NAMBE
Room Cummings Ballroom - Session NAMBE1-TuM
Magnetism, Superconductivity, and Quantum Computing
Moderator: Patrick Strohbeen, New York University

8:15am **NAMBE1-TuM-1 Welcome & Sponsor Thank Yous**,

8:30am **NAMBE1-TuM-2 NAMBE Young Investigator Awardee Talk: Epitaxial Integration of Dissimilar Semiconductors for Infrared Optoelectronics**, ***Kunal Mukherjee***, Stanford University **INVITED**

Integrating dissimilar semiconductors on a single crystal platform can power the next generation of electronics and photonics applications. In such a platform, semiconductors like III-V and IV-VI materials bring exciting new properties to the table and leverage the scale and functionality of conventional silicon technology. The synthesis of high-quality semiconductor thin films while mediating this dissimilarity, however, is quite the materials science challenge. These very differences in properties also lead to unusual interfaces and crystal defects such as dislocations that severely degrade device performance. In this talk, we update our understanding of how dislocations are bad for epitaxially-integrated telecom lasers on silicon using new microscopy and microanalysis tools, and we present on our progress in engineering dislocation tolerance in such devices using MBE-grown III-V (InAs) quantum dots. With an eye towards materials and devices naturally more tolerant to dislocations, we will show new opportunities that arise from MBE-grown IV-VI (PbSe-SnSe) mid-infrared light emitters and crystalline-crystalline phase change materials grown epitaxially on III-V substrates

9:00am **NAMBE1-TuM-4 MBE Synthesis of Altermagnetic MnTe Exhibiting an Anomalous Hall Effect**, *S. Bey, X. Liu,* University of Notre Dame*; A. Ievlev,* Oak Ridge National Laboratory*; S. Bennett,* Naval Research Laboratory*; M. Zhukovskyi, T. Orlova,* ***Badih A. Assaf***, University of Notre Dame

Altermagnets are a new class of magnetic materials that host a spin polarization texture on the Fermi surface despite being antiferromagnetic [1]. An anomalous Hall effect (AHE) can result from this spin texture under specific conditions dictated by the magnetic anisotropy of the material. Hexagonal α-MnTe is an altermagnet where the AHE has already been reported but is not understood [2] [3]. We have successfully synthesized MnTe by molecular beam epitaxy on GaAs (111) and SrF2 (111) and doped with In. The lattice mismatch between MnTe and the two substrates is +3.8% and +1.2% however in both cases, a heteroepitaxial growth is achieved with [11 -2 0] direction of MnTe aligning with the [1-10] direction of the substrate. We reveal this by carrying out systematic high-resolution x-ray diffraction in the specular and off-specular direction. On both substrates, MnTe hosts an anomalous Hall effect, generally unexpected in collinear antiferromagnets. The conductivity of MnTe is found to be higher when it is grown on GaAs. We find that In doping alters the carrier density to below 10^{19} holes/cm^3 without signficantly changing the conductivity We exploit this tuning of the transport parameters to study the scaling law relating the anomalous Hall and longitudinal conductivity in this protypical altermagnet. [4]

[1] L. Šmejkal, J. Sinova, and T. Jungwirth, *Beyond Conventional Ferromagnetism and Antiferromagnetism: A Phase with Nonrelativistic Spin and Crystal Rotation Symmetry*, Phys Rev X **12**, 031042 (2022).

[2] R. D. Gonzalez Betancourt et al., *Spontaneous Anomalous Hall Effect Arising from an Unconventional Compensated Magnetic Phase in a Semiconductor*, Phys Rev Lett **130**, 036702 (2023).

[3] K. P. Kluczyk et al., *Coexistence of Anomalous Hall Effect and Weak Net Magnetization in Collinear Antiferromagnet MnTe*, ArXiv 2310.09134 (2023).

[4] N. Nagaosa, J. Sinova, S. Onoda, A. H. MacDonald, and N. P. Ong, *Anomalous Hall Effect*, Rev Mod Phys **82**, 1539 (2010).

9:15am **NAMBE1-TuM-5 Lateral Strain and Magnetism Patterning in Flexomagnetic GdAuGe Thin Films via Helium Ion Implantation**, ***Zachary LaDuca***, *T. Samanta, T. Jung,* University of Wisconsin - Madison*; M. Brahlek, T. Ward, A. Chen,* Oak Ridge Natinal Laboratory*; N. Hagopain, F. Fei, T. Xi, K. Su, M. Arnold, P. Voyles, J. Xiao, J. Kawasaki,* University of Wisconsin - Madison

Strain gradients provide a new degree of freedom to precisely tune the ferroic properties of quantum materials. However, studying the effects of strain gradients on materials properties has proven to be a great challenge, as it is difficult to control strain gradients in bulk crystals and epitaxial films. Here, using patterned helium ion implantation, we demonstrate top-down control of strain gradients and flexomagnetism ($M \propto \nabla \epsilon$) in epitaxial GdAuGe thin films on Graphene/Ge (111). Unstrained GdAuGe is antiferromagnetic, with a Néel temperature of 17K. Uniform strain up to 4.5% along the c-axis suppresses the Néel temperature to 8K yet preserves antiferromagnetic ordering in GdAuGe. Remarkably, patterned strain gradients induce a transition to ferro/ferrimagnetic ordering around 100K, subsequently followed by an antiferromagnetic transition at approximately 8K. These results confirm the presence of flexomagnetism rather than piezomagnetism ($M \propto \epsilon$) or magnetostriction ($M^2 \propto \epsilon$). Furthermore, the presented results underscore the efficacy of patterned helium ion implantation as a novel and versatile method for controlling strain, strain gradients, and their impact on material properties.

This work was supported by the Air Force Office of Scientific Research and the National Science Foundation via the Wisconsin MRSEC.

9:30am **NAMBE1-TuM-6 Synthesis and Fabrication of Superconducting Germanium Alloys for Quantum Information**, ***Patrick Strohbeen***, *J. van Dijk, I. Levy, M. Mikalsen, A. Danilenko, W. Schiela, J. Shabani,* New York University

Germanium as a platform for quantum information has been rapidly gaining interest in the last five years due in large part to drastic improvements in 2D hole gas quality (2DHG) [1]. As a result, there is immediate interest in using the Ge 2DHG in superconductor-semiconductor (S-Sm) hybrid platforms for quantum information [2]. Indeed, recent experimental works have shown a hard superconducting gap in a Ge quantum well [3] as well as long parity lifetimes [4]. However, the Josephson junctions created thus far have required direct contact to the quantum well region which is likely to drastically reduce carrier mobilities within the junction region [5]. In addition, growth of superconducting materials compatible with group IV semiconductors enables the growth of buried superconducting layers for more complex devices, such as the merged-element transmon [6]. In this talk I will discuss our recent work on the growth of superconducting binary germanium alloys and their promise for quantum information applications. This work will be discussed in the context of both planar and out-of-plane device architectures and the utility afforded by germanium alloys.

[1] M. Myronov et al.,Small Sci. 3, 2200094 (2023).

[2] G. Scappucci et al.,Nat. Rev. Mater.6, 926-943 (2021).

[3] A. Tosato et al.,Commun. Mater. 4, 23 (2023).

[4] M. Hinderling et al.,arXiv:2403.03800 (2024).

[5] D. Laroche et al.,AIP Adv. 5, 107106 (2015).

[6] R. Zhao et al.,Phys. Rev. Applied 14, 064006 (2020).

9:45am **NAMBE1-TuM-7 Molecular Beam Epitaxy Growth of Al and Ta Multilayers for Superconducting Qubits**, ***Kevin A. Grossklaus***, *D. Miller, L. Burkhart, A. Sabbah, M. Gingras, B. Nidezielski, C. O'Connell, H. Stickler, D. Calawa, A. Melville,* MIT Lincoln Laboratory*; A. Goswami,* Massachusetts Institute of Technology*; D. Kim, J. Yoder, M. Schwartz,* MIT Lincoln Laboratory*; W. Oliver,* Massachusetts Institute of Technology*; K. Serniak,* MIT Lincoln Laboratory

Superconducting qubits have advanced from proof-of concept demonstrations to broad deployment of a variety of qubit designs into many-qubit quantum processors.Reducing materials- and processing-induced losses in superconducting qubit circuits remains a critical focus in the effort to reduce qubit decoherence and improve overall performance.For the superconducting base metal used in a qubit, the metal’s microstructure, the interfaces between the metal and its surroundings, crystalline defects, and the presence of contaminants in the metal interior or on its surface may all be expected to play a role in the performance of a final device.Because loss may come from a variety of sources, it is often difficult to unambiguously link changes in specific superconducting material properties and structure to changes in qubit performance.For this reason, deposition of superconducting metals by molecular beam epitaxy (MBE) may serve as a valuable method for understanding and isolating the material factors that affect their performance in superconducting qubits.As an approach, MBE allows for careful control of source material quality, vacuum conditions, deposition rate, layer thicknesses, and interface sharpness.Thus, MBE allows for deposition of superconducting materials with very low contamination and deposition conditions that can be known with a high degree of precision.

In this work we will present results from the low temperature MBE deposition of Al and Ta/Al multilayers on silicon substrates.Superconducting co-planar waveguide (CPW) resonators will be used to probe expected material performance for qubit applications. Characterization of the as-deposited metals and data from CPW resonators fabricated using them will be shown.Materials characterization of epitaxial Al layers by AFM, XRD, XPS, RHEED, and TEM will be shown and discussed in terms of both the benefits of deposition by MBE and implications for superconducting device performance.Similarly, characterization of Ta/Al bilayers will be shown and the impacts of bilayer deposition on the structure of both Ta and Al layers will be discussed.Finally, the possible impacts of Ta/Al bilayers on the material sources of qubit loss and next steps in improving the quality of MBE grown Ta/Al multilayer structures will be considered.

This material is based upon work supported under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the U.S. government or the U.S. Air Force.

10:00am **NAMBE1-TuM-8 Electrical, Magnetic, and Thermoelectric Characterizations of Strange Metallicity in Epitaxial Thin Film Kagome Intermetallics***, **Minyong Han**, C. John, J. Zheng, S. Fang, J. Checkelsky,*
Massachusetts Institute of Technology

The observation of strange metallicity in a paramagnetic kagome intermetallics Ni_3In has demonstrated the role of hopping-frustration-induced *d*-electron flat band in generating Kondo-like behaviors even in the absence of *f*-electrons in the lattice [1]. A number of bulk single crystal experiments consistently suggest the potential presence of a quantum critical point in a proximate phase space. This calls for a platform that enables versatile materials tunings along various non-thermal control axes. In this talk, we present successful stabilization of Ni_3In in epitaxial thin film form using Molecular Beam Epitaxy. We discuss key aspects of the synthesis which are critical in attaining high crystallinity and flat morphology at the same time. Electrical transport under a wide temperature range reveals that quantum fluctuation is strongly influencing the electronic conduction even when the system is confined in thin film structure. Magnetoresistance and magneto-Seebeck responses suggest the relevance of spin fluctuation in generating such a behavior. We also present high precision magnetometry suitable for probing those spin fluctuations in our films – the task that is typically nontrivial in paramagnetic thin films with dramatically reduced sample volume. In the end, we will propose useful post-synthesis thin film engineering techniques for controlling the quantum criticality in Ni_3In. (ref: [1] L. Ye et al., Nat. Phys. (2024), doi.org/10.1038/s41567-023-02360-5)

Author Index

Bold page numbers indicate presenter