PCSI

Room Ballroom South - Session PCSI-TuM1

Magnetic Materials (2D, Monolayers, & Heterostructures)

Moderator: Xiao-Xiao Zhang, University of Florida

8:30am **PCSI-TuM1-1 Efficient Control of 2D Magnets**, ***Cheng Gong,*** University of Maryland, College Park **INVITED**

The emergent two-dimensional (2D) layered magnets provide ideal platforms to enable the atomically thin magneto-optical and magnetoelectric devices. Though many have envisioned that 2D magnets should allow efficient control of magnetism by a variety of external stimuli, true breakthroughs are still lacking, with limited proof-of-concept demonstrations reported thus far. There appear to be fundamental obstacles for efficient control, e.g., through electrical and optical means. In this talk I will analyze the challenges and present our theoretical and experimental progress on efficient electrical and optical control of 2D magnets. Specifically, the results show that the voltage of a few volts can effectively change the magnetic anisotropy of 2D magnets and the laser shinning of tens of uW/um^2 can effectively affect the domain behaviors of 2D magnets. These efficient controls of 2D magnets potentially open up new avenues towards low-power spintronics and photonics.

9:10am **PCSI-TuM1-9 Surface-Bulk Difference in van der Waals Magnets**, ***Liuyan Zhao,*** University of Michigan, Ann Arbor **INVITED**

The successful isolation of monolayer to few-layer magnetic atomic crystals from van der Waals (vdW) magnets have opened a new pathway of researching two-dimensional (2D) magnetism [1,2,3]. Over the past half a decade, the vdW and 2D magnet library has been greatly expanded, and new magnetic phenomena have been discovered in the 2D limit. Yet, one key question has been brought up: what is the distinction amongst bulk, surface and 2D magnetism for a vdW magnet? This question is well motivated by the observations of 2D behaviors in 3D vdW magnets, as well as the contrasts between 2D layers and 3D bulk, for systems such as CrI_3, CrSBr, $NiPS_3$, etc.

In this talk, we will show the surface-bulk difference in two archetype vdW magnets, CrI_3 [4] and CrSBr [5]. In CrI_3, it has been thought that the 3D bulk hosts the ferromagnetic (FM) state below T_c = 61K whereas the 2D films realizes the layered antiferromagnetic (AFM) order below T_N = 45K. We will show from our optical magneto-Raman spectroscopy measurements that even in a 3D bulk CrI_3, we capture clear signatures of layered AFM, in addition to the known bulk FM. We attribute the layered AFM signature here to the surface magnetism, which is the same as that of the 2D layers but distinct from that deep in the 3D bulk (Figure 1a). In CrSBr, it has the same layered AFM order in both 3D bulk and 2D layers, but surprisingly with a higher critical temperature in the 2D case. We will show with our nonlinear optical measurements that multiple characteristic temperature scales appear in the 3D bulk CrSBr, including a surface ($T_{surface}$) and a bulk (T_{bulk}) onset temperature between which the surface one is unexpectedly higher than the bulk one (Figure 1b). Our results on these two systems demonstrate that the surface of vdW magnets can well be distinct from their bulk.

[1] Cheng *et al* Nature 546, 265 (2017)

[2] Huang *et al* Nature 546, 270 (2017)

[3] Wang *et al* ACS Nano, 16, 6960 (2022)

[4] Li *et al* Phys. Rev. X, 10, 011075 (2020)

[5] Guo *et al* arXiv 2309.01047 (2023)

9:50am **PCSI-TuM1-17 Surface Investigation of Hexagonal Non-Collinear $D0_{19}$-Mn_3Ga Thin Film on Gan(0001) Substrate**, ***Ashok Shrestha,*** *A. Abbas, D. Ingram, A. Smith,* Ohio University

In recent years, Mn_3Ga has garnered significant attention due to its exotic physical properties and potential applications in spintronic devices [1,2]. One of the most intriguing, yet less explored, phases is the hexagonal antiferromagnetic phase of Mn_3Ga ($D0_{19}$), which exhibits anomalous Hall effect and topological Hall effect in distinct temperature ranges [2]. 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.

The experiments are carried out in an ultra-high vacuum chamber equipped with a molecular beam epitaxy system and a room-temperature scanning tunneling microscope. Initially, the GaN epilayer is deposited on a GaN (0001) substrate at 700 ^oC under gallium-rich conditions, followed by the growth of $D0_{19}$-Mn_3Ga at 250 ^oC under manganese-rich conditions. Reflection high-energy electron diffraction is used during growth to monitor the sample, and the *in-plane* lattice constant is evaluated. Various *in-situ* techniques confirm that the grown sample exhibits epitaxial growth. Furthermore, scanning tunneling microscopy image shows the hexagonal atomic arrangements with an average *in-plane* atomic spacing of 5.37 ± 0.05 Å. However, the atomic spacing varies in the local region. The 1 x 1 surface structure of hexagonal $D0_{19}$-Mn_3Ga (a = 5.40 Å [2]) is shown in Fig. 1. Moreover, multiple flat terraces and steps with height of 2.20 Å are observed. The measured step height corresponds to the c/2 value of $D0_{19}$-Mn_3Ga (c = 4.39 Å [2]). The *ex-situ*- X-ray diffraction clearly shows the Mn_3Ga 0002 peak, and the calculated *d*-spacing matched well with the step heights measured by scanning tunneling microscope. These measurements are consistent with the theoretically reported *c*-value of $D0_{19}$-Mn_3Ga. The concentration of manganese and gallium in the sample is confirmed to be 3.2:1.0 by Rutherford backscattering. Various *in-situ* and *ex-situ* measurements confirm the $D0_{19}$-Mn_3Ga growth. Further work is planned to investigate the non-collinear antiferromagnetism using spin polarized scanning tunneling microscope.

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[1] L. Song, B. Ding, Appl. Phys. Lett. **119**, 152405 (2021).

[2] Z. H. Liu, Scientific Reports **7**, 515 (2017).

9:55am **PCSI-TuM1-18 Enhancement of Microwave to Optical Spin-Based Quantum Transduction via a Magnon Mode**, ***Tharnier O. Puel,*** Department of Physics and Astronomy, University of Iowa*; A. T. Turflinger, S. P. Horvath, J. D. Thompson,* Department of Electrical Engineering, Princeton University*; M. E. Flatté,* Department of Physics and Astronomy, University of Iowa, Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands

The highly localized 4f electrons of rare-earth-doped materials provide a simple atom-like level structure with a spin-photon interface, telecom-wavelength optical transitions, potential for long spin and optical coherence times, and the ability to realize high-density doping. Proposals for microwave to optical quantum transduction using rare-earth ions[PRL113,203601(2014)] rely on spin-flip transitions from microwaves that couple to optical inter-4f transitions. An example is the Er^{3+} ion's transition |J=15/2> to |J=13/2> at telecom wavelength. The oscillator strengths (g_b) of the microwave excitations of the Er^{3+} are particularly weak leading to poor transduction efficiencies. We describe an approach to dramatically enhance the microwave coupling without diminishing the optical oscillator strength (g_a) for Er^{3+} ions. The microwave excitation is coupled to a magnon (g_m) of a magnetic material, e.g., yttrium iron garnet (YIG). The Er^{3+} ions are embedded in an insulator and live close to the interface with the magnet. The iron lattice of the YIG will strongly couple to the Er^{3+}. We predict that the microwave-magnon coupling allows higher transduction rates that dramatically exceeds the previous set up.

10:00am **PCSI-TuM1-19 Magnetic Modulation and Large Magnetoresistance in Cr_5Te_8**, *M. Vaninger, S. Kelley,* University of Missouri*; F. Ye,* Oak Ridge Natinal Laboratory*; X. Zhang,* Nanjing University, China*; T. Heitmann,* University of Missouri*; A. Mazza,* Los Alamos National Laboratory*; Y. Hor, A. Sarikhani,* Missouri S&T*; G. Bian,* ***Paul Miceli,*** University of Missouri

Because of the ability to manipulate their structure and properties, metallic 2D van der Waals materials that exhibit ferromagnetism (FM) are of considerable potential interest for spintronics applications. Cr_5Te_8 is such a system whose structure consists of layers of $CrTe_2$ having additional Cr intercalated between the layers.$CrTe_2$ itself is known to be a strong ferromagnet up to room temperature [1].Cr_5Te_8 is FM below T_{c1}=155K with perpendicular magnetic anisotropy and it exhibits a large (10%) negative magneto-resistance effect above T_{c1} over a narrow temperature range [2].

We have performed neutron diffraction measurements to explore the magnetic behavior in a temperature range above T_{c1} and as a function of applied magnetic field.A modulated antiferromagnetic phase is observed, which has a wavevector perpendicular to the van der Waals layers and a period that is triple the unit cell length.The modulated spin structure is canted with a significant component in the van der Waals layers.The modulation is robust with field applied in-plane but it is quickly destroyed with a field applied perpendicular to the layers.Our magnetic phase diagram shows that the transition from FM to the modulated phase at T_{c1} is strongly first-order with a true FM transition occurring at a higher temperature, T_c=180K.We show that the large magnetoresistance observed in transport arises from the in-plane components of the magnetic moments.Since the spin modulation is controlled at relatively low magnetic

field and the intercalated Cr can be tuned, 2D systems such as these have potential for spintronic applications.

Support: NSF-DMR; the University of Missouri Research Reactor.Spallation Neutron Source at Oak Ridge National Lab is supported by the US Department of Energy.

[1] Room-temperature intrinsic ferromagnetism in epitaxial CrTe2 ultrathin films X. Zhang *et al.*, *Nature Communications***12**:2492 (2021) [https://www.nature.com/articles/s41467-021-22777-x]

[2] Self-Intercalation Tunable Interlayer Exchange Coupling in a Synthetic Van der Waals Antiferromagnet X. Zhang *et al.*, *Advanced Functional Materials* 2202977 (2022) [https://onlinelibrary.wiley.com/doi/abs/10.1002/adfm.202202977]

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