed Almishal, Jon-Paul Maria,* Pennsylvania State University

Computational studies predict CaO as a promising host crystal suitable to sustain optically addressable QuBits with long coherence times due to low natural abundance of calcium isotopes with nuclei with net spin and low spin orbit coupling, allowing defect states to be well isolated from magnetic noise. In this work we experimentally engineer bismuth and rare earth lanthanide dopants in varying concentration levels in an ultra-high purity, low defect CaO thin film to experimentally verify defect structure and coherence times. Reactive RF Sputtering is selected as a desirable physical vapor deposition method allowing tunable deposition rates through changes in magnetron power and cathode working distance to the substrate. Relaxed (001) oriented CaO films are grown on r-plane sapphire single crystal substrates achieving film heteroepitaxy. Host crystal purity is paramount to achieving long spin coherence times, as any magnetic impurities may interact with defect states. To minimize chemical impurity, we develop an ultra-high purity calcium sputtering source by hydrothermal sintering. 1- and 2-inch calcium hydroxide (99.999% pure) to above 95 % theoretical density. Sintering temperatures below 150°C inhibit solid state diffusion of contaminants into the source target, maintaining exceptionally high target purity throughout all processing stages. Calcium oxide thin films and dopants are co-sputtered via an off-axis geometry to mitigate anion bombardment, allowing for increased deposition rates, smooth film morphology, high density, and low film mosaicity as quantified via XRD and XRR. High deposition temperatures (875°) allow for film deposition with high crystallinity. Dopant concentration down to the single part-per-million level is quantified by induction coupled plasma optical emission spectroscopy via film dissolution in aqueous solution. Dopant concentration is coupled with deposition rate from the calcium and dopant source magnetrons and is experimentally tuned by changing dopant magnetron working distance and power, in turn modifying calcium and dopant source flux to the substrate. Oxygen vacancy defects that scale with Er are identified in the CaO lattice via deep UV photoluminescence measurements performed with a 248 nm laser excitation at room temperature – these provide an interesting pathway to infer dopant concentrations. Finally STEM analysis, including electron ptychography, that shows film microstructure, lattice strains, and defects will be presented.

QS-ThP-9 Physical Vapor Deposition of Highly Crystalline Cerium Oxide (CeO_2) Thin Films for Quantum Information Technology*, **Andrey Shults,** Saeed Almishal,* The Pennsylvania State University*; Sooyoon Hwang,* MIT*; Amirehsan Alizadehherfati,* University of Maryland*; James LeBeau,* MIT*; Edo Waks,* University of Maryland*; Jon-Paul Maria,* The Pennsylvania State University

CeO_2 is a well-known host for defect-generated qubits that offers high relaxation and coherence times desirable in quantum computing applications. Scalable and reproducible qubit performance with large spin coherence lifetimes requires materials with high crystallinity, low point defect concentrations, and excellent surface quality. In this work, we investigate structural and electronic properties of erbium doped CeO_2 to better understand how the crystalline quality and the defect chemistry affect its performance in quantum information technology. Utilizing RF magnetron sputtering from CeO_2 ceramics, we can tune the crystalline quality by methodically adjusting the deposition parameters such as substrate temperature, total pressure, gas ratio, and stage bias. We find that high deposition temperatures and low oxygen flows yield films with smooth surfaces (<1nm RMS), outstanding crystallinity, and low mosaicity (<0.2° FWHM rocking curve) but also create oxygen vacancies. We demonstrate that a subsequent thermal anneal in oxygen atmosphere heals the films and improves electrical properties. By dilute-doping CeO_2 with optically-active erbium, we can introduce defect qubits without altering the overall crystalline quality. During the erbium co-sputtering, we can modulate dopant levels from tens to hundreds parts per million throughout the CeO_2 thickness, as confirmed by inductively coupled plasma atomic emission spectroscopy. Photoluminescence spectroscopy results show a strong erbium emission at ~1510 nm with a 3.7 ms lifetime in agreement with theoretical calculations. Transmission electron microscopy confirms homogenous erbium doping within the film, coherent film-substrate interface, dense and continuous growth, and a smooth surface. Ultimately, we use a rich combination of characterization probes to better understand the connection between thin film structure and electronic properties that give rise to high-performing defect qubits.

Author Index

Bold page numbers indicate presenter