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Novel Phase Formation and Magnetism at the Sb₂Te₃/Ni₈₀Fe₂₀ Interface

A. Will-Cole¹, James Hart², Adrian Podpirka³, Matthew Matzelle⁴, Nirjhar Bhattacharjee¹, Shreya Patel⁵, Isabel Martos-Repath¹, Bin Lou¹, Sarah Tolbert⁵, Arun Bansil⁴, Judy J. Cha², Don Heiman^{4,6}, and Nian X. Sun^{1*}

¹Department of Electrical Engineering, Northeastern University, Boston, MA 02115, USA

²Department of Materials Science, Cornell University, Ithaca, NY, USA

³Johns Hopkins Applied Physics Laboratory, Laurel, MD, USA

⁴Physics Department, Northeastern University, Boston, MA 02115, USA

⁵Chemistry Department, University of California Los Angeles, Los Angeles, CA, USA

⁶Plasma Science and Fusion Center, MIT, Cambridge, MA 02139 USA

*Corresponding author: n.sun@northeastern.edu

Abstract: Investigation into the interface formed between Sb₂Te₃/Ni₈₀Fe₂₀ heterostructures – this is studied using temperature dependent magnetometry, scanning transmission electron microscopy, ferromagnetic resonance, and theoretical support.

Keywords: topological insulators, antiferromagnetic phase, spintronic heterostructures

Over the past several decades, 3D imaging of reflective objects have matured and been commercialized. Topological insulators have insulating bulk state and two-dimensional metallic surfaces enabled by topologically protected Dirac surface states [1]. Topological insulators, specifically Bi_{1-x}Sb_x alloys and van der Waals chalcogenides X₂Q₃ (X = Bi, Sb, Bi_{1-x}Sb_x; Q = Se, Te) with tetradymite structure, exhibit large charge-to-spin conversion efficiencies, strong spin-momentum locking, and conductive surface states which make them ideal for applications in spin-orbit-torque magnetic memories [2]-[7]. For spin-orbit-torque devices based on topological insulators and ferromagnets, there remains integration feasibility considerations such as interfacial orbital hybridization, novel interfacial chemical phases, etc. However, this is often overlooked or not mentioned in literature on spin-pumping in these topological insulator/metallic ferromagnet heterostructures [8]-[10]. More recently, there have been theoretical studies on the interface between topological insulators and metal contacts, namely Au/Bi₂Se₃ and graphene/Bi₂Se₃ do not inhibit spin-momentum locking of the surface states, while Pd and Pt strongly couple to Bi₂Se₃ and cause delocalization of the surface states and less efficient spin-momentum locking [11]. Additionally, confirmed through experiment, band bending occurs at the Bi₂Se₃/metallic interface due to variation in electron affinity of Bi₂Se₃ (4.45 eV) and work functions of transition metal contacts (~5 eV) [12]. Interfacial layer formation between Bi₂Se₃/metal contacts and Bi₂Se₃/magnetic materials has been confirmed with X-ray photoelectron spectroscopy – besides Au which was found inert, the metals were ranked by reaction strength (determined by the amount of Bi₂Se₃ consumed) as followed Pd < Ir < Co < CoFe < Ni < Cr < NiFe < Fe [13]. More recently, phase separation of the ferromagnetic layer in the Ni₈₀Fe₂₀/Bi₂Se₃ heterostructure due to Ni-diffusion resulting in a ternary magnetic phase of Ni:Bi₂Se₃ [14]. Further study of selective Ni-diffusion uncovered a novel antiferromagnetic phase at the interface of sputtered Bi₂Te₃/Ni₈₀Fe₂₀ [15]. The interfacial phase of NiBi₂Te₄ formed and was found to have a Néel temperature of 63 K [15]. This Néel temperature of 63 K is significantly higher than that reported for intrinsic antiferromagnetic topological insulator, MnBi₂Te₄, which exhibits magnetic order below 20 K [16],[17]. We suspect the sputtered Bi₂Te₃ grown on amorphous SiO₂/Si substrate has mosaicity present, despite *c*-axis orientation, which may limit the diffusion depth of the Ni into the topological insulator film, thus limiting the uniformity and thickness of the interfacial antiferromagnetic phase.¹⁵ In this current work, we grew the topological insulator, Sb₂Te₃, with molecular beam epitaxy, therefore the film should be highly ordered and epitaxial, therefore the diffusion depth of the Ni into the Sb₂Te₃ may be much deeper, providing a smaller gradient resulting in a more homogeneous antiferromagnetic interlayer formation at the interface. The goal of this study is to characterize the topological insulator/ferromagnet heterostructure of molecular beam epitaxy grown Sb₂Te₃/DC sputtered Ni₈₀Fe₂₀. The Sb₂Te₃/Ni₈₀Fe₂₀ heterostructures were examined with temperature-dependent magnetometry, high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM), and theoretical calculations.

We first studied the temperature dependent magnetic hysteresis behavior of the Sb₂Te₃/Ni₈₀Fe₂₀ bilayer using a superconducting quantum interference device (SQUID). We observed negative exchange bias behavior in this system. Exchange bias is an effect observed in coupled ferromagnetic/antiferromagnetic materials and arises due to uniaxial anisotropy induced at the interface between the two layers [18]. This indicates there is an antiferromagnetic phase at

the $\text{Sb}_2\text{Te}_3/\text{Ni}_{80}\text{Fe}_{20}$ interface. We also investigated the measured moment as a function of temperature from room temperature to 3 K, then we took the derivative of this curve to identify the Néel temperature. From these results, we found a Néel temperature of ~ 40 K – this is interesting, because the intrinsic topological antiferromagnetic phase MnBi_2Te_3 has a Néel temperature of 20 K, however the NiBi_2Te_4 at the interface of $\text{Bi}_2\text{Te}_3/\text{Ni}_{80}\text{Fe}_{20}$ has a Néel temperature of 63 K [15]. After we discovered exchange bias and therefore formation of antiferromagnetic interface, we used high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) to further study the interface phases present. We found a NiTe_2 -type structure at the interface. Additionally, we studied the ferromagnetic resonance response of $\text{Sb}_2\text{Te}_3/\text{Ni}_{80}\text{Fe}_{20}$ heterostructure versus a control sample of $\text{Ni}_{80}\text{Fe}_{20}$ (Py). We found that an enhancement in Gilbert damping and reduction in effective magnetization for the $\text{Sb}_2\text{Te}_3/\text{Ni}_{80}\text{Fe}_{20}$ bilayer, which indicates the presence of spin pumping. In broadband ferromagnetic resonance measurement, at resonance the $\text{Ni}_{80}\text{Fe}_{20}$ magnetization precession acts as a source of angular momentum, and since Sb_2Te_3 acts as a spin sink due to large spin-orbit-coupling, this leads to spin pumping across the interface into the Sb_2Te_3 layer. Therefore, there is a loss in angular momentum in the $\text{Ni}_{80}\text{Fe}_{20}$ due to spin pumping across the interface.

Here we have discovered an antiferromagnetic phase formation at the interface of the $\text{Sb}_2\text{Te}_3/\text{Ni}_{80}\text{Fe}_{20}$ heterostructure. This was confirmed with temperature dependent magnetometry and HAADF-STEM. HAADF-STEM revealed the prevalence of a NiTe_2 -type structure. Theoretical support work is on-going to confirm that the NiTe_2 can support antiferromagnetic coupling between Ni-sites.

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