Quantum Science and Technology Mini-Symposium
Room 208 W - Session QS1-MoA

Advanced Materials for Quantum Information Science

Moderators: Kasra Sardashti, University of Maryland College Park, **David Pappas**, Rigetti Computing

1:30pm **QS1-MoA-1 Growth and Characterization of Thin-Film A15 Nb-Al Intermetallics for Superconducting Quantum Electronics**, ***Joseph Falvo***, University of Maryland College Park; *Elizabeth Henry,* Clemson University; *Ashish Alexander,* University of Maryland; *Hussein Hijazi,* Rutgers University; *Ivan Lainez,* University of Maryland; *Leonard Feldman,* Rutgers University; *Kasra Sardashti,* Laboratory for Physical Sciences

As superconducting qubit technology progresses, there is an increasing demand for materials with high critical temperatures and critical magnetic fields to allow for devices to be more robust against external excitations. A15 intermetallic compounds, a family of superconductors explored in the 1950's through the 1970's, provide one potential avenue to such high critical values. In this work, we synthesize Nb3Al, one of many A15 compounds, as a thin film by co-sputtering from elemental targets, followed by a rapid thermal annealing procedure. We confirm the realization of the desired ratio and crystal structure within our films by Rutherford backscattering (RBS) and X-ray diffractometry, respectively. For films with thickness close to 200 nm, we achieve thin films with Tc greater than 16 Kelvin and zero-temperature critical fields greater than 30 T. Additionally, we report single-photon microwave quality factors of 1.9x105 and estimates for kinetic inductance similar to NbN at comparable thickness.

1:45pm **QS1-MoA-2 Extending the Specific Resistance of Alox Thin Films by Tuning Plasma Oxidation Time for Qis Devices**, ***Runze Li***, University of Maryland, College Park; *Joshua Pomeroy,* National Institute of Standards and Technology

We are extending the range of the specific resistance for our Plasma-AlOx tunnel barriers based on adjusting the oxidation time to reach 1 GΩ*um^2. Device instabilities like charge drift and loss tangent are persistent problems for QIS devices like Josephson junctions that significantly reduce the device stability or shorten the decoherence time. By using plasma oxidation and *in situ* techniques for device fabrication, we have greatly increased the stability of our AlOx tunnel junctions. We believed that generating oxygen atoms in the plasma results in higher reactivity than the oxygen molecules present in natural oxidation. Hence, a denser and less defective aluminum oxide is formed through plasma oxidation. As a result, we have observed a ≈ 50 times increase in the plasma-AlOx based Single Electron Transistors (SETs) compared to naturally oxidized AlOx based SETs (Zimmerman, 2008). We will report on the fabrication and characterization of our plasma-AlOx thin film for thickness and composition change v.s. oxidation time.

2:00pm **QS1-MoA-3 Molecular Beam Epitaxy of Germanium Quantum Wells with Epitaxial Aluminum**, ***Jason Dong***, *Joshua Thompson, Chomani Gaspe, Riis Card, Kasra Sardashti,* Laboratory for Physical Sciences; *Shiva Davari Dolatabadi, Hugh Churchill,* University of Arkansas; *Kyle Serniak, Thomas Hazard,* MIT Lincoln Laboratory; *Christopher Richardson,* Laboratory for Physical Sciences

Voltage tunable Josephson junctions (JJs) are an alternative route towards tuning the critical current of JJs in quantum circuits to enable new functionalities, and replace the current carrying flux lines and squids that are currently used. Germanium JJs implemented on float-zone silicon substrates allow for scalable integration with low-loss superconducting circuit elements, and enable a gate tunable transmon with longer coherence times. Here, Ge quantum wells (QW) with epitaxial aluminum contacts are grown by molecular beam epitaxy.

Strained Ge-QWs are grown on $Si_{0.2}Ge_{0.8}$ virtual substrates. The $Si_{0.2}Ge_{0.8}$ virtual substrates are grown with a reverse graded buffer layer on float zone silicon. Epitaxial aluminum is grown *in situ* on the Ge quantum wells to create high-transparency superconducting contacts that proximitize the underlying Ge-QWs. From low-temperature magneto-transport measurements, a 2 K mobility exceeding 45,000 cm^2/Vs is observed for samples with a 22-nm deep QW. The effect of growth conditions on the structural quality and low-temperature mobility will be discussed. The structural quality of the samples is investigated with X-ray diffraction, atomic force microscopy, and defect selective etching. Reverse graded buffer layers with the thickness exceeding 1.5 µm are found to be required to eliminate most structural defects. The limiting scattering mechanisms are identified from analysis of the carrier density dependence of the mobility and potential routes towards improving the mobility will be discussed.

2:15pm **QS1-MoA-4 Spatially and Spectrally controlled MBE Grown InAs/GaAs Quantum Dots for Device Platforms**, ***Nazifa Tasnim Arony***, University of Delaware; *Lauren N. McCabe,* University of Delaware (Now at Yale University); *Joshya Rajagopal, Lan Mai, Lottie Murray, Prashant Ramesh, Matthew Doty, Joshua Zide,* University of Delaware

InAs quantum dots (QDs) grown epitaxially on GaAs substrates have emerged as promising candidates for single-photon emitters, particularly due to their compatibility with established semiconductor manufacturing techniques. This compatibility paves the way for scalable quantum devices in fields like quantum sensing, computing, and information processing. However, for the production of fully functional epitaxial quantum devices on a large scale, uniformity in spatial, spectral, and structural properties, along with scalability, is essential. Recent work from our group has introduced a method for site-controlled QD growth, where InAs/GaAs QDs are grown on nano-fabricated substrates featuring site-templated arrays of nano-pits [1]. Despite these developments, fabrication processes often introduce impurities that can adversely affect their optical performance, and hence, maintaining high-quality optical emission from these site-controlled QDs is still a major challenge. In response to this issue, this study investigates the use of quantum dot columns (QDCs) as a buffer layer above the initial site-templated QD arrays. This approach effectively "buries" defects beneath the QDCs, thereby enhancing the optical quality of the top QDs of interest. Additionally, we present initial photoluminescence (PL) data showcasing the spectral control over InAs/GaAs QDs achieved through the 'cap and flush' technique, which enables the tuning of their emission properties.

[1] J. Vac. Sci. Technol. B 38, 022803 (2020)

2:30pm **QS1-MoA-5 Epitaxy of Superconducting Germanium Thin Films for Integrated Quantum Electronics**, ***Patrick Strohbeen***, New York University; *Julian Steele, Ardeshir Baktash,* university of queensland, Australia; *Alisa Danilenko,* new york university; *Axel Leblanc, Jechiel van Dijk,* New York University; *Yi-Hsun Chen, Lianzhou Wang,* university of queensland, Australia; *Salva Salmani-Rezaie,* Ohio State University; *Eugene Demler,* ETH Zurich, Switzerland; *Peter Jacobson,* university of queensland, Australia; *Javad Shabani,* New York University

Superconducting group IV materials are highly promising for quantum information due to the homoepitaxial alignment with the underlying substrate, reducing material disorder at the film/substrate interface. Furthermore, increasing interest in germanium systems for both spin qubits, gate-tunable superconducting qubits, and topological phases has put a spotlight on the necessity for thin film superconductors that readily interface with group IV systems. However, the hyperdoped phase is thought to require dopant incorporation above typical thermodynamical solubility limits and thus most efforts have been focused on non-equilibrium techniques. Very recent work has shown that superconductivity is observed in Ga-doped germanium system using molecular beam epitaxy. In this talk we will present an expanded study towards illuminating the atomic fine structure of superconducting germanium thin films grown via MBE. We observe that our superconducting MBE-grown films exhibit well-dispersed Ga-dopants throughout the film as substitutional defects via synchrotron-based X-ray scattering and absorption experiments. Cross-sectional electron microscopy imaging shows the homoepitaxial interface between the Ge substrate and the superconducting Ge film is well-defined, the films are of high crystalline quality, and no Ga clustering is found. Band structure calculations further suggest that the observed crystal structure induced a narrow-band state at the R-point in the Brillouin Zone, posing a new possible mechanism for the observed superconducting state.

2:45pm **QS1-MoA-6 High Purity Physical Vapor Deposition CaO Thin Films for Quantum Information Science**, ***Jake DeChiara***, *Saeed Almishal,* Pennsylvania State University; *Jon-Paul Maria,* Pennsylvania State Univeristy

CaO has generated substantial interest in the quantum informatics community as a novel solid state QuBit host. In this work we aim to experimentally verify the existence of Schottky defects with rare earth and bismuth interstitials in a high purity CaO thin film host grown on R-plane Sapphire. We study reactive RF sputter and pulsed laser deposition techniques utilizing metallic calcium and $Ca(OH)_2$ targets. X-ray fluorescence reveals that metallic calcium targets contain substantial chlorine impurities, which adversely affects CaO film growth via sputtering. We demonstrate $Ca(OH)_2$ as an intriguing candidate as a calcium source for

physical vapor deposition due to its availability in high (99.999%) purity and relatively low cost. We utilize a hydrothermal sintering method to attain target density above 95 % while maintaining high chemical purity. All CaO thin films grown were found to achieve single orientation in the (0 0 2) direction, as verified via X-Ray diffraction. Film thickness evaluated by X-Ray reflectivity measurements revealed a faster deposition rate from the metallic calcium target compared to the $Ca(OH)_2$ target during sputter deposition. Deposition growth rates achieved from the $Ca(OH)_2$ targets were highly linear and suggest high target stability and reliability. CaO films grown by pulsed laser deposition attained high crystallinity, relatively fast deposition rates, and single orientation. We have identified a wide range of methods in the physical vapour deposition processing space which permit further investigation into the defect structure of doped CaO thin films.

3:00pm **QS1-MoA-7 Epitaxial Control of Magnetism and Superconductivity in Quantum Materials**, ***Matthew Brahlek***, Oak Ridge National Laboratory **INVITED**

Understanding and designing functional quantum phenomena presents significant challenges due to the complexity of integrating structurally dissimilar materials and managing intertwined factors such as valence, spin, orbital, and structural degrees of freedom. In this talk, I will highlight recent discoveries that demonstrate how novel phenomena can emerge at the interfaces of materials synthesized as high-quality thin films via molecular beam epitaxy. I will also discuss how advancements in x-ray techniques have provided new insights into the origins of these properties. These findings include emergent and tunable ferromagnetism [1], interfacially enhanced superconductivity [2–3], and the proposed emergence of altermagnetism [4]. A key takeaway is that these breakthroughs are made possible by the tight integration of material synthesis with structural and spectroscopic x-ray-based probes. This combined approach is essential for unraveling the origins of functional quantum phenomena and exploring how these exotic phases can be controlled—potentially paving the way for next-generation microelectronic devices.

[1] M. Brahlek *et al.*, Nano Letters, 23, 7279-7287 (2023); 10.1021/acs.nanolett.3c01065

[2] R. G. Moore *et al.*, Advanced Materials, 35, 2210940 (2023); 10.1002/adma.202210940

[3] A.-H. Chen *et al.*, Advanced Materials, 202401809 (2024); 10.1002/adma.202401809

[4] M. Chilcote *et al.*, Advanced Functional Materials, 2405829 (2024); 10.1002/adfm.202405829

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