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Unidirectional spin-Hall magnetoresistance in HgTe topological insulator-ferromagnet heterostructures

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The surface states of three-dimensional topological insulators (TIs) exhibit a large spin-orbit coupling leading to spin-momentum locking, the electron spin being locked perpendicularly to the electron momentum. This property is promising for spintronic applications, as the Rashba Edelstein effect can create, from a charge current at the conducting surface of a TI, a spin accumulation. Reciprocally, the injection of a spin current creates a net charge current by inverse Edelstein effect. Recently, we have demonstrated a large spin-to-charge conversion efficiency in strained mercury telluride (HgTe) TI at room temperature [1], with conversion rates one order of magnitude higher compared to conventional materials. Achieving the mirror charge-to-spin conversion would be of great interest for memory and logic application, with two effects in particular that could be exploited. First, the spin-orbit torques (SOT), in which the spin accumulation induces a torque on the magnetization [2], and which can be used as a switching mechanism in a magnetoresistive random access memories (SOT-MRAM). Second, the Unidirectional Spin-Hall Magnetoresistance (USMR), in which - depending on the relative directions between the spin accumulation and the magnetization - the system holds a high or a low resistance state [3]. While conventional SOT devices suffer from a three-terminal geometry, this USMR effect has potential to be used as a new reading mechanism for developing a novel type of SOT-MRAM with a two-terminal geometry and smaller footprint.

Here we report unidirectional spin-Hall magnetoresistance in HgTe topological insulator-ferromagnet heterostructures up to room temperature. Results are shown from a 3 µm wide Hall bar device, made of a NiFe ferromagnetic layer with in-plane magnetization on top of an HgTe layer with a thin HgCdTe insertion to protect the TI surface state. Harmonic measurements of the longitudinal and Hall resistance are performed to investigate both USMR and spin-orbit torque effects. A change in the nonlinear magnetoresistance upon switching the magnetization from +y to –y direction is demonstrated, corresponding to the signature of the USMR driven by Eldelstein effect. Anomalous Nernst and spin Seebeck effects are measured from the nonlinear magnetoresistance in the x direction, showing negligible contributions. The results show USMR efficiency of 2.6 ppm A. cm^{-1} at 10K, three times higher than in ferromagnet-normal bilayer and on the same order of low temperature Bismuth Selenide TI. USMR signal is seen to increase linearly with the current density, confirming the unidirectional nature of USMR in HgTe. Experimental results at room temperature further show comparable USMR efficiency, bringing HgTe compatible for room temperature applications. Ongoing material engineering is discussed to improve further the USMR efficiency on HgTe system, the high efficiency observed in this first demonstration constituting an important step towards SOT-MRAM with two-terminal geometry at room temperature.

[1] P. Noel et al., Phys. Rev. Lett., 120, 167201 (2018).
[2] I. M. Miron et al., Nature 476, 189–193 (2011).
[3] C. O. Avci et al., Nature Physics 11, 570–575 (2015).