Spin-orbit torque-ferromagnetic resonance with topological insulators

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The Dirac bands formed at the interface between a three-dimensional topological insulator (TI) and a trivial insulator are characterized by their spin-helicity, arising from the combination of a large spin-orbit coupling and time reversal invariance [1]. This spin-momentum locking potentially makes TIs extremely efficient charge-to-spin converters, able to exert a large spin-orbit torque (SOT) on an adjacent ferromagnet (FM). The torque produced by current-biased helical topological states is analogous to the Rashba SOT, but is expected to be much larger owing to the absence of partly compensated spin sub-bands. SOT-induced ferromagnetic resonance (SOT-FMR) gives access to the nature and magnitude of the torques. So far, only few studies have focused on SOT-FMR in TI/FM multilayers, and a large spin torque has been reported [2-4]. However, little is known about TI/metal interfaces. Charge doping together with a strong hybridization between topological bands and metallic states is suspected to deeply weaken the spin-momentum locking, which questions the origin of the reported SOT [5]. In order to understand how TI/metal interfaces influence the nature and magnitude of SOT, we performed systematic SOT-FMR on TI/NM/Py multilayers with different normal metal (NM) spacers.

In contrast to previous SOT-FMR experiments performed with TIs, (i) we studied multilayers fully grown in the same ultra-high vacuum system, without intermediate exposure to air; (ii) we deposited TIs on lattice-matched $BaF_2(111)$ substrates, which makes possible the growth of low-doped and truly single-crystalline films (full suppression of rotational domains and twin defects); (iii) we investigated the temperature dependence of the SOT-FMR signals down to 4 K; (iv) we systematically studied the impact of a spacer inserted between the TI and Py on the SOT-FMR efficiency; and (v) we complemented transport measurements by a systematic characterization of TI/NM interfaces with x-ray photoelectron spectroscopy. A $(Bi_{0.4}Sb_{0.6})_2Te_3$ alloy grown by molecular beam epitaxy was used as the TI layer, designed to show a low carrier density and bulk insulating behavior (Fig. 1a). Al, Ag and Te were used as NM spacers. SOT-FMR measurements (Fig. 1b) reveal that the nature of the TI/NM interface strongly impacts both the magnitude and the type of the SOT exerted on Py. For instance, $(Bi_{0.4}Sb_{0.6})_2Te_3$/Py multilayers show a dominant field-like torque whereas $(Bi_{0.4}Sb_{0.6})_2Te_3$/Ag/Py exhibit an FMR line shape characteristic of anti-damping torque (Fig. 1c). Our results show that the determination of SOTs in TI/NM/FM devices by SOT-FMR requires analyses beyond standard ones, and imply that a careful engineering of interfaces with TIs is necessary to enhance the helical states-induced SOTs.

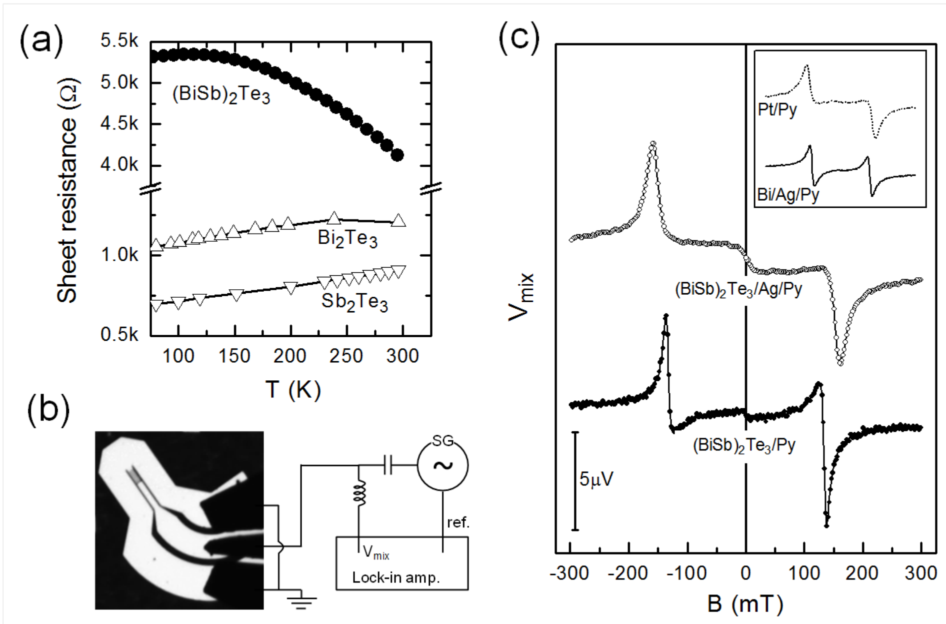

Figure 1: (a) Sheet resistance of TIs showing the bulk insulating character of $(Bi_{0.4}Sb_{0.6})_2Te_3$. (b) Schematic diagram of the SOT-FMR measurement with a TI/NM/Py multilayer embedded in a coplanar waveguide. (c) SOT-FMR spectra measured on $(Bi_{0.4}Sb_{0.6})_2Te_3$/Py and $(Bi_{0.4}Sb_{0.6})_2Te_3$/Ag/Py at room temperature. Inset: typical signals from a spin Hall system (Pt/Py) and a Rashba system (Bi/Ag/Py).

References

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