Direct-current modulation in spin torque ferromagnetic resonance spectra in permalloy/Pt bilayer films

S. Hirayama[1, 2], S. Kasai[2], and S. Mitani[1, 2]

[1] Graduate School of Pure and Applied Sciences, Univ. of Tsukuba
[2] National Institute for Materials Science

Spin Hall effect is the conversion phenomenon from charge to spin currents in heavy metals due to the spin orbit interaction, and the conversion efficiency is called the spin Hall angle. It can be characterized by ferromagnetic resonance in ferromagnetic (FM)/heavy metal (HM) bilayer films, namely spin torque ferromagnetic resonance (ST-FMR) measurements.

In ST-FMR measurements in FM/HM bilayer films, there have been two evaluation methods utilized, namely the spectrum intensity ratio (SIR) and the effective damping modulation (EDM) methods proposed by Liu et al. in 2011 [1]. In the SIR method, the intensity ratio between symmetric and asymmetric components of the ST-FMR spectrum gives spin Hall angle, while in the EDM method the degree of the damping modulation with respect to direct current (DC) density in HM is proportional to the spin Hall angle [2, 3]. So far, these two methods have been used complementarily; however, it appears that the phenomenon of EDM has been little understood. In this study, we examined the DC effect on ST-FMR spectra [4].

Permalloy (Py) (5 nm)/Pt (8 nm) films on sapphire substrates were prepared by using rf magnetron sputtering and fabricated into the rectangular shape samples of 1 μm in width and 6 μm in length, respectively. The applied RF power and frequency were 3 dbm and 12 GHz, respectively. The external magnetic field was swept from 2.8 to 0 kOe with the relative angle θ on the direction of the DC+RF current flow, and the magnitude of DC density in Pt (J_{dc}^{Pt}) was varied from -2.52 to 2.52•10^{11} A/m^2. The output voltage that is generated by rectification effect in EDM is detected by using an amplitude modulation method with a bias-tee.

Figure 1 shows ST-FMR spectra V_{obs} on the various DC at θ=10˚, where for their symmetric V_{sym} and asymmetric V_{asym} components are also shown. V_{sym} shows DC modulation clearly, while V_{asym} is not modulated. The spin Hall angle evaluated from the half width of half maximum of the V_{sym} peaks as a function of J_{dc}^{Pt}, i.e., from the EDM method, was 0.034, which is a reasonable value for Pt [3]. On the other hand, since the unexpectedly large change in the magnitude of V_{sym} occurred by applying J_{dc}^{Pt}, it was not able to determine the spin Hall angle in the regime of SIR. Namely, anomalous DC modulation was observed for Vsym in the ST-FMR with applying a DC at an unconventional angle θ of 10˚ (cf. 45˚ in conventional EDM methods).

This work was partly supported by JSPS KAKENHI Grant Number 16H06332 and 17K18892. The authors acknowledge K. Uchida and R. Iguchi for various discussions. One of the authors (S.H.) acknowledges the National Institute for Materials Science for the provision of a NIMS Junior Research Assistantship.

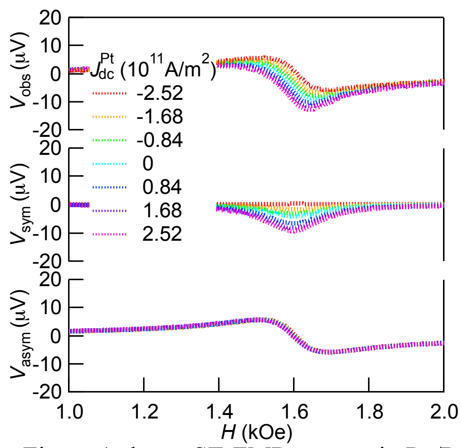

Figure 1 shows ST-FMR spectra in Py/Pt films for (a) observed spectra, (b) derived symmetric components and (c) derived asymmetric components, respectively.

References

[1] L. Liu et al., Phys. Rev. Lett. **106**, 036601 (2011).
[2] K. Kondou et al., Appl. Phys. Express **5**, 073002 (2012).
[3] S. Kasai et al., Appl. Phys. Lett. **104**, 092408 (2014).
[4] S. Hirayama et al., Appl. Phys. Express **11**, 013002 (2018)