Origin of the background signal in spin torque ferromagnetic resonance

Kyoto Univ. [1] **°Motomi Aoki**[1]**, Yuichiro Ando**[1]**, Ei Shigematsu**[1]**, Ryo Ohshima**[1]**, Teruya Shinjo**[1]**, Masashi Shiraishi**[1]

E-mail: aoki.motomi.53r@st.kyoto-u.ac.jp

Spin-torque ferromagnetic resonance (ST-FMR) has been widely used for estimation of the spin Hall angle (SHA) of a nonmagnetic material (NM) [1]. Figure 1 shows a typical measurement setup for the ST-FMR. DC voltage, V_{DC}, in a NM/ferromagnetic metal (FM) bilayer structure is measured under microwave irradiation. When we plot V_{DC} as a function of external magnetic field, B_{ext}, V_{DC}-B_{ext} curve is sum of symmetric and anti-symmetric Lorentzian functions around the ferromagnetic resonance (FMR) field. By analyzing this resonance curve, SHA can be quantitatively estimated.

Whereas most researches using ST-FMR have focused on the V_{DC}-B_{ext} curve only around the FMR condition, background (BG) signals in the ST-FMR have been neglected because it does not affect curve fitting of the resonance spectrum. Figure 2 shows the V_{DC}-B_{ext} curve of a W(6 nm)/Co(1 nm) sample with microwave power, P_{MW} = 5 dBm, and microwave frequency, f_{MW} = 9 GHz. Large BG signal whose polarity changes with respect to the magnetization direction was observed. From B_{ext}, P_{MW}, f_{MW}, θ, temperature, and NM dependences, we conclude that the BG signal is produced by the spin-dependent unidirectional spin hall magnetoresistance [2], origin of which is the spin Hall effect of the NM and spin-dependent electron mobility of the FM [3]. Therefore, analysis of the BG signal also gives the value of the SHA, which enables effective crosscheck for estimation of the SHA using the ST-FMR method. In addition, given that the BG signal is proportional to y component of the magnetization, spin-orbit torque (SOT) magnetization switching can be detected. Figure 3 shows the signal of the SOT magnetization switching detected by using the BG signal. After initializing magnetization by large external magnetic field, B_{SET}, we measured difference in the BG signal, ΔV_{BG}, between before and after injecting pulse current. A clear hysteresis with a threshold current density, J_{PLS}, of 3×10^7 A/cm^2 was observed, which is consistent with the previous research on SOT switching via the spin Hall effect of W detected by using a magnetic tunnel junction [4].

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[3] C. O. Avci *et al*., Nat. Phys. **11**, 570 (2015). [4] C. F. Pai *et al*, Appl. Phys. Lett. **101**, 1222404 (2012).

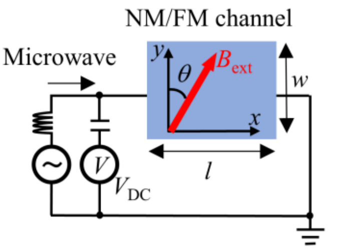

Fig. 1. A schematic of the device and the electrical circuit.

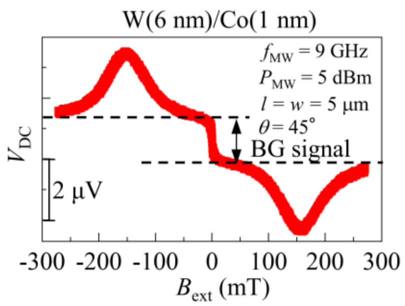

Fig. 2. ST-FMR spectra with the BG signal for W/Co device.

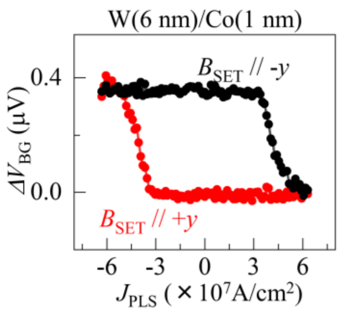

Fig. 3. SOT switching of Co detected by the BG signal.