Quantum Science and Technology Mini-Symposium
Room Central Hall - Session QS-ThP

Quantum Science and Technology Mini-Symposium Poster Session

QS-ThP-1 Characterization of Planar Ta Damascene Resonators for Quantum Information Science Applications*, **Drew Rebar**, F. Ponce, B. VanDevender, M. Warner, J. Macy,* PNNL*; T. Nanayakkara, C. Zhou, M. Liu,* Brookhaven National Laboratory*; S. Papa Rao,* NY CREATES*; E. Bhatia,* SUNY POLY, Albany

Transmon qubits are one of the leading technologies for quantum information science (QIS) with fabrication and characterization techniques accessible by numerous laboratories around the world.In recent years, efforts at coherence time optimization have shifted focus to the performance of the underlying superconducting material and accompanying surface oxides.While earlier devices were fabricated from Al and Nb, the current state-of-the-art transmons are fabricated from Ta with coherence times up to 0.5 milliseconds.Our research focuses on Ta coplanar waveguide (CPW) resonators fabricated by a damascene technique which yields pristine metal structures entrenched in silicon substrates.While the participation ratio of the dielectric substrate is increased, the device edges remain oxide free from the entrenchment and a nitride capping layer.Our recent studies revealed a current best Q value on the order of 105 at low power.This work, performed in collaboration with NY CREATES/SUNY Poly and BNL, will be discussed along with the prospect of further improvements.

QS-ThP-2 DNA-Enabled Precise Arrangement of Colloidal Quantum Dots and Rods on Device Substrates*, **Xin Luo**, C. Chen, M. Bathe,* MIT

Colloidal quantum dots (QDs) and rods (QRs) are promising quantum materials with unique electronic and optical properties for quantum science applications such as quantum computation, sensing, simulation, and communication. While colloidal QDs and QRs can be dispersed in solvents and readily integrated on surfaces and in devices using solution-based assembly techniques, scalable and deterministic arrangement of single and arrayed QDs/QRs on devices with sub-10 nm resolution remains a challenge. We employ robust DNA origami templates to guide the incorporation of colloidal QDs and QRs on device substrates with nanoscale precision.

DNA origami is a powerful platform for the precise assembly and organization of functional nanomaterials, enabling the creation of complex, tailor-made structures with unprecedented accuracy and programmability. While DNA-modified molecules and colloidal metallic nanoparticles are routinely assembled onto DNA origami, QDs and QRs have been challenging to incorporate due to low DNA conjugation efficiency. We have developed an ultrafast dehydration-assisted method to conjugate a dense layer of ssDNA onto QDs/QRs directly from organic solvent to facilitate their precise and stable assembly on DNA origami templates [1]. To arrange QR arrays on the surface, we developed a Surface-Assisted Large-Scale Assembly (SALSA) strategy to fabricate 2D DNA origami lattices tethered by unique crossover interactions directly on a solid substrate [1]. Alignment of the QRs in the 2D lattice was achieved through predefined binding strands linearly arranged on the origamis to unlock polarized light emission along the long axis of the arrayed QRs. To integrate DNA-templated QDs/QRs into chip-based photonic devices, we further employed lithography to guide the deterministic patterning of precisely positioned and oriented individual DNA origami templates on silicon chips. Landing pads of matching size and shape of the DNA origami were first fabricated using electron beam lithography, followed by origami placement through electrostatic interaction-guided self-assembly. QDs and QRs were then assembled onto the origami templates with predefined position and orientation. Our methods offer significant potential for the precise integration of high-quality colloidal QDs and QRs as quantum emitters for integrated quantum photonics.

1. Chen, C., Luo, X., Kaplan, A. E. K., Bawendi, M. G., Macfarlane, R. J., & Bathe, M. (2023). **Science Advances**, 9(32), eadh8508.

QS-ThP-3 ManQala - a Quantum Game with Implications for Quantum State Engineering*, **Thomas A. Searles**,* University of Illinois - Chicago

The ability to prepare systems in specific target states through quantum engineering is essential for realizing the new technologies promised by a second quantum revolution. Here, we cast the fundamental problem of state preparation as ManQala, a quantum game inspired by the West African sowing game mancala. Motivated by optimal gameplay in solitaire mancala, where nested nearest-neighbor permutations and actions evolve the state of the game board to its target configuration, ManQala acts as a pre-processing approach for deterministically arranging particles in a quantum control problem. Once pre-processing with ManQala is complete, existing quantum control methods are applied, but now with a reduced search space. We find that ManQala-type strategies match, or outperform, competing approaches in terms of final state variance even in small-scale quantum state engineering problems where we expect the slightest advantage, since the relative reduction in search space is the least. These results suggest that ManQala provides a rich platform for designing control protocols relevant to quantum technologies.

QS-ThP-4 Correlating the Electronic Structure with the Emergence of Magnetism in $PdCo_2$*, **Jessica McChesney**,* Argonne National Laboratory

Long-range ferromagnetism is induced in the nonmagnetic layered oxide $PdCoO_2$ with the implantation of He. This onset of magnetism was found to be reversible with annealing and tied directly with local lattice distortions. In order to correlate the changes in the electronic structure with the onset of magnetic order, we mapped the Fermi surface and performed resonant photoemission to determine the character of the bands as a function of doping.

QS-ThP-5 How Can Quantum-Based Sensors Be Used for “Nist on a Chip” Sustainability Solutions?*, **Jay Hendricks**,* NIST-Gaithersburg*; B. Goldstein,* NIST

This poster covers a bit of metrology history of how we got to where we are today and gives a forward-looking vision for the future of measurement science and its important role in our daily lives. The role of NIST as a National Metrology institute (NMI) is briefly described considering the world-wide redefinition of units that occurred on May 20th, 2019. The re-definition of units is now aligned with physical constants of nature and fundamental physics which opens new realization routes with quantum-based sensors and standards. The NIST on a Chip program (NOAC) is briefly introduced in this context.

The technical core is a deeper dive into research on measurement methods for pressure, the Fixed Length Optical Cavity (FLOC) and for vacuum the Cold Atom Vacuum Standard (CAVS). What is exciting about many of these new measurement approaches is that they are both primary (relying on fundamental physics), are quantum-based and use photons for the measurement readout which is key for taking advantage of the fast-growing field of photonics. The FLOC will enable the elimination of mercury barometers pressure standards worldwide and the CAVS will be first primary standard for making vacuum measurements below 1.3×10^{-5} Pa. A Sensitive Photonic Thermometer (SPOT) will be introduced, along with other sensing technologies that the NOAC program is currently investigating such as flux, magnetic field, and mass and torque.

Quantum-based metrology systems, however exciting, do raise new challenges and several important questions: Can these new realizations enable the size and scale of the realization to be miniaturized to the point where it can be imbedded into everyday devices? What will be the role of metrology institutes in the is new ecosystem of metrology and measurement? What will be the NMI role for solutions aimed at sustainability and environment? This posterwill begin to explore these important philosophical questions.

QS-ThP-6 Advancing Quantum Materials Growth and Characterization with Cluster Systems*, **Yashwanth Balaji**, M. Surendran, A. Gashi, A. Kemelbay, S. Aloni, A. Schwartzberg,* Lawrence Berkeley National Laboratory

Superconducting quantum materials research is increasingly focused towards the fabrication of robust quantum processors to enable practical quantum computation. As these processors scale in size and complexity, they become more susceptible to various loss mechanisms, with material-related losses being a major source of decoherence. Traditional fabrication methods, such as evaporation and sputtering, have shown to introduce defects in thin metallic films, as well as lossy and noisy dielectrics. Advances in fabrication techniques and the exploration of new materials are necessary to develop qubits that are more robust to decoherence. Achieving this requires exploring various material growth techniques in a controlled manner, guided by real-time feedback from in situ characterization. Additionally, employing novel fabrication techniques that allow simultaneous application of multiple growth techniques without breaking vacuum are crucial.

In this context, we present the use of a cluster deposition and characterization system at Berkeley Lab's Molecular Foundry user facility to advance the exploration and optimization of quantum materials. The integrated system combines multiple deposition tools — including e-beam evaporation (deposition, oxidation and ion milling), reactive sputtering and nitride and oxide ALD chambers—with a suite of characterization systems including XPS, ellipsometry, optical emission spectroscopy and Auger spectroscopy. The system also includes a glove box for inert sample loading and unloading, and automated wafer transfer integrated in a unified vacuum system. By facilitating multi-deposition processes, this setup opens up new possibilities for creating novel materials that were previously unattainable. The in situ characterization capability during growth provides a deeper understanding of growth mechanisms and defect control, facilitating rapid feedback and maintaining pristine interfaces between device layers.

We demonstrate the capabilities of this system through the optimization and integration of Josephson junctions incorporating different material stacks and superconducting nitrides (NbN, TiN, and NbTiN) backed up by electrical and material characterization techniques. We will discuss the ongoing and future directions for device development, highlighting how this cluster tool system, along with the characterization suite at the Molecular Foundry, provides an in-depth platform for materials growth and exploration.

QS-ThP-7 Superconducting Nitrides for Next-Generation Quantum Information Processing*, **Mythili Surendran**, Y. Balaji, A. Kemelbay, A. Gashi, A. Schwartzberg, S. Aloni,* Lawrence Berkeley National Laboratory

Superconducting nitrides such as niobium nitride (NbN) and titanium nitride (TiN) and their alloys are extensively studied for next-generation quantum information processing due to their favorable superconducting properties, including high critical temperature, high critical field and low resistivity. Additionally, their compatibility with standard semiconductor fabrication processes facilitates the integration of superconducting qubits and circuits with other electronics. These materials exhibit low microwave losses, leading to high Q-factors in resonators, thereby enhancing coherence times and qubit performance. The ability to achieve these properties depends on precise control over thin film growth, ensuring accurate structure, stoichiometry, and defect concentration. However, understanding the influence of process parameters, crystalline and interfacial quality and chemical composition is still limited in the literature due to challenges such as lack of controlled experimental setups and characterization techniques. Thus, a systematic investigation into the fundamental properties of these superconductors and their impact on quantum computing device performance is essential.

In this study, we present a comprehensive analysis of NbN, TiN and NbTiN thin films deposited using DC reactive sputtering in a cluster tool system. Extensive structural, chemical and electrical characterization of nitride thin films sheds light on how crystallinity and chemical composition influence the critical temperature. Improved vacuum conditions in the cluster tool reduce oxygen contamination within the films. We also explore the effects of process parameters such as substrate selection, deposition temperature, and nitrogen partial pressure on achieving epitaxial nitride thin films. Additionally, we report on key superconducting properties such as critical temperature, upper critical field, superconducting gap, coherence length, and their relationship to structure and stoichiometry. This work provides a coherent approach to synthesizing high-quality superconducting nitrides with precise and reproducible properties, which is crucial for quantum computing applications.

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