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.

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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).

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