Room-temperature spin injection and spin-to-charge conversion in a ferromagnetic semiconductor / topological insulator heterostructure

°(PC)Shobhit Goel [1,2], Nguyen Huynh Duy Khang [3], Le Duc Anh [1,4], Pham Nam Hai [2,3,5], and Masaaki Tanaka [1,2,5]
Univ. of Tokyo [1], CREST, JST [2], Tokyo Tech. [3], PRESTO, JST [4], CSRN, Univ. of Tokyo [5]
E-mail: goel@cryst.t.u-tokyo.ac.jp

Room temperature injection and detection of spin-polarized carriers from ferromagnetic semiconductors (FMSs) are strongly required for spintronics device applications. So far, the spin injection has been reported only in the prototypical Mn-doped III-V FMS (Ga,Mn)As at a very low temperature < 120 K [1]. This is because Mn-doped FMSs show Curie temperature (T_C) much lower than 300 K. Recently, (Ga,Fe)Sb has shown high T_C > 300 K [2] and clear ferromagnetic resonance (FMR) at 300 K [3]. Here, we demonstrate the first room-temperature spin injection by spin pumping in a (Ga,Fe)Sb/ BiSb heterostructure, where (Ga,Fe)Sb is a FMS and BiSb is a topological insulator (TI). Despite the very small magnetization of (Ga,Fe)Sb at room temperature (45 emu/cc), we clearly detect spin injection from (Ga,Fe)Sb by utilizing the inverse spin Hall effect (ISHE) in the topological surface states of BiSb with a large spin Hall angle [4].

For this study, we prepared two samples: sample A [BiSb/(Ga,Fe)Sb] and sample B [(Ga,Fe)Sb, reference sample] by first growing epitaxial 50-nm-thick ($Ga_{0.75}$,$Fe_{0.25}$)Sb on AlSb/AlAs/GaAs/semi-insulating GaAs(001) substrates by molecular beam epitaxy and then grew poly-crystalline 7-nm-thick BiSb by sputtering. Fig. 1(a) shows the FMS/TI bilayer structure and coordinate axes used in the spin pumping. The magnetic properties of both samples are characterized by magnetic circular dichroism (MCD) spectroscopy, magneto-transport measurement, and superconducting quantum interference device (SQUID) magnetometry. We confirmed intrinsic ferromagnetism in both samples with T_C > 300 K. Next, we detect ISHE signals under FMR conditions. Fig. 1(b) (top panel) shows FMR spectra measured at 300 K for the (Ga,Fe)Sb film. The observed electromotive force (EMF) signals for sample A and sample B are shown in Fig. 1(b) (bottom panel). By fitting theoretical curves to the observed ISHE signals in symmetric and asymmetric components, we found that the planar Hall effect (PHE) contribution in ISHE is negligible in (Ga,Fe)Sb. This is contrasting to the case of Mn-doped FMS (Ga,Mn)As, which showed a dominant contribution from PHE (~88%) [1]. Furthermore, by carefully analyzing the voltage signals at various magnetic field directions, temperatures, and microwave powers, we distinguish the intrinsic ISHE signals from parasitic galvanomagnetic contributions, such as anomalous Hall effect (AHE) and PHE. Moreover, from the transport measurement, we have found that the electrical conductivity of poly-crystalline BiSb is 100 times larger than that of (Ga,Fe)Sb, due to the surface-state conduction of BiSb. By assuming spin diffusion length of BiSb ~1 nm, we estimated the inverse spin Hall angle to be ~2.5, which is very large compared with other materials such as Si, Bi_2Se_3, Pt, and other heavy metals. Our study provides the first step towards efficient spin injection and detection in practical semiconductor spintronic devices operating at room temperature.

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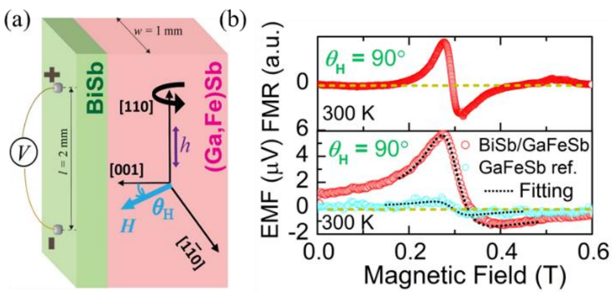

FIG.1 (a) BiSb/(Ga,Fe)Sb bilayer device and coordinate system used in the spin pumping experiment, where θ_H is the applied magnetic field angle. (b) FMR spectra of ($Ga_{0.75}$,$Fe_{0.25}$)Sb (top panel), EMF signal of sample A (red), and sample B (cyan) at 300 K and $\theta_H = 90°$ (bottom panel). The black dotted curves show theoretical fitting.

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