Fermi Level Dependent Spin Pumping from a Magnetic Insulator into a Topological Insulator: Supplementary Information

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1. Reflection high energy electron diffraction (RHEED) data.

RHEED provides useful information about the crystalline and surface quality of the samples during epitaxial growth. The figures below show RHEED patterns obtained after the epitaxial growth of a $(Bi,Cr,Sb)_2Te_3$ film grown on YIG.

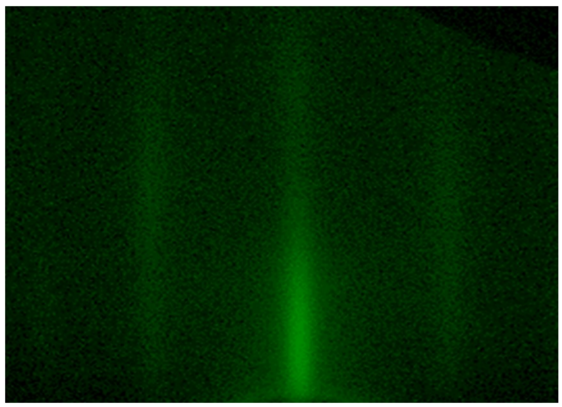


Figure S1: RHEED pattern of a 10-nm thick layer of $(Bi,Cr,Sb)_2Te_3$ film grown on YIG.

2. Control measurements to rule out artifacts in spin pumping measurements.

A recent paper [1] pointed out that measurements of the kind reported in our manuscript can result in spurious signals that mimic all the standard characteristics of spin pumping (including the asymmetry in magnetic field direction and linear dependence on microwave power). Such artifacts are expected to be found in experimental geometries that use thick YIG substrates. They arise from a Seebeck effect due to a lateral thermal gradient created by nonreciprocal magnetostatic surface spin wave propagation in thick YIG substrates. We do not expect these artifacts in samples such as ours where the YIG is only 20 nm thick. Nonetheless, to definitively rule out such artifacts, we carried out control measurements wherein the microstripline is placed below and above the topological insulator/ferrimagnetic insulator bilayer sample as shown in Fig. S1 below. The reversal in sign of the measured voltage confirms that is is indeed due to the inverse spin Hall signal arising from spin pumping.

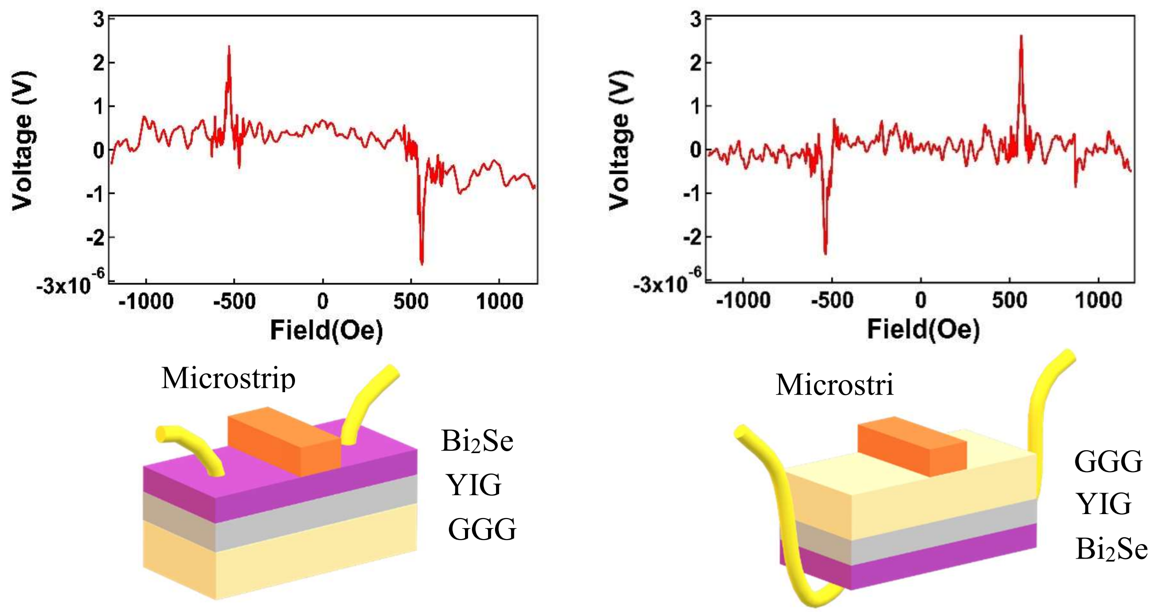
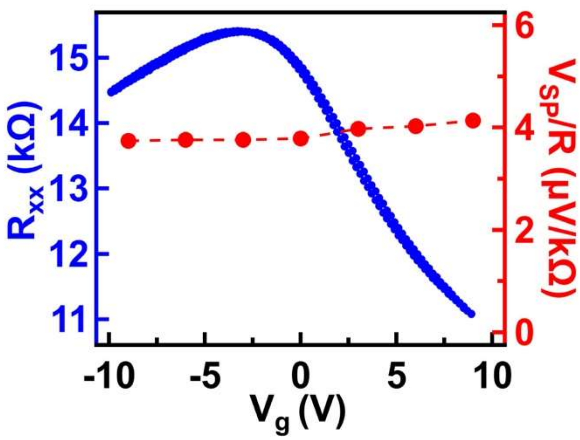


Figure S2: Spin pumping signal of a YIG (30 nm)/Bi_2Se_3 (24 nm) heterostructure grown on a GGG substrate measured at T = 300 K in the regular configuration mentioned in the main text (a) and in an inverted one (b).

[1] P. Wang, L.-F. Zhou, S.-W. Jiang, Z.-Z. Luan, D.-J. Shu, H.-F. Ding, and D. Wu, Phys. Rev. Lett. 120, 047201 (2018).

3. Fermi energy dependence of the spin-charge conversion efficiency as measured by spin pumping.

Fig. S3. The spin-charge conversion efficiency during the spin pumping process is well quantified using the ratio V_{SP}/R_{xx} [2]. This is shown in the figure below for a top gated $(Bi,Cr,Sb)_2Te_3$/YIG sample as a function of the gate voltage, demonstrating that the spin-charge conversion efficiency (like the spin Hall conductivity) does not change much as the Fermi energy is varied through the bulk gap and across the Dirac cone of the surface states. The data correspond to those shown in Fig. 2 (b) of the main manuscript.



[2] H. Wang, J. Kally, J. S. Lee, T. Liu, H. Chang, D. R. Hickey, K. A. Mkhoyan, M. Wu, A. Richardella, and N. Samarth, *Phys. Rev. Lett.* **117**, 076601 (2016).