Non-reciprocal magnetotransport properties of α-Sn/(In,Fe)Sb magnetic topological bilayers

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Among many topological materials, α-Sn stands out as a unique and promising candidate: It is the only elemental material that shows multiple topological phases, such as topological Dirac semimetal (TDS) and topological insulator (TI), which can be controlled by various means such as strain, thickness, or applying electric fields [1]. When α-Sn is grown on an InSb (001) substrate, a diamond-type α-Sn thin film experiences in-plane compressive strain, which leads to formation of two Dirac points in the three-dimensional (3D) band structure and drives the α-Sn film into a TDS phase. Recently, we have successfully grown single-crystalline α-Sn thin films on InSb (001) using molecular beam epitaxy (MBE). In these α-Sn thin films, very high quantum mobilities of both the topologically non-trivial bulk (1800 cm^2/Vs) and surface states (30000 cm^2/Vs) were obtained for the first time, which firmly position α-Sn as one of the most promising platforms for systematic studies of various topological physics and devices [2].

In this work, we study magnetotranport properties of α-Sn thin films grown on ferromagnetic semiconductor (FMS) (In,Fe)Sb layers [3]. The sample structure consists of (from top to bottom) α-Sn (2 nm) / $(In_{1-x},Fe_x)Sb$ (x = 13.8%, 10 nm, Curie temperature T_C > 300 K) / InSb buffer (100 nm) / undoped InSb (001) substrate (Fig. 1a). Although the FMS (In,Fe)Sb is highly resistive at low temperature [3], we observe clear magnetic hysteresis in the magnetoresistances of the heterostructures, which indicates that magnetic coupling is induced in the α-Sn layer by the magnetic proximity effect (MPE) from the underlying (In,Fe)Sb. As shown in Fig. 1b, when an in-plane magnetic field $\boldsymbol{B}$ is applied parallel to the current $\boldsymbol{I}$, the magnetized α-Sn thin film shows very large linear magnetoresistances that are odd-functions of $\boldsymbol{B}$ ($R_{B\text{-odd}}/R_0$ ~ 250%, where $R_{B\text{-odd}}$ and R_0 are the odd-function component and the resistance at zero magnetic field, respectively). Furthermore, a nonreciprocal magnetoresistance component $R_{I\text{odd\_}B\text{odd}}$, which is an odd function of both $\boldsymbol{B}$ and $\boldsymbol{I}$, is also observed (Fig. 1b, red circles). The nonreciprocal component $R_{I\text{odd\_}B\text{odd}}$ increases proportionally to the current $\boldsymbol{I}$, which indicates that it results from a non-linear response in the magnetotransport properties of α-Sn (Fig. 1c). These novel magnetotransport properties are considered to originate from the breaking of spatial inversion symmetry and time reversal symmetry in the α-Sn/$(In_{1-x},Fe_x)Sb$ heterostructures.

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References

[1] D. Zhang et al., *Phys. Rev. B* **97**, 195139 (2018). [2] L. D. Anh, K. Takase et al., *Adv. Mater.* **33**, 2104645 (2021). [3] N. T. Tu et al., *Appl. Phys. Express* **11** (6), 063005 (2018).

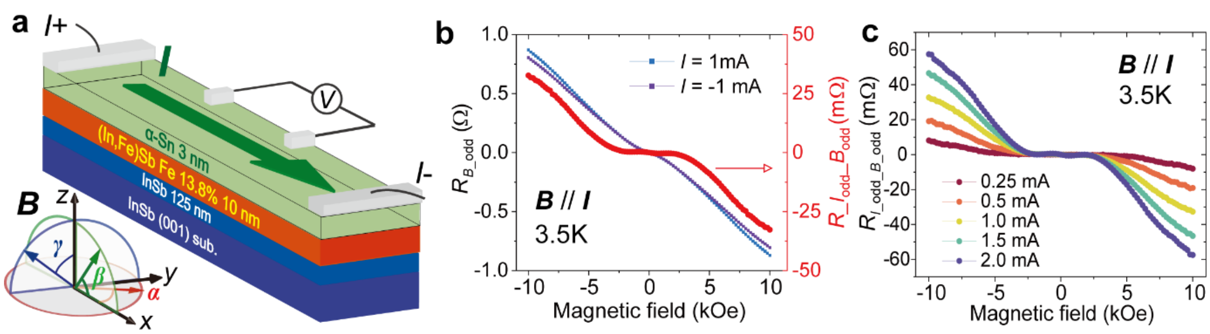

Fig. 1 (a) Sample structure and measurement configuration. (b) Large odd-parity magnetoresistance $R_{B\text{-odd}}$ (blue and purple squares, left axis) and nonreciprocal magnetoresistance component $R_{I\text{odd\_}B\text{odd}}$ (red circles, right axis) in the α-Sn/$(In_{1-x},Fe_x)Sb$ sample. (c) Magnetic field dependence of $R_{I\text{odd\_}B\text{odd}}$ at various current I = 0.25 – 2.0 mA. All data are measured at 3.5 K.