Quantitative characterization of current-induced spin-orbit torques in a perpendicularly magnetized GaMnAs single film

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Magnetic random-access memory (MRAM) is a promising candidate for next-generation universal memory, which can realize higher storage capacity, faster operation and non-volatility. Electrical control of magnetization by the current-induced spin-orbit torque (SOT) has been intensively studied, because it can lead to low-power magnetization switching in MRAM. We have recently demonstrated efficient full SOT magnetization switching in single-layer GaMnAs films with perpendicular magnetic anisotropy (PMA)[1]. By suppressing the field-like torque contribution, the critical switching current density J_c can be decreased to 4.6×10^4 A/cm^2, which is three orders of magnitude lower than J_c in typical metal multilayer systems[2,3]. However, it still remains an unsolved problem to quantify the SOT components in the single-layer GaMnAs.

Here we report the quantitative characterization of the SOT effective fields in a perpendicularly magnetized GaMnAs single layer by using harmonic Hall measurements. We grew a $(Ga_{0.9}Mn_{0.1})As$ (7 nm) / InGaAs (500 nm) heterostructure on a GaAs (001) substrate by molecular beam epitaxy, and patterned Hall bars with 5 μm × 20μm for Hall measurements. The current flows mostly in the GaMnAs layer. The first and second harmonic Hall voltages (V_ω and $V_{2\omega}$) were measured by sweeping an external field H_{ext} nearly in the film plane with a tilting angle θ_H of 84° (with respect to the perpendicular axis). Firstly, the anisotropy field (H_{an}) was estimated to be 20.3 kOe by the first harmonic Hall signals, as shown in Fig. 1a. The tilting angle of the magnetization, θ can be estimated from the result shown in the inset of Fig. 1a by θ = arccos ($V_\omega/V_{\omega,\,sat}$), where the $V_{\omega,\,sat}$ is the saturated V_ω. Secondly, the $V_{2\omega,\,\parallel}$ and $V_{2\omega,\,\perp}$ were measured in the longitudinal (Fig. 1b) and transverse (Fig. 1c) schemes, where the in-plane component of H_{ext} is parallel and perpendicular to the applied current, respectively. Based on the results, the damping-like and filed-like fields (H_{DL} and H_{FL}) are estimated to be 17.2 Oe and 7.1 Oe at 10 K, respectively. Therefore, the total SOT field per unit current density (χ) can be estimated as 170.1 Oe/(10^6 A/cm^2), which is one order of magnitude higher than that in typical metal multilayer systems[3]. Figure 1d shows the temperature (T) dependence of χ, indicating that the χ_{DL} and χ_{FL} decrease with the increase in T. Our results will promote the understanding of the SOT mechanism in a single-layer GaMnAs with PMA and enhance the efficiency of magnetization switching.

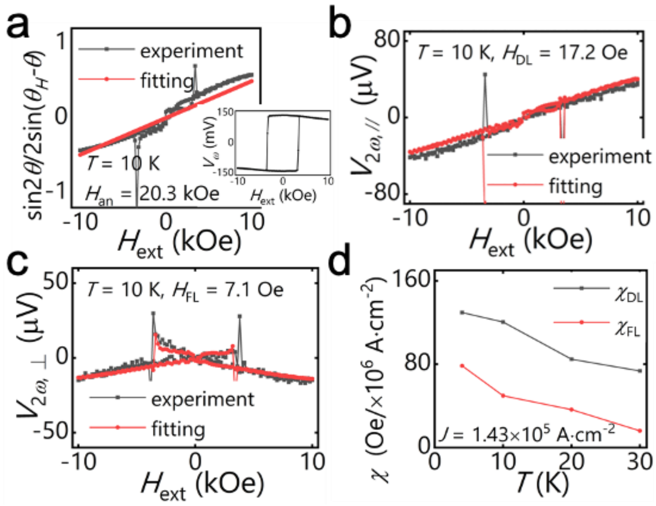

Fig.1. Quantitative characterization of SOT effective fields in a perpendicularly magnetized GaMnAs single layer.

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