Magnetic Interfaces and Nanostructures
Room 121 - Session MI+2D+AC+TF-WeA

2D Magnetism and Magnetic Nanostructures

Moderators: Mikel Holcomb, West Virginia University, **Tiffany Kaspar**, Pacific Northwest National Laboratory

2:15pm **MI+2D+AC+TF-WeA-1 Interface Tunable Magnetism in Transition Metal Telluride Thin Films and Heterostructures***, **Hang Chi**,* University of Ottawa, Canada **INVITED**

Novel quasi-2D magnets are attracting much attention recently. In situ prepared sharp interfaces are desirable for strain engineering and/or hybridizing with other quantum systems, enabling fundamentally new phenomena and opportunities for spintronics [1]. Ferromagnetic Cr_2Te_3 ultrathin films, optimally grown on Al_2O_3(0001) and $SrTiO_3$(111) using molecular beam epitaxy, manifest an extraordinary sign reversal in the anomalous Hall conductivity as temperature and/or strain are modulated. The nontrivial Berry curvature in the electronic-structure momentum space is believed to be responsible for this behavior [2]. Furthermore, when proximitized with $(Bi,Sb)_2Te_3$-type topological insulator, via the Bloembergen-Rowland interaction, magnetic ordering in monolayer Cr_2Te_3 is favorably enhanced, displaying an increased Curie temperature [3]. Combining ab initio simulation, advanced scanning tunneling microscopy, magnetic force microscopy, transmission electron microscopy, magneto transport and particularly depth-sensitive polarized neutron reflectometry, Cr_2Te_3 has been established as a far-reaching platform for further investigating the marriage of magnetism and topology. These findings provide new perspectives to the magnetic topological materials in general, that are topical for the future development of topological spintronics.

References

[1] H. Chi and J. S. Moodera, "Progress and prospects in the quantum anomalous Hall effect", APL Mater. 10, 090903 (2022). https://doi.org/10.1063/5.0100989

[2] H. Chi, Y. Ou, T. B. Eldred, W. Gao, S. Kwon, J. Murray, M. Dreyer, R. E. Butera, . . . J. S. Moodera, "Strain-tunable Berry curvature in quasi-two-dimensional chromium telluride", Nat. Commun. 14, 3222 (2023). https://doi.org/10.1038/s41467-023-38995-4

[3] Y. Ou, M. Mirzhalilov, N. M. Nemes, J. L. Martinez, M. Rocci, A. Akey, W. Ge, D. Suri, . . . H. Chi, "Enhanced Ferromagnetism in Monolayer Cr_2Te_3 via Topological Insulator Coupling", arXiv:2312.15028 (2024). https://doi.org/10.48550/arXiv.2312.15028

Acknowledgment

We acknowledge the support of the Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant RGPIN-2024-06497.

2:45pm **MI+2D+AC+TF-WeA-3 AVS National Student Awardee Talk/Falicov Student Award Finalist Talk: Probing Intrinsic Magnetization Dynamics of the $Y_3Fe_5O_{12}/Bi_2Te_3$ Interface at Low Temperature***, A. Willcole,* Sandia National Laboratories, USA*; V. Lauter,* Oak Ridge National Laboratory, USA*; A. Grutter,* National Institute of Standards and Technology (NIST)*; C. Dubs,* INNOVENT e.V. Technologieentwicklung, Germany*; D. Lidsky,* Sandia National Laboratories, USA*; **Bin Luo**[12],* Northeastern University, US*; M. Lindner, T. Reimann,* INNOVENT e.V. Technologieentwicklung, Germany*; N. Bhattacharjee,* Northeastern University, US*; T. Lu, P. Sharma, N. Valdez, C. Pearce, T. Monson,* Sandia National Laboratories, USA*; M. Matzelle, A. Bansil, D. Heiman, N. Sun,* Northeastern University, US

Topological insulator-magnetic insulator (TI-MI) heterostructures are essential in spintronics, enabling magnetization control via topological surface state-induced spin orbit torque. However, many TI-MI interfaces often face issues like contamination in the magnetic insulator and a low-density transitional region in the topological insulator, which obscure the system's intrinsic properties. In this study, we addressed these challenges by depositing sputtered Bi_2Te_3(BT) on liquid phase epitaxy grown $Y_3Fe_5O_{12}$ (YIG)/$Gd_3Ga_5O_{12}$. The liquid phase epitaxy grown YIG exhibits exceptional interface quality, without an extended transient layer derived from interdiffusion processes of the substrate or impurity ions, thereby eliminating rare-earth impurity-related losses in the MI at low temperatures. At the TI-MI interface, high resolution depth-sensitive polarized neutron reflectometry confirmed the absence of a low-density transitional growth region of the TI. The demonstrated BT/YIG system is uniquely suited to elucidate the intrinsic TI-magnetic insulator magnetization dynamics due to the lack of an extended transient layer in the magnetic insulator at the magnetic insulator-substrate interface and lack of a low density, intergrowth region of the TI at the TI-magnetic insulator interface.

By overcoming these undesirable interfacial effects, we isolate and probe the intrinsic low-temperature magnetization dynamics and transport properties of the TI-MI interface. Using temperature dependent ferromagnetic resonance (FMR) we found a strong damping enhancement at low temperature due to the topologically protected Dirac surface states (TSS) in the Bi_2Te_3 film – a signature of significant spin pumping. Accompanying the damping enhancement, we also observed a large induced in-plane magnetic anisotropy for the BT/YIG heterostructure. We explain this by spin-pumping and spin-momentum locking, due to which the precessing spins of the YIG are forced to align with the spins pumped into the TSS and therefore remain locked in the plane of the BT/YIG interface. The temperature dependence of the magnetotransport which supports the suppression of bulk conduction, and the emergence of weak-antilocalization is consistent with the low temperature enhanced spin pumping in the BT/YIG that we observed, highlighting the interplay between the transport and spin pumping behavior in the TI-MI system. Further study of TI-magnetic insulator interfaces, specifically magnetic insulators with perpendicular magnetic anisotropy, are pertinent to potentially unlock high temperature quantum anomalous hall effect (QAHE) heterostructures, and the next generation of low power spintronics.

3:00pm **MI+2D+AC+TF-WeA-4 Falicov Student Award Finalist Talk: Surface Investigation of ε-phase Mn3Ga on GaN (0001) Substrate using Scanning Tunneling Microscopy***, **Ashok Shrestha**[3], A. Abbas, D. Ingram, A. Smith,* Ohio University

Antiferromagnetic materials have garnered significant attention due to their exotic properties and possible applications in next generation spintronic memory and computing devices [1]. In recent years, research on non-collinear antiferromagnetic materials such as Mn_3X (X: Ir, Ge, Sn, Ga) has heightened due to non-trivial, topological properties of these materials with unique spin textures [2]. Among these Mn-based antiferromagnets, Mn_3Ir has been commonly employed for applications [3]. As Ir is an expensive metal, efforts have been made to explore Ir-free antiferromagnets. Particularly, Mn_3Ga emerges as a promising candidate due to its versatile texture, magnetic ordering, and properties akin to Mn_3Ir [4]. Among the three distinct phases of Mn_3Ga, one of the most intriguing yet less explored is the ε-phase ($D0_{19}$-Mn_3Ga), which exhibits anomalous Hall effect and topological Hall effect in distinct temperature ranges [3]. In this presentation, we will delve into the growth and surface studies of a thin film of $D0_{19}$-Mn_3Ga on a Ga polar- GaN (0001) substrate.

We have successfully grown an epitaxial ε-phase Mn_3Ga layer using molecular beam epitaxy. The sample quality, lattice constants and crystal structure of the grown film were determined by *in-situ* reflection high energy electron diffraction and *ex-situ* X-ray diffraction. Upon examination with scanning tunneling microscopy, the surface revealed multiple terraces and row-like structures. Notably, the edges of the terraces form 120° angles with each other, consistent with the hexagonal crystal structure of the ε-phase Mn_3Ga. Additionally, we observed several stackings of just a monolayer, with their heights matching the c/2 value of Mn_3Ga. These measurements are further confirmed by X-ray diffraction. At atomic resolution, hexagonally arranged atoms with a 1 × 1 crystal structure were observed. The measured average *in-plane* atomic spacing was 5.37 ± 0.05 Å, deviating only -0.56% from theoretical predictions (5.40 Å). However, atomic spacing exhibited local variations. Other interesting structures were also observed in the scanning tunneling microscopy images, which will be discussed in the presentation. Chemical analysis via Rutherford backscattering confirmed the sample's Mn:Ga ratio as 3.2:1.0, which depends on the growth temperature. Further research will involve exploring non-collinear antiferromagnetism using spin-polarized scanning tunneling microscopy, with results to be presented at the conference.

References:

Chen et al., APL Mater.**11**, 111026 (2023).

Qin et al., Nature **613**(7944), 48 (2023).

Hernandez et al., Surf. and Interface **41**, 103167 (2023).

1. Liu et al., Sci. Rep. **7**(1), 515 (2017).

[1] **AVS National Student Awardee**

[2] **Falicov Student Award Finalist**

[3] **Falicov Student Award Finalist**

3:15pm **MI+2D+AC+TF-WeA-5 Thermally Generated Spin Transport Across Magnetic Interfaces***, **Hari Srikanth,*** USF Tampa **INVITED**

Spin-heat coupling and thermo-spin transport are topical areas of interest for the spintronics community. The origin of longitudinal Spin Seebeck effect (LSSE) and its relationship with magnetic anisotropy as well as magnon propagation across magnetic insulator/heavy metal interfaces have remained challenging issues. LSSE induces incoherent magnon excitations with the application of a temperature gradient across the thickness of a magnetic material. Although the ferrimagnetic insulator $Y_3Fe_5O_{12}$ (YIG) is known as the benchmark system for LSSE, other members of the insulating rare earth iron garnet family, *e.g*. the compensated ferrimagnet Gd_3Fe5O_{12} (GdIG), ferrimagnet insulator $Tm_3Fe_5O_{12}$ (TmIG) etc., are of interest and have received less attention from the point of view of spin-caloritronics. We have pioneered the technique of RF transverse susceptibility to probe the effective magnetic anisotropy in magnetic materials and heterostructures. Combining the RF transverse susceptibility with LSSE measurements, we have shown correlation between bulk and surface anisotropy with the field and temperature dependence of LSSE in YIG/Pt heterostructures and other compensated ferrimagnets like GdIG. Our recent work on TmIG/Pt heterostructures with varying film thickness reveals the clear role of anisotropy and Gilbert damping on the LSSE. From RF susceptibility, LSSE and broadband FMR experiments, quantitative analysis of the magnon propagation length and its correlation with magnetic anisotropy and Gilbert damping has been done. Overall, this talk would present new results in the thermal spin transport of garnet heterostructures which are of fundamental importance in spin transport across magnetic interfaces.

4:15pm **MI+2D+AC+TF-WeA-9 Spin Switchable 2D-Superlattice Metal-Halide Perovskite Film via Multiferroic Interface Coupling***, **Bogdan Dryzhakov,*** Oak Ridge National Laboratory*; B. Hu,* University of Tennessee Knoxville*; V. Lauter,* Oak Ridge Natinal Laboratory

Solution-processible 2D-phase metal-halide perovskites have emerged as a remarkable class of semiconducting, exhibiting a wide-range of optoelectronic properties and multi-functionalities. In this work, interfacing ferromagnetic spins with this semiconductor's Rashba band yields magnetic field control over the excited state spin degrees of freedom, as demonstrated through optical analogues that resolve the spin polarization in steady-state and dynamics, and in-situ neutron scattering methods, where a photo-ferromagnetic profile is depth-resolved. The 2D-superlattice perovskite films are prepared using an optimized, low-cost spin-cast method, resulting in highly crystalline and smooth thin films with a well-defined alternating layered structure of self-assembled organic cations and lead-iodide octahedra. Within the anisotropic 2D-planes of MHPs, fluorinated A-site ligands distort the lattice, yielding robust ferroelectricity and Rashba bands arising from broken inversion symmetry and strong spin-orbit coupling. Spin-switchable circularly polarized photoluminescence (CPL) between σ+ and σ- polarizations is achieved at the multiferroic perovskite/Co interface by manipulating the ferromagnetic spins on the Co surface between positive and negative magnetic field directions. This switching behavior arises from selective interactions between the ferromagnetic spins on the Co surface and the circularly polarized σ+ and σ- orbitals within the perovskite's Rashba band structures. Polarized neutron reflectometry measurements reveal long-range interactions of the Co magnetism to the perovskite's spin-polarized excitons, with chemical (NSLD) and magnetization (MSLD) depth profiles indicating optically induced magnetization through the perovskite's thickness. This work presents a fundamental platform for exploring spin selectivity effects within Rashba band structures using CPL studies in multiferroic perovskite/ferromagnetic interfaces.

4:30pm **MI+2D+AC+TF-WeA-10 Engineering the Hybrid Nanocolumnar Metamaterial Platforms for Advanced Optical and Magnetic Applications***, **Ufuk Kilic**, C. Briley,* University of Nebraska-Lincoln*; R. Feder,* Fraunhofer Institute for Microstructure of Materials and Systems, Germany*; D. Sekora,* University of Nebraska-Lincoln*; A. Ullah,* University of Nebraska - Lincoln*; A. Mock,* Weber State University*; C. Binek,* University of Nebraska - Lincoln*; H. Schmidt,* Friedrich Schiller University, Germany*; C. Argyropoulos,* The Pennsylvania State University*; E. Schubert, M. Schubert,* University of Nebraska - Lincoln

The hybrid metamaterial platforms have garnered remarkable attention in various subdiciplines of physics, chemisty, and biology due to their wide range of advanced functionalities including strong tunable optical and magnetic anisotropies, the ability to confine, modulate, and control of light, to engineer new permanent nanomagnets, for example. In this study, we employed a custom-built ultra-high vacuum electron-beam glancing angle deposition technique [1] to fabricate spatially-coherent, super lattice type nanocolumnar heterostructure metamaterial platforms from both hard (cobalt) and soft (permalloy) magnetic materials. Furthermore, by using atomic layer deposition technique, we incorporate ultrathin interface layer (~1.4 nm) of Al_2O_3 between the magnetic nano-columnar subsegments. This interface engineering at nanoscale provides another angle of freedom to tune both the magnetic and optical properties of hybrid nanocolumnar metamaterial platforms.

By taking the advantage of the generalized spectroscopic ellipsometry technique, we reached out the complex anisotropic dielectric properties of the fabricated structures. Our analysis involves widely used anisotropic Bruggeman effective medium model approach which provides to extract optical and structural properties, accordingly [2]. Moreover, to perform magnetic characterization of our fabricated metamaterial design, we employed both generalized vector magneto-optic ellipsometry and vibrating sample magnetometer measurements [3]. In order to delve into the fundamental driving mechanisms behind the anisotropic tunable magneto-optic responses from the proposed metamaterial platforms, we conducted a series of systematic micromagnetic and finite element modeling simulations, as well. We believe that these new structural metamaterial designs can result in the development of next-generation sensing devices, permenant nanomagnets, magnetic recording technologies, on-chip nanophotonic and opto-magnetic device applications.

References:

[1] Kilic, U., et al. Sci Rep 9, 71 (2019).

[2] Schmidt, D., and Schubert, M., J. Appl. Phys. 114.8 (2013).

[3] Briley, Chad, et al. Appl. Phys. Lett. 106.13 (2015).

4:45pm **MI+2D+AC+TF-WeA-11 Magnetic Field Affects Oxygen Evolution Reaction Only in Metal Oxy-Hydroxides***, **Filippo Longo,*** Chemical Energy Carriers and Vehicle Systems Laboratory, Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland*; R. Peremadathil Pradeep, E. Darwin, H. Hug,* Magnetic and Functional Thin Films Laboratory, Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland*; A. Borgschulte,* Chemical Energy Carriers and Vehicle Systems Laboratory, Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland

Ni-based electrodes have been largely employed in alkaline electrolyzers for the production of H_2 and O_2 [1]. Due to the sluggish kinetics of the oxygen evolution reaction (OER), many experimental approaches have been employed to boost the catalytic performance of such electrodes [2]. The application of an external magnetic field during OER has shown outstanding catalytic improvement [3]. Despite considerable research effort, the understanding of its origin is still object of debate [4,5]. In this work we show how the Ni-based electrodes improve their catalytic activity towards OER during the application of an external magnetic field. We investigate in detail the catalytically active surface, the microscopic, electronic, and magnetic structures by soft- and hard X-ray photoelectron spectroscopy combined with impedance spectroscopy and magneto-optical measurements. It is relevant in this context that the oxy-hydroxide formed during OER is the catalytically active compound, and is thus likely also the origin of the magnetic effect. To underline the importance of the oxy-hydroxide formation, we employ a multilayered system made of Co-Pt-Ru multi-lattices, exhibiting much more favorable magnetic properties (such as strong perpendicular magnetic anisotropy) than nickel. Interestingly, hardly any improvement of OER is found. The various findings corroborate the picture of spin-exchange interaction of metal-oxide bonds as the underlying mechanism of the magneto-chemical effect.

[1] S. W. Sharshir et al., International Journal of Hydrogen Energy (2023).[2] J. S. Kim et al., Adv. Energy Mater. (2018), 8, 1702774.[3] F.A. Garcés-Pineda et al., Nat Energy 4, 519–525 (2019).[4] T. Wu et al., Nat Commun 12, 3634 (2021).[5] X. Ren et al., Nat Commun 14, 2482 (2023).

Author Index

Bold page numbers indicate presenter