Precise analysis of angle-dependent spin-orbit torque for electrodeposited CoPt thin film by integrating the low and high field second harmonic Hall measurements

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Magnetic nanopillars with a high aspect ratio are desired for three-dimensional domain wall motion memory [1]. In terms of the fabrication process, one of the most promising methods is to fill μm deep holes with magnetic materials such as CoPt by electrodeposition. We have established the electrodeposition technique for deposition of the CoPt ultrathin films exhibiting strong perpendicular magnetic anisotropy (PMA) with adjustable magnetic properties across various composition [2]. Additionally, spin-orbit torque (SOT) applied to the magnetization (***m***) of the CoPt film was demonstrated with the low-field 2nd harmonic Hall measurement [3]. In this study, a high-field method [4] is introduced to distinguish SOT from thermal effect signals to determine spin Hall angle (SHA). Additionally, we reanalyze previous low-field results together with the high-field model using general expression of SOT [5], revealing angle-dependent SOT effective field. This combined approach enables a precise evaluation of the SHA, suggesting the self-SOT in the CoPt.

Figure 1(a) shows experimental setup. We carried out a high-field harmonic Hall measurement with H_{ext} much larger than the effective anisotropy field of the CoPt film. The obtained signals and fitting curves are shown in Fig. 1(b). The experimental data are reproduced by fitting curve, indicating successful separation of SOT from the thermal effect. Using the combined approach, we evaluated the damping-like fields (H_{DL}) considering the angle dependence of ***m*** [5] as shown in Fig. 1(c). H_{DL} exhibits angle dependence of ***m***. The difference of H_{DL} for ***m***//x and ***m***//z are significant compared to a reported value [5], implying self-SOT [6]. Based on these H_{DL} values, the SHA are determined to be 0.19 (***m***//z) and 0.25 (***m***//x), surpassing that of Pt, suggesting the existence of self-SOT of the CoPt layer.

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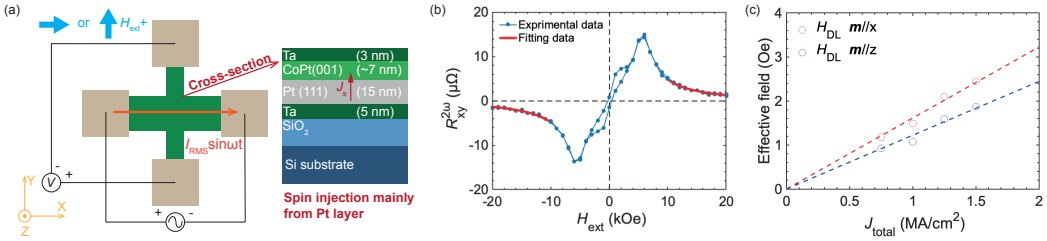

Fig. 1. (a) Stack structure of the Hall bar. (b) High field fitting results. (c) H_{DL} with angle dependence of ***m***. The current density J_{total} is calculated with the area of the cross-section of the entire stack.