Angle resolved second harmonic technique for precise evaluation of spin orbit torque in strong perpendicular magnetic anisotropy systems

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Spin-orbit torque (SOT) originated from the spin Hall effect has been attracted much attention because it can manipulate magnetization with ultra-low power consumption (~fJ), which is a promising feature for next-generation spintronic devices. For the development of SOT devices, it is essential to quantitatively evaluate the spin Hall angle θ_{SH}, which represents the strength of the spin Hall effect. A low field second harmonic technique has been used for quantitative evaluation of SOT thanks to its simple experimental setup and high throughput [1]. However, the low field second harmonic method cannot distinguish SOT from various magneto-thermoelectric effects (MTEs) caused by a temperature gradient, such as the normal Nernst effect (ONE), anomalous Nernst effect (ANE), and spin Seebeck effect (SSE). Although a high field second harmonic method can distinguish SOT from MTEs, an external magnetic H_{ext} larger than the effective anisotropy field $H_{\mathrm{k}}^{\mathrm{eff}}$ is required, which makes it difficult to apply to strong perpendicular magnetic anisotropy (PMA) systems.

Here, we propose a generalized angle-resolved second harmonic method that can disentangle SOT from ANE, SSE, and ONE. In our angle-resolved method, we measure the second harmonic Hall resistance $R_{\mathrm{xy}}^{2\omega}$ while varying the polar angle of magnetic field θ_{H} at various H_{ext}. When θ_{H} is small, $R_{\mathrm{xy}}^{2\omega}$ linearly varies with θ_{H}, and the value of its slope divided by $|H_{\mathrm{ext}}|$ is given by the polynomial function of $|H_{\mathrm{ext}}| + H_{\mathrm{k}}^{\mathrm{eff}}\ ^{-1}$. Then, ONE, ANE+SSE, and SOT can be extracted from the coefficients of 0th, 1st, and 2nd order terms, respectively. To demonstrate that the angle-resolved method can accurately evaluate θ_{H} in a strong PMA system, we fabricated BiSb (10 nm) / CoPt (1.6 nm) stacks by magnetron sputtering. Here, $H_{\mathrm{k}}^{\mathrm{eff}}$ of CoPt layer is 9.9 kOe. Fig.1 shows a result of our angle-resolved second harmonic measurements. We obtained $\theta_{\mathrm{SH}}^{\mathrm{eff}}$ of 4.7 from the polynomial fitting. We also carried out measurements using the low field method, from which we obtained $\theta_{\mathrm{SH}}^{\mathrm{eff}}$ of 4.6 after subtracting MTEs estimated from the angle-resolved method. These results indicate that our angle-resolved method can disentangle SOT and MTEs and accurately evaluate $\theta_{\mathrm{SH}}^{\mathrm{eff}}$ in strong PMA samples [2].

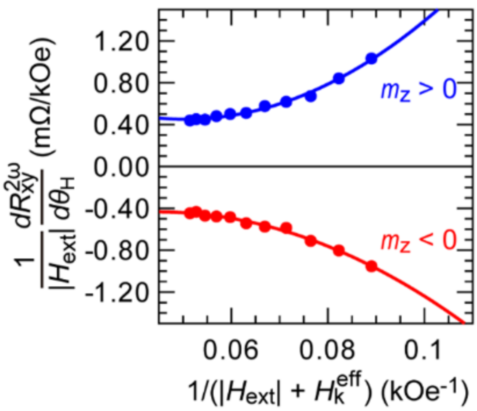

Fig. 1. $|H_{\mathrm{ext}}|^{-1} dR_{\mathrm{xy}}^{2\omega}/d\theta_{\mathrm{H}}$ **as a function of** $|H_{\mathrm{ext}}| + H_{\mathrm{k}}^{\mathrm{eff}}\ ^{-1}$ **measured with an alternative current of 3.4 mA in BiSb / CoPt heterostructure.**

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References:

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