Quantum Information Science Focus Topic
Room 302 - Session QS+EM+MN+NS-WeA

Systems and Devices for Quantum Information

Moderators: Megan Ivory, Sandia National Laboratories, **Dave Pappas**, Rigetti Computing

2:20pm **QS+EM+MN+NS-WeA-1 Photonics-Integrated Microfabricated Surface Traps for Trapped Ion Applications**, ***Megan Ivory**, W. Setzer, N. Karl, J. Schultz, J. Kwon, M. Revelle, R. Kay, M. Gehl, H. McGuinness,* Sandia National Laboratories **INVITED**

Some of the more advanced quantum systems for applications spanning clocks, sensors, and computers are based on the control and manipulation of atoms.While these atomic systems have led to promising results in laboratory systems, the transition of these devices from the laboratory to the field remains a challenge.Recently, advances in compact vacuum technology, microfabricated surface traps, and integrated photonics are paving the way toward deployable solutions.Here, I discuss ongoing efforts at Sandia National Laboratories to leverage microfabricated surface traps for low size, weight, and power (SWaP) deployable trapped-ion systems, and the unique systematics presented by these integration efforts.In particular, I present initial demonstrations of trapped ions utilizing multilayered waveguides for UV and visible/IR light and single photon avalanche detectors integrated with microfabricated surface traps.I also present characterization of heating rates and frequency shifts in these integrated devices, and an outlook for further reducing SWaP via compact vacuum systems.

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3:00pm **QS+EM+MN+NS-WeA-3 Toward Heterogeneous Quantum Networks: Interfacing Trapped Ion, Superconducting, and Integrated Photonic Qubits**, ***Kathy-Anne Soderberg**, A. Paul,* Air Force Research Laboratory; *N. Barton, A. Brownell,* Murray Associates; *D. Campbell,* Air Force Research Laboratory; *C. Craft,* Technergetics; *M. Fanto, D. Hucul,* Air Force Research Laboratory; *A. Klug,* Griffiss Institute; *M. LaHaye,* Air Force Research Laboratory; *M. Macalik,* Booz Allen Hamilton; *K. Scalzi,* Technergetics; *J. Schneeloch,* Air Force Research Laboratory; *M. Senatore,* Griffiss Institute; *E. Sheridan,* National Academies of Sciences, Engineering, and Medicine; *D. Sica,* Griffiss Institute; *A. Smith, Z. Smith, C. Tison,* Air Force Research Laboratory; *C. Woodford,* Griffiss Institute **INVITED**

Effective and efficient ways to connect disparate qubit technologies is an outstanding challenge in quantum information science. However, the ability to interface different qubit modalities will have far-reaching implications for quantum computing and quantum networking. Here we present plans and progress toward interfacing trapped ion, superconducting, and integrated photonic qubits for the purpose of entanglement distribution in a quantum network. We will also discuss how this work connects to the AFRL distributed quantum networking testbed.

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4:20pm **QS+EM+MN+NS-WeA-7 Superconductor/Semiconductor Heterostructures for Quantum Computing Applications**, ***Chris Palmstrøm,*** University of California, Santa Barbara **INVITED**

Superconductor/semiconductor heterostructures have potential for quantum computing applications. Coupling superconductivity to near surface quantum wells (QW) and nanowires of high spin-orbit semiconductors have allowed the observation of zero bias peaks, which can be a signature of, but not proof of, Majorana Zero Modes, a key ingredient for topological computing. These results of induced superconductivity pave the way for lithographically defined complex superconductor/semiconductor nanostructured networks necessary for quantum computation.

Our efforts have focused on developing high mobility of near surface quantum wells of the high spin-orbit semiconductors InAs, InSb and $InAs_ySb_{1-y}$. Rather than relying on post growth lithography and top down etching to form semiconductor nanostructures, we have investigated the development of shadow superconductor growth on atomic hydrogen cleaned MOVPE-grown vapor-liquid-solid InSb nanostructures and in-vacuum chemical and molecular beam epitaxy selective area grown InAs nanostructures. We have identified Sn as an alternative for Al for use as superconductor contacts to InSb vapor-liquid-solid nanowires, demonstrating a hard superconducting gap, with superconductivity persisting in magnetic field up to 4 Tesla. Further, a small island of Sn-InSb exhibits the two-electron charging effect, a clear indication of a supercurrent.

In more conventional superconductor qubits, a dramatic size reduction of the superconducting transmon devices is predicted by the development of merged element transmon devices based on superconductor/semiconductor/superconductor heterostructures. These superconductor/semiconductor/superconductor heterostructures also allow for selective control of conductance modes in planar lateral multi-terminal Josephson Junctions

In this presentation, progress in developing superconductor/semiconductor heterostructures for quantum computing applications will be presented. This will include progress in in-situ patterning and selective area growth, multi-terminal Josephson Junctions and the recent progress towards developing a Si fin based merged element transmon – the FinMET.

5:00pm **QS+EM+MN+NS-WeA-9 High Throughput Measurements of III-V Semiconductor Materials Stack of 2DEG-Based Tunable Couplers**, ***Nicholas Materise,*** Colorado School of Mines; *J. Pitten,* University of Colorado at Boulder; *W. Strictland,* New York University; *A. McFadden,* National Institute for Science and Technology (NIST); *J. Shabani,* New York University; *E. Kapit,* Colorado School of Mines; *C. McRae,* University of Colorado at Boulder

Recent success in integrating cryogenic semiconductor classical systems with superconducting quantum systems promises to reduce the room temperature classical signal processing bottleneck. Incorporating semiconductor quantum devices with superconducting ones as tunable couplers and hybrid quantum systems requires quantitative estimates of the loss introduced by those devices. We report loss measurements of the III-V semiconductor stack used in 2DEG-based gatemon qubits and couplers using a superconducting microwave cavity. Extending the high throughput, low-cost substrate measurement method to thin films grown by molecular beam epitaxy, we can investigate surface roughness losses, bulk losses, and interface losses in a single microwave package. As with our previous measurements of substrates, we perform comparison studies with CPW resonators to validate our approach.

5:20pm **QS+EM+MN+NS-WeA-10 Strong Coupling between a Superconducting Microwave Resonator and Low-Damping Magnons Using Vanadium Tetracyanoethylene Thin Films**, *Q. Xu, H. Cheung,* Cornell University; *D. Cormode, H. Yusuf,* The Ohio State University; *Y. Shi,* University of Iowa; *M. Chilcote,* Cornell University; *M. Flatté,* University of Iowa; *E. Johnston-Halperin,* The Ohio State University; ***G. D. Fuchs**,* Cornell University **INVITED**

Hybrid quantum systems – in which excitations with distinct origin are hybridized through a resonant interaction – are attractive for quantum technologies because they enable tunability and the ability to combine desirable properties of each excitation. Here we study the hybrid excitation of a superconducting microwave resonator mode and a ferromagnetic resonance mode of vanadium tetracyanoethylene ($V[TCNE]_x$) thin films. Our work addresses a key challenge for hybrid superconducting resonator-magnon devices: the integration of a low damping thin-film material with microfabricated superconducting circuits. $V[TCNE]_x$ is a molecular-based ferrimagnet with exceptionally low magnetic damping – as low as 5×10^{-5} at room temperature. The ability to grow thin films of this material at low temperature via chemical vapor deposition and pattern it via lift-off processing enables the fabrication of integrated quantum magnon devices using this material. We couple a $V[TCNE]_x$ magnon mode to the mode of a thin-film Nb lumped-element LC resonator and demonstrate strong coupling, characterized by cooperativities in above 10^2. Characterization of this hybrid resonator-magnon system in both the frequency domain and the time domain reveals hybridization between resonator photons and magnons. This work demonstrates a pathway for scalable and integrated quantum magnonic technologies.

6:00pm **QS+EM+MN+NS-WeA-12 Role of Point Defect Disorder on the Extraordinary Magnetotransport Properties of Epitaxial Cd_3As_2**, ***Jocienne Nelson**, A. Rice, C. Brooks, I. Leahy, G. Teeter, M. van Schilfgaarde, S. Lany, B. Fluegel, M. Lee, K. Alberi,* NREL

Three-dimensional topological semimetals host extremely large electron mobilities and magnetoresistances making them promising for a wide range of applications including in optoelectronic devices, renewable energy, and quantum information. However, the extent to which disorder influences the properties of topological semimetals remains an open question and is relevant to both the understanding of topological states and the use of topological materials in practical applications. As a particular example, epilayers of the prototypical Dirac semimetal Cd3As2 exhibit high electron mobilities despite a having very high dislocation densities.[1,2]

Native point defects are inevitable in crystalline materials and introduce long and short-range disorder potentials that will impact carrier transport behavior. To understand their role in topological semimetals, we use molecular beam epitaxy to achieve unmatched and systematic control of point defect concentrations in Cd_3As_2. By reducing the concentration of scattering point defects, we increased the mobility from 5000 to 18,000 cm2/Vs and the magnetoresistance from 200% to 1000%. We find good agreement with the guiding center diffusion model, which indicates point defects are essential to the large linear magnetoresistance in topological semimetals.[3] However, the degree of linear magnetoresistance, is found to correlate inversely with measures of disorder. Our results demonstrate the importance of engineering high quality material with dilute concentrations of point defects to optimize the magnetoresistance properties in topological semimetals.[4]

[1] A.D. Rice, K. Park, E.T. Hughes, K. Mukherjee and K. Alberi, *Phys. Rev. Mater.*, **3**, 121201(R) (2019)

[1] M. Goyal, S. Salmani-Rezaie, T.N. Pardue, B. Guo, D.A. Kealhofer and S. Stemmer, *APL Mater.*, **8**, 051106 (2020)

[1] I.A. Leahy, Y.-P. Lin, P.E. Siegfried, A.C. Treglia, J.C.W. Song, R.M. Nandkishore and M. Lee*, PNAS*, **115**, 10570 (2018)

[1] J. N. Nelson, A. D. Rice, C. Brooks, I. A. Leahy, G. Teeter, M. Van Schilfgaarde, S. Lany, B. Fluegel, M. Lee, K. Alberi *arXiv:2206.10023* (2022).

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