2DCC MIP at Penn State, DMR-2039351

External User Project - 2022

Understanding signatures of emergent magnetism in topological insulator/ferrite bilayers

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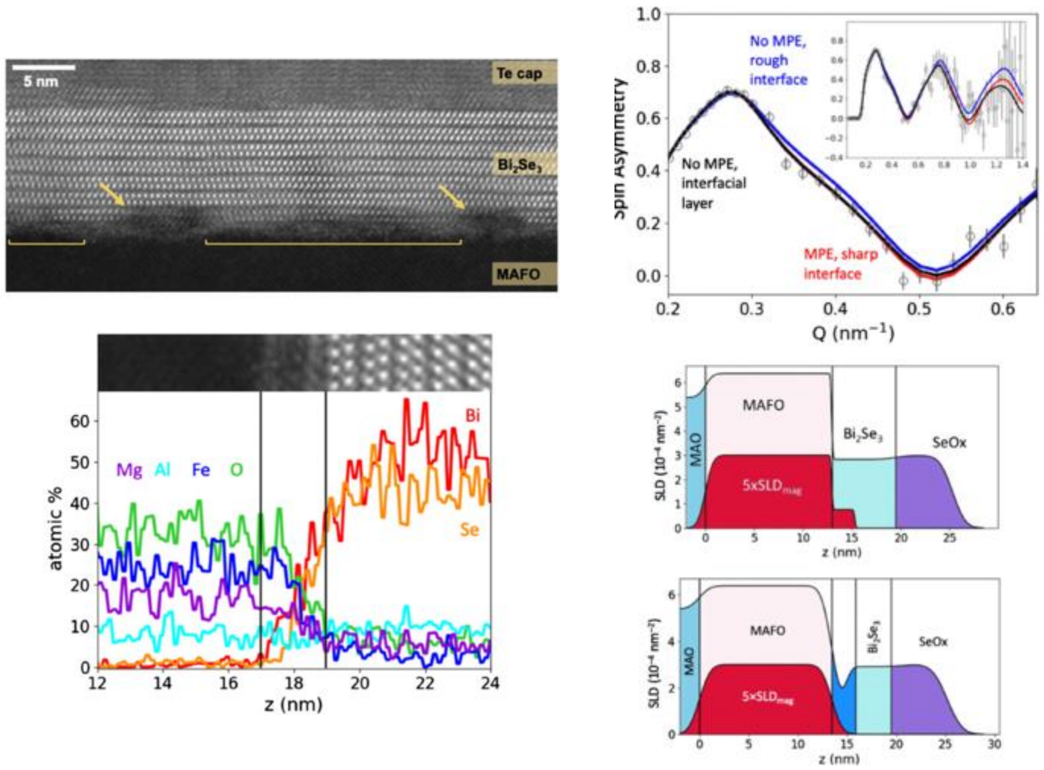
Project Summary: The emergence of magnetism via a proximity effect has been exploited in many low-dimensional materials, including ultrathin film and 2D materials. By doing so, one can realize magnetic properties in these materials not observed in the bulk nor achievable via doping or functionalization. Magnetic proximity effects (MPEs) have been studied in a variety of magnetic heterostructures for many applications including spintronics, valleytronics, and topological phenomena. Crucial to the observation of a theoretically predicted MPE is an abrupt interface with little to no interdiffusion or interface roughness. Nonidealities at the interface can give rise to behaviors that appear to be a MPE. This study addressed the constraints on interpreting evidence for MPE in thin film bilayers that interface a ferromagnetic insulator (FI), $MgAl_{0.5}Fe_{1.5}O_4$, with the canonical topological insulator (TI), Bi_2Se_3. Although measurements of electrical transport (Hall effect) and polarized neutron reflectometry (PNR) provided the necessary indications of PME, we found that these were not sufficient. Nonlinear Hall effect data can be interpreted as signatures of an anomalous Hall effect or conduction of multiple carrier types due to interfacial charge transfer, while magnetic profiles deduced from PNR data can be modeled with either a MPE induced in Bi_2Se_3 or a disordered layer at the interface. We used X-ray reflectivity and high resolution transmission electron microscopy (HRTEM) to show the presence of an interfacial layer between the FI and TI, consistent with interdiffusion at the interface rather than a MPE in the Bi_2Se_3. Together, our results indicate that careful characterization of interfacial microstructure is essential in identifying a magnetic proximity effect in a topological insulator.

The detailed findings are published in *Physical Review Letters* **128**, 126802 (2022); DOI: 10.1103/PhysRevLett.128.126802

2DCC Role: This user project exploited the 2DCC MBE facility for epitaxial growth of the Bi_2Se_3 thin films on user-supplied substrates of $MgAl_{0.5}Fe_{1.5}O_4/MgAl_2O_4$. HRTEM studies of these bilayers were also carried out by 2DCC personnel.



Structural characterization using HRTEM (left panels) and magnetic profilometry using PNR of a $MgAl_{0.5}Fe_{1.5}O_4/Bi_2Se_3$ bilayer (right panels). PNR alone cannot definitively identify MPE near the interface and may also be consistent with a magnetic signal due to interdiffusion. HRTEM analysis (accompanied by x-ray reflectometry, not shown) is essential for correctly interpreting PNR data.