Spin injection into the topological crystalline insulator SnTe using spin pumping

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Topological insulators (TIs) possess gapless metallic surface states (SSs) that are protected by the time-reversal symmetry (TRS) [1]. The SSs have attracted great attention for spintronics applications particularly because a giant spin Hall angle $\theta_{\mathrm{SHE}} \approx 3.0$ (θ_{SHE} corresponds to the spin-to-charge current conversion efficiency) was reported in TI Bi_2Se_3 [2]. On the other hand, it was reported that since the SSs are protected by the TRS, the SSs are broken when a ferromagnetic material is deposited on the surface due to a magnetic perturbation [3]. Meanwhile, topological crystalline insulators (TCIs), which have the gapless metallic SSs, also have received a lot of attention in recent years. Unlike TIs, the SSs in TCIs are protected by the mirror symmetry of the crystal. Thus, the SSs in TCIs are expected to be robust against the breaking of TRS due to the magnetic perturbation. SnTe is a typical and promising TCI, and the topological SSs has been experimentally confirmed by the studies of angle-resolved photoemission spectroscopy and electrical transports [4, 5].

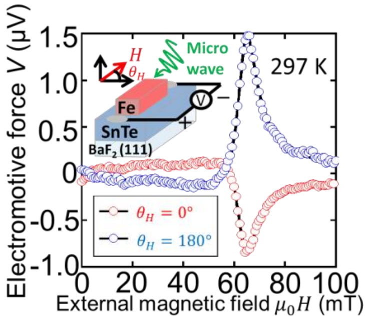

FIG. 1. Electromotive force V measured at the SnTe spin detector with θ_{H}= 0° and 180°. Open circles represent the experimental data and solid curves are the fittings obtained using Eq. (1).

In our spin-pumping experiments, we used a Fe (16 nm) / SnTe (70 nm) bilayer structure grown on a BaF_2 (111) substrate by molecular beam epitaxy [5]. At the ferromagnetic resonance (FMR) conditions, the dynamical exchange interaction drives the spin pumping, injecting a pure spin current into the SnTe layer. This gives rise to an electromotive force V in the SnTe layer through the inverse spin Hall effect (ISHE). As shown in the inset of Fig. 1, we fabricated a rectangular-shaped mesa structure of the Fe layer (1.5 mm×0.2 mm) by argon ion milling. The sample was placed near the center of a TE_{011} cavity of an electron spin resonance system (JEOL JES-FA300, microwave frequency: 9.1 GHz). An external magnetic field H was applied at an angle of θ_{H}.

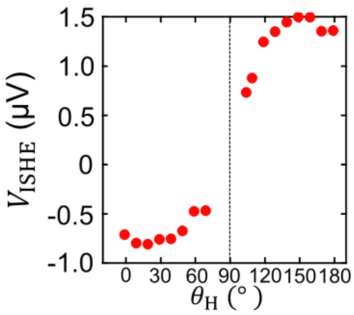

FIG. 2. H dependence of V_{ISHE} for various θ_{H}.

Figure 1 shows the V-H curves when θ_{H} is 0° and 180°, respectively. As shown in the figure, the V-H curves exhibit a FMR peak at $\mu_0 H$ = 63 mT, which changes sign by reversing magnetic fields. We measured V-H curves for various θ_H and analyzed them by fitting to the function composed of the both contributions from the ISHE (symmetrical Lorentzian curve centered at H=H_{FMR}) and the anomalous Hall effect (AHE; asymmetrical curve) as follows [6]:

$$V = V_{\mathrm{ISHE}}\frac{\Gamma^2}{(H-H_{\mathrm{FMR}})^2+\Gamma^2} + V_{\mathrm{AHE}}\frac{-2\Gamma(H-H_{\mathrm{FMR}})}{(H-H_{\mathrm{FMR}})^2+\Gamma^2}, \qquad (1)$$

where V_{ISHE}, V_{AHE}, and Γ are the amplitudes of the electromotive force induced by ISHE and AHE, and a damping constant, respectively. V_{ISHE} was estimated for various θ_{H} as plotted in Fig. 2. As shown in Fig. 2, V_{ISHE} exhibits an antisymmetric behaviors against θ_{H} with its center at $\theta_{\mathrm{H}} \approx 90°$ and the maximal value of $|V_{\mathrm{ISHE}}|$ at around 0° or 180°. This behavior is consistent with the expected one expressed as $V_{\mathrm{ISHE}} \propto J_{\mathrm{C}} \propto J_{\mathrm{S}} \times \sigma$, where J_{C}, J_{S}, and σ are the charge current density, the spin current density, and the spin-polarization vector, respectively [6]. These results indicate that the spin current was injected from the Fe layer and successfully detected in the SnTe layer.

Acknowledgement: This work is supported by Grants-in-Aid for Scientific Research including the Specially Promoted Research and the Project for Developing Innovation Systems of MEXT. Part of this work was carried out under the Cooperative Research Project Program of RIEC, Tohoku University.

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