Spin-Dependent Phenomena in Magnetic Insulator/Topological Insulator Heterostructures

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The strong spin-orbit coupling (SOC) in topological insulators (TI) locks the spin of the surface Dirac electrons orthogonal to its two-dimensional momentum. In heterostructures comprised of TI and a magnetic insulator (MI), the surface electron spins of TI are also exchange coupled to spins of the MI. The presence of these two interactions can give rise to unique spin-dependent phenomena. If the exchange interaction is sufficiently strong to induce ferromagnetism in TI surface states, the time reversal symmetry in TI is broken which is required to show the quantum anomalous Hall effect. Even in the absence of a ferromagnetic order, on one hand, the spin current carried by magnons in MI can be efficiently converted to an electric voltage. On the other hand, this outward flow of spin angular momentum produces a torque on the magnetization of the MI which drastically modifies the spin dynamics of the MI. In our MI/TI heterostructures, the MI is an atomically flat rare earth iron garnet film, either yttrium iron garnet (YIG) or thulium iron garnet (TIG), both grown by laser molecular beam epitaxy. By choosing different substrates, YIG and TIG have in-plane and perpendicular magnetic anisotropies, respectively [1, 2]. The TI is a 5 nm thick $(Bi_xSb_{1-x})_2Te_3$ grown by molecular beam epitaxy. Its Fermi level position can be tuned from the bulk valence to conduction bands through the band gap. We have observed induced ferromagnetism in both YIG/TI and TIG/TI [3, 4]. Above the induced ferromagnetic ordering temperature T_c (T_c ~ 150 K for YIG/TI), we have found that both spin Seebeck coefficient and Gilbert damping in YIG are greatly enhanced as the Fermi level approaches the Dirac point when the Bi/Sb ratio is systematically tuned. We conclude that the spin-momentum locked surface states in TI are responsible for the anomalously large enhancement in both effects.

[1] Chi Tang, Mohammed Aldosary, Zilong Jiang, Houchen Chang, Benjamin Madon, Kyle Chan, Mingzhong Wu, Javier E. Garay, and Jing Shi, *Exquisite growth control and magnetic properties of yttrium iron garnet thin films,* APL **108**, 102403 (2016).
[2] C. Tang, P. Sellappan, Y.W. Liu, Y.D. Xu, J. E. Garay, and Jing Shi, *Anomalous Hall hysteresis in $Tm_3Fe_5O_{12}$/Pt with strain-induced perpendicular magnetic anisotropy*, Phys. Rev. B **94**, 140403 (R) (2016).
[3] Z.L. Jiang, C.-Z. Chang, M. R. Massir, C. Tang, Y.D. Xu, J. S. Moodera, A. H. MacDonald, and Jing Shi, *Enhanced spin Seebeck effect signal due to spin-momentum locked surface states*, Nat. Comm. **7**, 11458 (2016).
[4] Chi Tang, Cui-Zu Chang, Gejian Zhao, Yawen Liu, Zilong Jiang, Chao-Xing Liu, Martha R. McCartney, David J. Smith, Tingyong Chen, Jagadeesh S. Moodera, and Jing Shi, *Above 400 K robust perpendicular ferromagnetic phase in a topological insulator*, Science Advances (in press).