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Dynamical spin injection into highly-orientated Bi(001) thin film

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Bismuth (Bi) is expected to have giant spin Hall angle (θ_{SHE}) due to its peculiar electron system (the Dirac electron system) and strong spin-orbit coupling.[1][2] We have reported that the θ_{SHE} of amorphous Bi is comparable with those of the other heavy metals e.g. Pd and Pt, in the last presentation.[3] In this presentation, we demonstrate spin injection into poly-crystal Bi, which is expected to have the Dirac electron system, by using a spin pumping technique, and estimate the θ_{SHE} and spin diffusion length (λ) of the poly-crystal Bi.

A 25-nm-thick Fe_3Si epitaxial layer was grown on a non-doped Si(111) substrate by molecular beam epitaxy (MBE) at 403 K. A Bi layer was formed on the Fe_3Si at room temperature (RT) by thermal resistance heating deposition (Fig. 1(a)). In the spin pumping measurement, the sample was placed in a nodal position of a TE_{102} cavity of an electron spin resonance (ESR) system (the microwave frequency was 9.60 GHz). An external static magnetic field was applied at an angle, θ_H, as illustrated in Fig. 1(a). In the ferromagnetic resonance (FMR) condition of the Fe_3Si layer, a spin angular momentum is transferred from the Fe_3Si layer to the Bi layer, resulting in generation of a pure spin current propagated perpendicular to the film plane of the Bi layer. Then, the spin current was converted into a charge current due to the inverse spin Hall effect (ISHE) of Bi. Figure 1(b) shows a X-ray diffraction pattern of the sample. Clear peaks are observed from the Bi film (Bi(003), (006) and (009)), which suggests that highly oriented Bi(001) was successfully grown on the Fe_3Si.

The FMR spectra and the DC electromotive force (EMF) were obviously observed at RT, where the microwave power was set to be 200 mW, as shown in Fig. 1(c) and (d). The polarity reversal of the EMF was observed when θ_H was changed form 0° to 180°. In addition, the line width of FMR spectra was increased by attaching the Bi layer. These results strongly suggest that the EMF was generated by the ISHE in the Bi layer. We will also talk about the evaluation of the θ_{SHE} and the λ from Bi thickness dependence of the EMF, and discuss correlation between the crystal structure of Bi and the θ_{SHE} in the presentation.

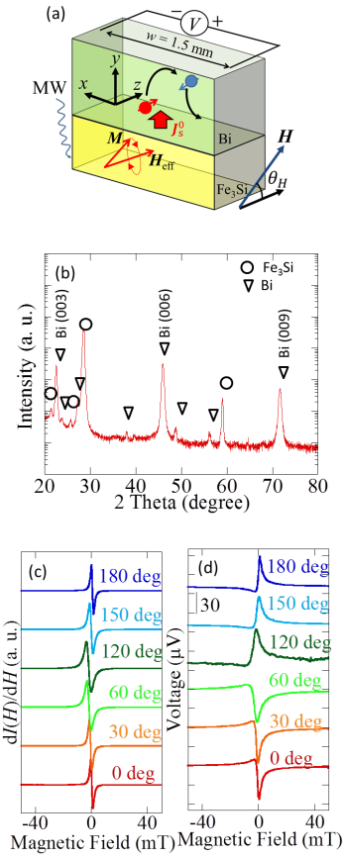

Fig.1 (a) A schematic illustration of the Bi/Fe_3Si sample for dynamical spin injection. (b) A X-ray diffraction pattern of Bi 200 nm/Fe_3Si. (c) (d) Field dependence of FMR signals and DC electromotive force signals measured at various θ_H.

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