## PCSI
## Room Keahou I - Session PCSI-WeA3
## Spin Transport and Spintronics
**Moderator: Michael Flatté**, University of Iowa

4:00pm **PCSI-WeA3-31 Quantum Sensing of Moiré Magnetism**, ***Chunhui (Rita) Du***, Georgia Institute of Technology, USA **INVITED**

Moiré magnetism featured by stacking engineered atomic registry and lattice interactions has recently emerged as an appealing quantum state of matter at the forefront of condensed matter physics research [1]. Nanoscale imaging of moiré magnets is highly desirable and serves as a prerequisite to investigate a broad range of intriguing physics underlying the interplay between topology, electronic correlations, and unconventional magnetism. In this talk, I will present our recent work on using nitrogen-vacancy (NV) centers to perform nanoscale quantum sensing and imaging of magnetic domains and spin fluctuations in twisted double trilayer (tDT) chromium triiodide $CrI_3$. We show that intrinsic moiré domains of opposite magnetizations appear over arrays of moiré supercells in low-twist-angle tDT $CrI_3$ [2]. In addition, spin fluctuations measured in tDT $CrI_3$ reveal two distinct magnetic phase transitions with separate critical temperatures within a moiré supercell [3]. Our results enrich the current understanding of exotic magnetic phases sustained by moiré magnetism and highlight the opportunities provided by quantum spin sensors in probing microscopic spin related phenomena on two-dimensional flatland.

[1]T. Song et al., Science **374**, 1140 (2021).

[2] M. Huang et al., Nat. Commun. **14**, 5259 (2023).

[3] S. Li et al.,Nat. Commun. **15**, 5712 (2024).

4:40pm **PCSI-WeA3-39 Strong on-Chip Microwave Photon-Magnon Coupling Using Ultralow-Damping Epitaxial $Y_3Fe_5O_{12}$ Films**, *S. Guo, D. Russell, J. Lanier, H. Da, C. Hammel,* ***Fengyuan Yang***, The Ohio State University

Yttrium iron garnet ($Y_3Fe_5O_{12}$, YIG) is one of the best magnetic materials for magnon-based quantum information science (QIS) because of its extremely low damping loss.For scalable on-chip QIS devices, ultralow-damping YIG films at mK temperatures are desired.However, almost all epitaxial YIG films are grown on rare-earth-containing garnet substrates which cause very large damping at low temperatures, hindering the use of YIG films for QIS studies.We report ultralow damping at 2 K in epitaxial $Y_3Fe_5O_{12}$ thin films grown on a diamagnetic $Y_3Sc_2Ga_3O_{12}$ (YSGG) substrate that contains no rare-earth elements (Figs. 1a-1b).The extremely low damping of the YIG epitaxial films on diamagnetic YSGG substrates at very low temperatures is highly promising for QIS studies.As an initial step in this regard, we integrate the YIG/YSGG films with superconducting resonators for the study of coupling between magnons in a YIG film and microwave photons emitted by a superconducting coplanar waveguide resonator (Fig. 1c).We observe strong coupling between magnons in patterned YIG thin films and microwave photons in a superconducting Nb resonator at 2 K (Fig. 1d). This is the first demonstration that ultralow-damping YIG epitaxial films on YSGG can be integrated with superconductor resonators to achieve strong microwave photon-magnon coupling at few Kelvin temperatures. Such ultralow-damping YIG films offer advantages over metallic ferromagnets for on-chip hybrid quantum systems that incorporate magnonic conduits, microwave superconductor resonators, and superconductor qubits for QIS applications that operate in the mK regime.

[1] S. D. Guo, D. Russell, J. Lanier, H. T. Da, P. C. Hammel, and F. Y. Yang, Nano Lett. **23**, 5055 (2023).

4:45pm **PCSI-WeA3-40 Device Architectures for Characterizing Spin Transport Through Chiral Defects in Semiconductors**, ***Jordan Neely***, *F. Haines, E. Renteria, R. Chowdhury, D. Prakash, D. Shima, F. Cavallo,* University of New Mexico

Recent theoretical studies have shown that screw dislocations (SDs) support the interplay of Rashba and Dresselhaus spin-orbit coupling (SOC). Such a phenomenon makes these line defects suitable hosts of coherent spin transport. Specifically, spin polarization arising from SD-induced coupling lies in a much narrower range of angles (0 to 90°) than that resulting from the Rashba or Dresselhaus effects. Furthermore, this spin polarization is protected from changes in electron momentum caused by scattering, potentially leading to a relatively long coherence time. In this work, we demonstrate the fabrication of device architectures for characterizing spin transport due to the unique interplay of Rashba and Dresselhaus SOC in SDs.We fabricated a vertical spin valve (VSV) based on single-crystalline semiconductor nano-membranes (NMs) engineered with 2D arrays of screw dislocations (SDs) throughout their thickness. The device includes a bottom soft ferromagnetic contact (e.g., NiFe), the NMs, and a top hard ferromagnetic contact (e.g., Co). The constitutive material of the NM may be Si, Ge, III-V compounds, or SiC. The first step in the fabrication of the VSV is patterning the NM into a 2D array of pixels with lateral sizes of a few hundred micrometers. At this stage of the process, the NM is bonded to a sacrificial-layer-coated substrate. The pixels are released in place by selective etching of the sacrificial layer. An adhesive stamp removes the pixels from the original substrate and transfers them onto a second array of patterned pixels at a controlled twist angle. Pixelation of NMs reduces the release time and increases the yield of the transfer process. The twisted NM pairs or twisted bicrystals (TBiCs) are then annealed at high temperature in an inert atmosphere to foster the propagation of the SDs. Annealed TBiCs are transferred to a bulk substrate coated with a soft ferromagnet. A dielectric barrier and a hard ferromagnet contact are fabricated using conventional top-down processes. The TBiCs top and bottom surfaces are left to oxidize in air at or above room temperature before the ferromagnets-NMs contacts are fabricated. We anticipate the interfacial oxides will facilitate spin injection from the ferromagnetic layers into SDs by direct tunneling. Structural characterization of the fabricated devices includes cross-sectional and plan-view transmission electron microscopy (TEM) to analyze the chemical and physical structure of the inter-faces and verify the occurrence of the SDs, respectively.

4:50pm **PCSI-WeA3-41 Orbital Hall Effect and Orbitronics in Magnetic Multilayers**, *I. Lyalin, Y. Zhu,* ***Roland Kawakami***, The Ohio State University

Orbitronics is an emerging field based on orbital currents, or the flow of orbital angular momentum, just as spintronics is based on spin currents. Analogous to the spin Hall effect (SHE) where a charge current produces a transverse spin current, an orbital Hall effect (OHE) can generate a transverse orbital current. Recently, magneto-optical measurements detected orbital accumulation at the surfaces of Ti [1] and Cr [2], providing the most direct evidence for the OHE. Currently, many of the basic properties of orbital currents are being established. Here, we report results on (1) the generation of torques on a magnetic layer from orbital currents and (2) the transparency of interfaces to orbital currents.

In the first study, we utilize magneto-optic Kerr effect (MOKE) to measure the orbital torque generated by an in-plane charge current in Cr/Fe bilayers. In the Cr layer, the charge current is converted to a transverse orbital current via OHE. After the orbital current enters the Fe layer, it is converted to a spin current by spin-orbit coupling, which in turn imparts a torque on the Fe magnetization through the exchange interaction. We call this the “orbital torque.” Interestingly, the orbital torque increases with the Fe thickness, which suggests that the orbital current is able to penetrate deeply into the Fe layer. Repeating the study on Pt/Fe bilayers where both spin currents and orbital currents are present, the Fe thickness dependence suggests that the torque from spin current is more interfacial in nature while the orbital torque is more bulk-like within the Fe layer.

In the second study [3], we utilize MOKE to investigate the transparency of orbital currents across interfaces. In Cr/X/Ni trilayers, where layer X is varied across the periodic table, we quantify the effect that the X layer has on the orbital torque on the Ni layer. Figure 1 shows the orbital torque efficiency in Cr/X/Ni. Comparing to the value without the X layer gives the transmission of orbital current across the X layer. Similar experiments on Pt/X/Ni investigate the transmission of spin current across the X layer. Comparing the results for Cr/X/Ni and Pt/X/Ni indicates that the transparency of orbital currents is similar to or greater than the transparency of spin currents for several X layers.

[1] Y. -G. Choi et al., Nature 619, 52 (2023).

[2] I. Lyalin et al., Phys. Rev. Lett. 131, 156702 (2023).

[3] I. Lyalin and R. K. Kawakami, Phys. Rev. B 110, 104418 (2024).

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