Waveguide structure effect and spin transparency in spin-torque ferromagnetic resonance measurements

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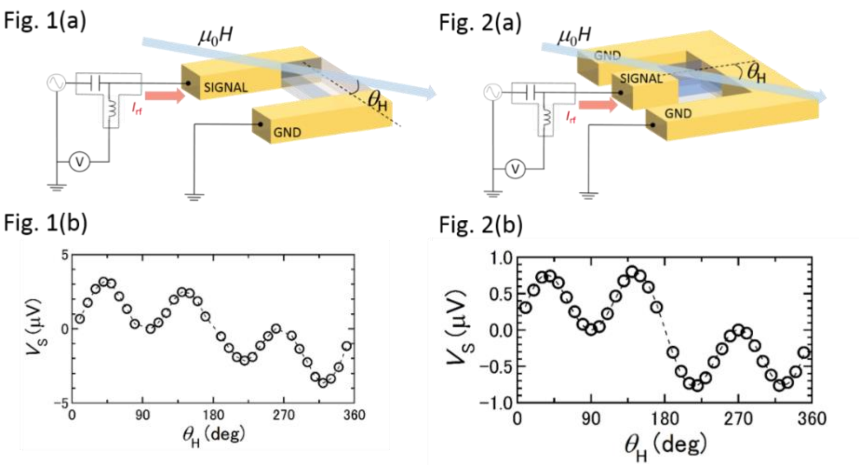
Spin current, a flow of spin-angular momentum without net charge, is intriguing from the view points of fundamental physics as well as applications for future spintronics devices. The spin current can be generated by the spin Hall effect (SHE) via spin-orbit coupling in materials. Therefore, it is so important to evaluate the spin Hall angle (SHA) associated with the SHE, which determines the conversion efficiency between charge and spin currents.

Spin-torque ferromagnetic resonance measurement (ST-FMR) [1] is one of the useful techniques for probing the SHE in the materials. This measurement allows us to investigate the SHA or spin-torque efficiency of the materials. In the measurement, radio-frequency (rf) current for inducing the FMR is injected into the sample from a signal generator through a waveguide.

Although the ST-FMR is an established technique, if the fabricated waveguide is imperfect, the detected signal contains parasitic components. For instance, when we perform this measurement by using a Ground-Signal (GS) waveguide structure device consisting of Co/Pt bilayer strip as shown in Fig 1(a), the extra components appear such as Fig 1(b). Normally only $\sin 2\theta \cos\theta$ component should appear in the field-angular dependence. On the other hand, we don't observe the extra components by using a Ground-Signal-Ground (GSG) waveguide like Fig 2(a), as shown in Fig 2(b). We found that the extra components observed in the GS waveguide structure come from extra *x*- and *z*- rf Oersted fields due to the waveguide imperfection.

Based on the signals by the GSG waveguide structure, we can extract the SHA precisely. Actually we directly obtain not SHA but spin-torque efficiency from the measurement. For the evaluation of SHA, we have to consider spin transparency at the interface between Co and Pt. In this presentation, we discuss the method for extracting the SHA of the materials through the ST-FMR measurement.

[1] L. Liu, T. Moriyama, D. C. Ralph, and R. A. Buhrman, Phys. Rev. Lett. **106**, 036601 (2011).



ST-FMR measurement setup by GS waveguide (Fig. 1(a)) or GSG waveguide (Fig. 2(a)).

Field-angular dependence of the detected symmetric voltage measured by GS waveguide (Fig. 1(b)) or GSG waveguide (Fig. 2(b)).

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