## PCSI

## Room Keahou I - Session PCSI-ThM1

## Topological Materials

**Moderator: Sven Rogge**, University of New South Wales, Australia

8:30am **PCSI-ThM1-1 Chirality, Spin and Orbital in Dna-Type Chiral Materials**, ***Binghai Yan,*** Pennsylvania State University **INVITED**

In chemistry and biochemistry, chirality represents the structural asymmetry characterized by non-superimposable mirror images for a material like DNA. In physics, however, chirality commonly refers to the spin-momentum locking of a particle or quasiparticle in the momentum space. While seemingly unrelated characters in different fields, the structural chirality leads to the electronic chirality featured by the orbital-momentum locking encoded in the wavefunction of chiral molecules or solids, i.e. the chirality information transfers from the atomic geometry to the electronic orbital. The electronic chirality provides deep insights into the chirality-induced spin selectivity (CISS), in which electrons exhibit salient spin polarization after going through a chiral material. I will introduce the most recent experimental progress and understanding on chirality-driven spintronics, optoelectronics, and their implications in biochemistry.

9:10am **PCSI-ThM1-9 Distinguishing Surface and Bulk Electromagnetism via Their Dynamics in an Intrinsic Magnetic Topological Insulator**, ***Khanh Duy Nguyen,*** *W. Lee,* University of Chicago*; J. Dang, T. Woo,* University of Florida*; G. Berruto, C. Yan, C. Ip, H. Lin, Q. Gao,* University of Chicago*; S. Lee,* Penn State University*; B. Yan,* Weizmann Institute of Science, Israel*; C. Liu, Z. Mao,* Penn State University*; X. Zhang,* University of Florida*; S. Yang,* University of Chicago

Bringing magnetism to the itinerant electronic states on the surface of three-dimensional (3D) topological insulators (TIs) is foundational to a variety of low-dimensional topological orders [1, 2]. The magnetism in 3D TIs can be established via various mechanisms. However, the unconventional Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction on the material surface is required for the time-reversal (*T*) symmetry breaking on the topological surface states (TSSs) in magnetic TIs (MTIs)[3]. This mechanism has been predicted to enhance the surface magnetism of 3D MTIs, where the itinerant Dirac fermions with vanishing Fermi momenta strongly favor ferromagnetic coupling [4]. Thus, the 2D RKKY interaction fundamentally determines the size of the *T*-symmetry–broken energy gap, and, consequently, the operating temperatures of low-dimensional topological orders, such as the quantum anomalous Hall effect.

Here, we combine time- and angle-resolved photoemission spectroscopy (trARPES) and time-resolved magneto-optical Kerr effect (trMOKE) to reveal this distinct mechanism contributing to the surface magnetism in $MnBi_2Te_4$(MBT): A quasi-2D state mediates the surface 2D RKKY interaction via *p-d* coupling on the top MBT layer, Fig. 1(a). While trARPES resolves the dynamics of the exchange gap in the *q*-2DS with meV-scale precisions, Fig. 1(b), trMOKE observes the evolution of the magnetization. We construct a 2D RKKY model involving localized Mn 3*d* moments and itinerant *p* electrons, which accounts for the rapid dynamics of the magnetization and the exchange gap. Furthermore, it can reconcile several open problems in MBT. These include the vanishing gap at the Dirac point of the TSSs [5] and the nonzero residual magnetization in even-layer MBT flakes [6]. Our work highlights the special magnetic interactions on the surface of MBT and establishes the physics foundation for effective ultrafast manipulation of magnetism in tandem with topological orders.

[1] C.-Z. Chang et al., *Science* **340**, 167170 (2013)
[2] C. Liu et al., *Nat. Mater.* **19**, 522–527 (2020)
[3] Q. Liu et al., *Phys. Rev. Lett.* **102**, 156603 (2009)
[4] J. Wang, B. Lian, S.-C. Zhang, *Phys. Scr.* **T164**, 014003 (2015)
[5] C. Yan et al., *Phys. Rev. B* **104**, l041102 (2021)
[6] S. Yang et al., *Phys. Rev. X* **11**, 011003 (2021)
*Publication reference: Nguyen *et al*., Sci. Adv. **10**, eadn5696 (2024)

9:15am **PCSI-ThM1-10 Infrared Absorption of α-Sn**, ***Jaden R. Love,*** *C. Armenta, A. Moses, S. Zollner,* New Mexico State University*; A. Engel,* University of California Santa Barbara*; C. Palmstrom,* University of California at Santa Barbara

Alpha-tin (α-Sn) is a zero-bandgap semiconductor with an inverted s-antibonding electron band. We discuss the presence of a strong $E_0$ peak in the extinction coefficient appearing at 0.41 eV in infrared spectroscopic ellipsometry measurements. We also discuss the changes seen in the dielectric function at low temperatures. The $E_0$ peak is attributed to allowed interband transitions from the $\Gamma_7^-$ VB ("electron") to the $\Gamma_8^{+v}$ heavy hole VB or the $\Gamma_8^{+c}$ light "hole" CB [1].

Previous mid-IR ellipsometry measurements of α-Sn grown pseudomorphically by molecular beam epitaxy on InSb or CdTe have a room temperature dielectric function with an $E_0$ peak at 0.41 eV. The strength of the $E_0$ peak is affected by hole doping of the α-Sn layer. Unintentional doping with In from the substrate layers were influenced by variations in substrate surface preparation or by growing on a different substrate (CdTe). The effects are noticeable at low temperatures. The $E_0$ peak for α-Sn grown on InSb demonstrated temperature invariance for both the amplitude and energy while the $E_0$ peak amplitude forα-Sn grown on CdTe diminishes with decreasing temperature [1].

An MBE was used to grow new 30 nm α-Sn layers on InSb (001) substrate terminated with Sb [2]. By terminating the surface with Sb the amount of background In doping is reduced, therefore limiting the allowed transitions between bands. This limitation leads to a reduction in the peak amplitude at low temperatures. Temperature dependent ellipsometry spectra were taken from 5K – 295K and show that the $E_0$ peak is larger at high temperatures for α-Sn layers with reduced doping.

This work was supported in part by: AFOSR (FA9550-24-1-0061), ARO (W911NF-22-2-0130), NSF (DMR-2423992), and SCALE-RH (W52P1J-22-9-3009).

[1] R. A. Carrasco, Appl. Phys. Lett. 113, 232104 (2018).

[2] A. N. Engel, Phys. Rev. Materials 8, 044202 (2024).

9:20am **PCSI-ThM1-11 Coulomb Disorder in $Cd_3As_2$ Thin Films**, ***Ian Leahy,*** *A. Rice, J. Nelson,* National Renewable Energy Laboratory*; H. Ness,* King's College London, UK*; M. van Schilfgaarde, K. Alberi,* National Renewable Energy Laboratory

Efforts to move topological semimetals (TSMs) toward applications requires understanding of defects and disorder in thin film analogues. Coulomb disorder has important consequences for the properties of topological semimetals (TSMs) [1, 2]. In TSMs, Coulomb disorder is introduced through the presence of charged native defects which become screened contingent on the Fermi energy ($E_F$) or carrier density (n). The resulting disorder potential is characterized by an average magnitude $eV_0$ and correlation length ξ. In the limit of weak disorder, when $eV_0<E_F$, nonsaturating linear magnetoresistance can emerge in many TSMs – generated from scattering from the disorder potential. In $Cd_3As_2$ , we have demonstrated the link between this linear magnetoresistance and the disorder potential [3,4]. Here, we utilize a series of (001)-$Cd_3As_2$ bulk-like thin films (gapless bulk) to study the effects of Coulomb disorder on the electrical transport for a range of carrier densities. The ultralow carrier densities we obtain have two main effects on the Coulomb disorder: i) the magnitude of the disorder potential increases as screening is reduced and ii) the Fermi energy is reduced, becoming more comparable to $eV_0$. The combination of these effects serves to move $Cd_3As_2$ into a strong Coulomb disorder regime with decreasing carrier density ($E_F \sim eV_0$), as shown in Figure 1. The solid black line is calculated for $Cd_3As_2$ using Ref. 1 and circles are placed in line with sample carrier densities. As $eV_0/E_F$ increases, we find a striking crossover in the magnetic field dependence of the resistivity from linear to quadratic. We connect this change in magnetoresistance to strong Coulomb disorder scattering [5,6].

References:

[1] B. Skinner, Phys. Rev. B, 90, 060202(R) (2014).

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[3] I. Leahy, et. al., 1808747115 (2018).

[4] J. N. Nelson, et. al., Phys. Rev. B, 107, L220206 (2020).

[5] Y. I. Rodionov, et. al., Phys. Rev. B, 107, 155120 (2023).

[6] I. Leahy et. al., In Prep (2024).

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9:25am **PCSI-ThM1-12 Gate-Tunable Ferromagnetism in Epitaxially Grown Semimetal-Ferromagnetic Semiconductor Heterostructures**, ***Emma Steinebronn,*** *S. Islam,* Penn State University*; A. Grutter, C. Jensen, J. Borchers,* NIST*; W. Yanez-Parreno,* Penn State University*; S. Ghosh,* University of Minnesota*; J. Chamorro, T. McQueen,* Johns Hopkins University*; C. Liu,* Penn State University*; A. Mkhoyan,* University of Minnesota*; N. Samarth,* Penn State University

The coexistence of time-reversal and inversion symmetry in Dirac semimetals (DSMs) is responsible for topologically protected, spin-

degenerate bulk states with Dirac dispersion. Breaking either of these symmetries results in a Weyl semimetal with broken Kramers degeneracy [1]. We explore this concept by using molecular beam epitaxy to interface a canonical DSM, $Cd_3As_2$, with a ferromagnetic semiconductor, $In_{1-x}Mn_xAs$, with perpendicular magnetic anisotropy (Fig 1 (a), (b)) [2]. Measurements of the anomalous Hall effect (AHE) in top-gated $Cd_3As_2/In_{1-x}Mn_xAs$ devices show that the ferromagnetic Curie temperature is highly gate-tunable (Fig. 1 (c)-(f)). We map out the AHE in these heterostructures as a function of sample structure and chemical potential.To gain additional insights into the exchange interactions at the heterointerface, we carry out polarized neutron reflectometry (PNR) measurements down to cryogenic temperatures. Preliminary analysis of the PNR data indicates a complex magnetic profile, with potential for a net magnetization within the $Cd_3As_2$. Work supported by NSF-DMR-2407130 and No. DGE1255832.

[1] S. Baidya and D. Vanderbilt, Phys. Rev. B **102**, 165115 (2020)

[2] S. Islam, E. Steinebronn *et al., arXiv*: 2403.18485

9:30am **PCSI-ThM1-13 Growth of $Cd_3As_2$ on GaAs(110) Substrates**, ***Anthony Rice**, I. Leahy, A. Norman, K. Alberi,* National Renewable Energy Laboratory

$Cd_3As_2$, a prototypical Dirac Semi-metal, provides an excellent platform for studying physics of topological materials. With a single band crossing that is well isolated from trivial bands and is near the intrinsic Ferm level, straightforward methods such as electrical measurements are viable options for studying these states in this material. Additionally, thin film growth methods have been extremely successful, including growth on III-V and II-VI substrates in [112] and [001] orientations. No effort to date has been reported on attempts at [110] oriented films, which could place the c-axis in-plane, allowing for measurements along it via lateral electrical measurements, and also introduce a new orientation for measurements such as ARPES to probe.

Here, $Cd_3As_2$ films are grown with MBE on GaAs[110] substrates using similar II-VI buffer structures as other reports on [111] and [001] oriented GaAs substrates. A thin layer of $Zn_3As_2$ is inserted between III-V and II-VI layers to remove tilting of layers which was observed in X-ray diffraction. Unlike previous efforts [1], no substrate miscut or lattice-matched layers are required to obtain mobilities above 10,000 $cm^2/V\text{-}s$. While out of plane lattice constants are consistent with [110] oriented films, transmission electron microscopy reveal 2 domains of c-axis orientation, consistent with either a-axis orienting in-plane. Despite these domains, no difference is observed in electron mobility parallel or perpendicular to these domains, however a large difference in the fractional magnetoresistance is observed. This difference can be explained by differences in defect spacings along these directions and using the guiding center of diffusion model. Possible routes toward single domain films will also be discussed.

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