Ferromagnetic thin film and spin current (6)

Product used：Electron spin resonance spectrometer (ESR)

***** Angular dependence (2) *****

The inverse spin-Hall effect generates the electric charge current J_C (electro motive force) toward the direction of vector product of the spin current (J_S) and the magnetization (σ), as expressed in eq. (1).

$$J_C \;//\; J_S \times \sigma \quad (1)$$

Therefore, polarity of the electro motive force also inverts as a magnetic direction against the sample inverts. It is an interesting property that the angular dependence of the inverse spin-Hall electro motive force shows the extremely different behavior from the ordinal FMR one.

Fig. 1 ES-UCR3X (Angular rotation device).

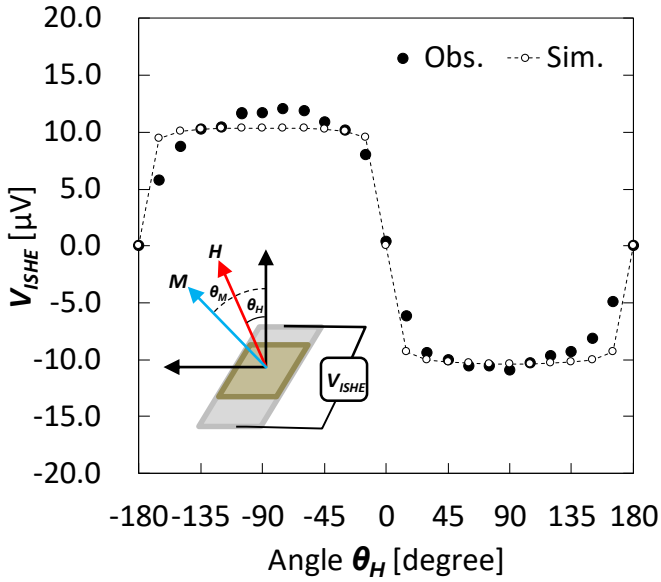
Sample and method

FMR spectra were measured with the step size of 15 degree against the applied magnetic field using the angular rotation device (ES-UCR3X in Fig. 1). The sample was the same metallic bilayer thin film reported on JEOL application note[1].

The angular dependence of the V_{ISHE} spectra

The dependence of V_{ISHE} signal on the magnetic field shows a drastic inverting phenomena, as shown in fig. 2. This is clearly different from FMR behavior. Substituting the obtained parameters from the angular experiment of FMR to eq. (2), the behavior of V_{ISHE} against the angular can be simulated[2, 3].

$$V_{ISHE} \propto K \frac{\sin\theta_M \left[4\pi M_S \gamma \sin^2\theta_M + \sqrt{(4\pi M_S)^2\gamma^2\sin^4\theta_M + 4\omega^2}\right]}{\alpha^2\left[(4\pi M_S)^2\gamma^2\sin^4\theta_M + 4\omega^2\right]} \quad (2)$$



Set Parameters & Conditions

Sample	$Py(Ni_{78}Fe_{22})/Pd$
Angle[deg.]	0–360
Temp.	Room Temp. (26C)
MW Frequency[MHz]	9441.523
MW Power[mW]	160
Ho[mT]	Sweep width 150 mT (corrected by Mn^{2+})
Mod. Width [mT]	0.0002/0.1
Mod. Freq. [kHz]	100
Mod. Phase [deg.]	0
Sweep Time[s]	30
Acc.	8
Amp. Gain	10(FMR) ISHE 40 dB(CA-261F2)＋0.6uF(LPF)→CN115
Tc[s]	0.01

Fig. 2 an experimental result and analysis of the angular dependence of V_{ISHE} spectra.

References

[1] JEOL RESONANCE Inc. Application note No. ER190002E.
[2] K. Ando, Y. Kajiwara, S. Takahashi, S. Maekawa, K. Takemoto, M. Takatsu, and E. Saitoh, Phys. Rev. B, 78(2008) , 014413.
[3] K. Ando, S. Takahashi, J. Ieda, Y. Kajiwara, H. Nakayama, T. Yoshino, K. Harii, Y. Fujikawa, M. Matsuo, S. Maekawa, and E. Saitoh, J. Appl. Phys. 109(2011), 103913 .

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