Magnetic Interfaces and Nanostructures Division
Room 330 - Session MI+2D+TF-ThM

Quantum Materials (2D)

Moderator: Zheng Gai, Oak Ridge National Laboratory

8:00am **MI+2D+TF-ThM-1 Exploration of Two Surfaces Observed in Weyl Semimetal $BaMnSb_2$, *Zheng Gai,*** *Q. Zou,* Oak Ridge Natinal Laboratory*; S. Huang,* University of South Carolina*; W. Ko, M. Fu,* Oak Ridge Natinal Laboratory*; Y. Yang, K. Zhao,* Louisiana State University*; S. Crittenden,* University of South Carolina*; E. Plummer,* Louisiana State University*; R. Jin,* University of South Carolina

Single crystalline $BaMnSb_2$ is considered as a 3D Weyl semimetal with the 2D electronic structure containing Dirac cones from the Sb sheet. The unique surface electronic structure can be probed by techniques such as angle-resolved photoemission spectroscopy (ARPES) and scanning tunneling microscopy/spectroscopy (STM/S). However, these techniques require an in-depth understanding of the surface structure and electronic properties. We report experimental investigation of low-temperature cleaved $BaMnSb_2$ surfaces using STM/S and low energy electron diffraction (LEED). By natural cleavage, we find two terminations: one is Ba1 (above the orthorhombic distorted Sb sheet) and another Sb2 (at the surface of the Sb/Mn/Sb sandwich layer). Both terminations show the 2 × 1 surface reconstructions, with drastically different morphologies and electronic properties, however. The reconstructed structures, defect types and nature of the electronic structures of the two terminations are extensively studied. The quasiparticle interference (QPI) analysis also reveals that the surface-projected electronic band structures strongly depend on the surface termination. The existence of defects can greatly modify the local density of states to create electronic phase separations on the surface in the order of tens of nm scale. Our observation on the atomic structures of the terminations and the corresponding electronic structures provides critical information towards an understanding of topological properties of $BaMnSb_2$.

8:20am **MI+2D+TF-ThM-2 Properties of Mn_3Sn Films Grown on Sapphire Substrates Using Molecular Beam Epitaxy*, Sneha Upadhyay,*** Ohio University*; T. Erickson, D. Ingram,* Ohio University*; K. Sun,* The University of Michigan , Ann Arbor*; A. Smith,* Ohio University

The kagome antiferromagnet Mn_3Sn is a fascinating material because it's one of the rare antiferromagnets that exhibits large anomalous Hall and Nernst effects. This opens a new area of research using functional antiferromagnets[1], but for future device applications, it requires fabricating high-quality thin films. There are reports of the controlled growth of Mn_3Sn on substrates like *m*-plane sapphire,[2] Pt/Al_2O_3 (0001)[3], and others using sputtering growth, but this often can result in polycrystalline films. In this work, we investigate the growth of Mn_3Sn films on *c-plane* sapphire substrates using molecular beam epitaxy. Effusion cells are used for Mn and Sn sources which are calibrated using a quartz crystal thickness monitor. The growth is monitored *in-situ* using reflection high energy electron diffraction and *ex-situ* measurements are carried out using X-ray diffraction, Rutherford backscattering, and cross-sectional scanning transmission electron microscopy. The samples are grown at 500 ± 9°C and 416 ± 9 °C with an Mn: Sn atomic flux ratio of 3.2: 1 on *c-plane* sapphire substrates for 60 mins. We observe streaky RHEED patterns at both temperatures indicating high-quality crystalline growth with 2 different orientations, (0001) and (11-20), which are also backed up by the XRD spectra. STEM verifies ~3:1 Mn to Sn stoichiometry but also reveals discontiguous films. After optimizing the growth conditions, the next phase of the study is to begin *in-situ* scanning tunneling microscopy and spin-polarized STM studies of the structural, electronic, and magnetic properties of the *as-grown* Mn_3Sn surfaces, and in this presentation, we plan to present initial results.

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[1] S. S. Zhang et al., "Many-body resonance in a correlated topological Kagome Antiferromagnet", Physical Review Letters 125, 046401 (2020).

[2] S. Oh, T. Morita, T. Ikeda, M. Tsunoda, M. Oogane, and Y. Ando, "Controlled growth and magnetic property of a-plane-oriented Mn3Sn thin film", AIP Advances 9,035109 (2019).

[3] Y. Cheng, S. Yu, M. Zhu, J. Hwang, and F. Yang, "Tunable topological Hall effects in noncollinear antiferromagnets Mn3Sn/Pt bilayers", APL Materials 9, 051121 (2021).

8:40am **MI+2D+TF-ThM-3 Interfacial Magnetism in Oxide Heterostructures*, Alex Demkov,*** The University of Texas at Austin **INVITED**

New functionalities and unexpected electronic structures can emerge in artificially engineered complex oxide heterointerfaces due to the coupling of multiple physical properties such as ferroelectricity, ferromagnetism, conductivity, charge transfer, etc. Here, we discuss heterointerfaces involving perovskite oxides $SrTiO_3$, $LaAlO_3$, and $BaTiO_3$, as well as a rock salt ferromagnetic semiconductor EuO. Combining theoretical analysis, experimental growth, and characterization techniques with atomic level resolution, we highlight some of these intriguing emergent interfacial phenomena. We consider several means of creating a two-dimension carrier gas, through band offset engineering, polarization doping, and oxygen vacancy doping. In addition, we also discuss ways of manipulating these electron/hole gases and their potential applications in new electronic devices.

Starting from the pioneering discovery of a 2DEG at the LAO/STO interface, interfaces of transition metal oxides have been at the center of many theoretical and experimental studies. This two-dimensional carrier gas is rather different from the one occurring in semiconductor heterostructures. Its origins and mechanisms of spatial localization are rather complex. Thanks to modern experimental and theoretical techniques, one can identify which of these mechanisms are actually present at a given interface. In some cases, we can also tailor the choice of specific materials where one mechanism dominates, allowing us to study that particular mechanism in more detail.

Owing to relatively large band gaps and the presence of occupied as well as empty ***d*** and***f*** states, the oxide interfacial 2DEG shows a higher degree of spatial confinement.It is a unique physical system where, in the span of just about a nanometer, one can create strong interactions between multiple order parameters leading to phenomena that in the bulk are either very small or forbidden by symmetry. Besides the fundamental physics interest, these multi-functional interfaces may one day be utilized for technological applications.

The work has been supported by the Air Force Office of Scientific Research under grants FA9550-18-1-0053 and FA9550-12-10494, the Texas Advanced Computing Center, and by the National Science Foundation under grants IRES–1358111.

9:20am **MI+2D+TF-ThM-5 Epitaxial 2D Van Der Waals Magnets*, Roland Kawakami,*** Ohio State University **INVITED**

In this talk, I will discuss our latest advances on the epitaxial growth of 2D van der Waals (vdW) magnets and their integration with topological insulators (TI). This work is motivated by the realization of topological phases such as the quantum anomalous Hall effect and highly efficient spin-orbit torque produced by TIs. We have focused on integrating 2D magnets $MnSe_2$, Fe_3GeTe_2 (FGT) and $CrGeTe_3$ (CGT) with TIs Bi_2Se_3 and Bi_2Te_3.

Our initial studies of $MnSe_2$ growth on Bi_2Se_3 showed a tendency for the interdiffusion of Mn into the Bi_2Se_3. While this was initially undesirable, this ultimately led to the synthesis of $MnBi_2Se_4$ (MBS), a new magnetic topological insulator. This is a vdW material with septuple layer (Se-Bi-Se-Mn-Se-Bi-Se) base units, similar to its cousin $MnBi_2Te_4$ (MBT). However, the vdW phase is not the thermodynamically stable phase and bulk crystals do not exist, so the epitaxial stabilization of MBS creates the opportunity to explore the magnetic and topological properties of this material. We find that MBS is a layered antiferromagnet, similar to MBT, but a difference is that the magnetic moments lie in the plane of the film. Angle resolved photoemission experiments show the presence of a topological surface state with Dirac dispersion.

For bilayers of 2D magnets and TIs, we have focused on FGT and CGT films. A key step has been the optimization of FGT by studying its growth on Ge(111) substrates. Here, we learned that kinetics play an important role in the epitaxial growth. By varying the deposition rate, we control the formation or suppression of an initial tellurium-deficient non-van der Waals phase (Fe3Ge2) prior to realizing epitaxial growth of the vdW FGT phase. Using cross-sectional scanning transmission electron microscopy and scanning tunneling microscopy, we optimize the FGT films to have atomically smooth surfaces and abrupt interfaces with the Ge(111) substrate. The magnetic properties of our high quality material are confirmed through magneto-optic, magnetotransport, and spin-polarized

STM studies. Importantly, this demonstrates how the interplay of energetics and kinetics can help tune the re-evaporation rate of chalcogen atoms and interdiffusion from the underlayer. Utilizing these insights, we have developed the growth of FGT and CGT on Bi_2Te_3 for the integration of 2D magnets with TIs.

11:00am **MI+2D+TF-ThM-10 Hybrid Superconductor-Semiconductor Device***, **Sergey Frolov**,* University of Pittsburgh **INVITED**

Research into the generation, confirmation and manipulation of Majorana zero modes has brought heightened interest to hybrid materials systems made of fairly conventional components such as s-wave superconductor metals and semiconductors. The game in this arena is to carefully tailor the properties of an electronic device to make possible the observation of exotic physics such as topological superconductivity. The main lesson that we have learned is that the path to any plausible discovery lies through painstakingly careful and very deep understanding of the materials properties and device fabrication conditions. This being true for such a standard set of materials, the lesson certainly applies to more exotic compounds.

In this talk I will briefly summarize the status of the search for Majorana modes in superconductor-semiconductor hybrid devices. I will also highlight other unusual phenomena that arise in these systems such as higher order Josephson effects, time-reversal symmetry broken Josephson current phase relations. I will also show how these materials can be used to build quantum circuits with enhanced functionality, not necessarily arising from topological protection.

11:40am **MI+2D+TF-ThM-12 Magnetotransport in Graphene/$Pb_{0.24}Sn_{0.76}Te$ Heterostructures: Finding a Way to Avoid Catastrophe***, G. Stephen,* Laboratory for Physical Sciences*; I. Naumov,* Howard University*; N. Blumenschein, L. Sun, **Jennifer DeMell**,* Laboratory for Physical Sciences*; S. Shirodkar, P. Dev,* Howard University*; P. Taylor,* Army Research Laboratory*; J. Robinson, P. Campbell,* Naval Research Laboratory*; A. Hanbicki, A. Friedman,* Laboratory for Physical Sciences

While heterostructures are ubiquitous tools to enable new physics and device functionalities, the palette of available materials has never been richer. Combinations of two emerging material classes, 2D materials and topological materials, are particularly promising because of the wide range of possible permutations that are easily accessible. Individually, both graphene and $Pb_{0.24}Sn_{0.76}Te$ (PST) are widely investigated for spintronic applications because graphene's high carrier mobility and PST's topologically protected surface states are attractive platforms for spin transport. Here, we combine monolayer graphene with PST and demonstrate a hybrid system with properties enhanced relative to the constituent parts. Using magnetotransport measurements, we find carrier mobilities up to 20,000 cm^2/Vs and a magnetoresistance approaching 100%, greater than either material alone. We also establish there are two distinct transport channels and determine a lower bound on the spin relaxation time of 4.5 ps. The results can be explained using the polar catastrophe model, whereby a high mobility interface state results from a reconfiguration of charge due to a polar/non-polar interface interaction. Our results suggest that proximity induced interfaces states with hybrid properties can be added to the still growing list of remarkable behaviors in these novel materials.

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