Spin Pumping in Bi_2Se_3 (MoS_2)/CFMS Layers

One of the effective ways for conversion of charge (spin) current to spin (charge) current is to exploit spin Hall effect (inverse spin Hall effect), which is the vital of recent spintronic applications. In this project, our aim is to prepare Heusler alloy based $Co_2Fe_xMn_{1-x}Si$ (CFMS) films on top of topological insulator Bi_2Se_3 and 2-dimensional chalcogenide MoS_2 films in order to understand the conversion mechanism between the Heusler alloy and the nonmagnetic materials. As the first step, we investigated the growth condition of those nonmagnetic materials and the spin pumping from the Heusler alloy.

The generation and control of spin current, which is the flow of spin angular momentum, are important research subjects for the contemporary spintronics. Spin current-based memory and storage devices are predicted to be faster, power efficient compared to spin polarized current devices [1]. One of the ways to convert from charge (spin) current to pure spin (charge) current is called spin Hall effect (inverse spin Hall effect). In the case of bilayer systems consisting of ferromagnetic (FM) layer and nonmagnetic (NM) layer, the conversion efficiency majorly depends on spin-orbit coupling strength of NM. For the spin pumping experiment, the FM layer works as a spin current source, where spins dissipate their spin angular momentum at the interfaces between the FM layer and the NM layer. As the NM material, the elemental heavy metals such as Pt, W, Ta, and Au are to investigate the spin pumping *via* ISHE [2].

Apart from the NM metals, topological materials and 2-dimensional chalcogenides have attracted much attention as materials for the spin-charge conversion. From this point of view, Bi_2Se_3 and MoS_2 are the potential candidates due to presence of spin momentum locking surface states and absence of inversion symmetry, respectively [3]. Therefore, it is indispensable to elucidate the spin-charge conversion mechanism in those topological materials and 2-dimensional chalcogenides for realizing next- generation spintronic devices.

In addition to the NM material exhibiting the high spin-charge conversion efficiency, the fast and low power consumption spintronic devices require the FM layer materials with low magnetic damping constant (α). In this context, Heusler alloys viz. $Co_2Fe_xMn_{1-x}Si$ (CFMS) are promising FM layer material showing the small value of $\alpha \sim 0.002$, which is one order of magnitude lower than those for the conventional FM materials such as a FeNi alloy (Permalloy). Some of Heusler alloys are also famous as a half metal theoretically predicted, which may allow us to create highly spin-polarized current. Considering the above points, the Heusler alloys and the topological materials or the 2-dimensional chalcogenides are important materials combination as a bilayer system for spin pumping experiment.

In this collaborative research, we proposed the investigations of spin pumping by measuring inverse spin Hall effect (ISHE) in Bi_2Se_3 (MoS_2) / CFMS bilayers. As the first step, we prepared the Bi_2Se_3 and MoS_2 thin films by electron beam evaporation, and investigated the spin pumping from the CFMS using the bilayer with CFMS and Pt layers.

Figure 1 shows the x-ray diffraction data for a 30 nm Bi_2Se_3 film deposited on Si (100) substrate. It shows the diffraction peaks corresponding to (003) family of planes of orientation only. Transmission electron microscopy confirmed the polycrystalline nature of the films [4]. We have observed magnetoresistance of ~ 7% in Bi_2Se_3 thin films. Similarly, we have prepared MoS2 films by electron beam evaporation. The thickness of MoS_2 films are kept about 10 nm to make sure the film is uniform and homogeneous. Raman scattering data indicate the MoS_2 phase formation of the films. We have observed spin pumping and invserse spin Hall effect in MoS_2/CoFeB bilayers which evidence that the MoS_2 exhibit high spin orbit coupling.

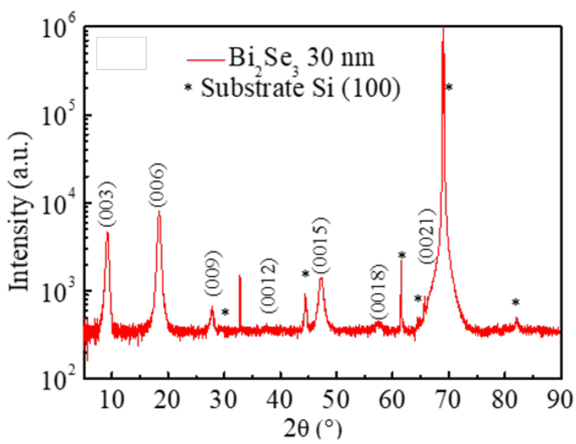

Fig. 1 X-ray diffraction profile of a 30nm Bi_2Se_3 film grown on the Si substrate measured in the θ-2θ geometry.

In addition to the investigation of film growth, we analyzed the ISHE voltage and damping results on CFMS (20 nm) / Pt (*t*) bilayers, where *t* was varied between 3 to 20 nm. On these bilayers, we performed the ferromagnetic resonance (FMR) measurement in the frequency range of 6 to 17 GHz. As a result, we observed the enhancement of damping for the samples attached with Pt, which is attributable to the large spin-orbit interaction of Pt. In order to confirm the spin injection originating from the spin pumping, we performed angle dependence measurement for the ISHE voltage. We did further analysis to disentangle the spin pumping voltage from other spin rectification effects such as anisotropic magnetoresistance, anomalous Hall effect. We found spin pumping voltage is dominating in our CFMS / Pt bilayers.

We have also performed analysis to quantify the spin mixing conductance, which is an important parameter corresponding to the ferromagnetic material. Figure 2 shows the spin mixing conductance as a function of Pt layer thickness. We show that CFMS exhibits a very high spin mixing conductance of 1.77 X 10^{20} m^{-2}. Furthermore, we have analyzed the interface transparency, which was evaluated to be 84% for CFMS / Pt system. This value is higher than the values reported for other ferromagnetic / heavy metal systems [5]. Our study shows that CFMS is an ideal FM layer for spin-charge conversion-based applications. We plan to deposit CFMS film on Bi_2Se_3 and MoS_2 and investigate the spin pumping for those bilayers in near future.

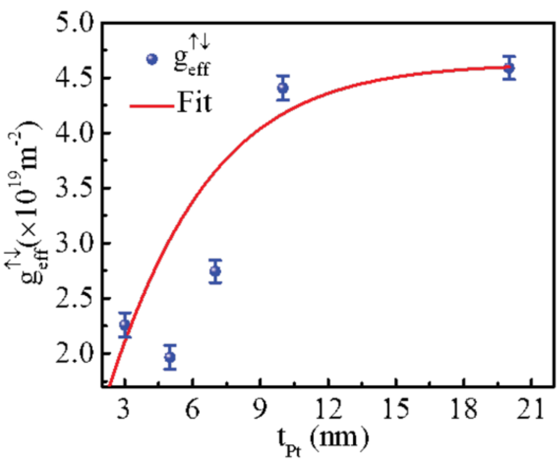

Fig. 2 Spin mixing conductance as a function of Pt layer thickness for the CFMS (20 nm) / Pt bilayers.

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