Spin-orbit torque strength and efficiency in a perpendicularly-magnetized ferromagnetic semiconductor GaMnAs single thin film

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Spin-orbit torque (SOT) magnetization switching, which is induced by a spin current generated by a charge current, is a promising phenomenon that can be used to improve the performance of magnetoresistive random access memory. In the conventional SOT systems, the magnetization reversal is based on the spin current injection from the adjacent paramagnetic layer with a large spin Hall angle, which results in a low switching efficiency limited by the interface. Recently, in order to increase the switching efficiency, SOT switching has been achieved in a single ferromagnetic layer, such as in a topological insulator using the surface state[1] and the ferromagnetic semiconductor GaMnAs using the field-like torque[2] or the damping-like torque[3].

Here, we quantitatively evaluated the SOT strength in a perpendicularly magnetized ferromagnetic semiconductor GaMnAs with the equivalent magnetic field ($\boldsymbol{H}_{\mathrm{equi}}$)[4] as shown in Fig. 1. The Hall resistance (R_{H}) is measured at 40 K with a current of ±0.3 mA applied along the $[\bar{1}10]$ direction and a fixed external magnetic field ($\boldsymbol{H}_{\mathrm{ext}}$) of 500 Oe applied at an angle β from the $[\bar{1}10]$ direction in the *y*-*z* plane. Since the magnetization switching is motivated by a combination of the SOT effect and the *z* component of $\boldsymbol{H}_{\mathrm{ext}}$, there appears an obvious opposite horizontal shift for the positive and negative current. Based on this horizontal shift, the magnitude of $\boldsymbol{H}_{\mathrm{equi}}$ is calculated to be 84.6 Oe and the efficiency is estimated to be 99 [Oe/(10^6 A/cm^2)], which is almost *two orders of magnitude lager* than that in the Pt/Co bilayer system, indicating that very efficient magnetization switching is realized in GaMnAs.

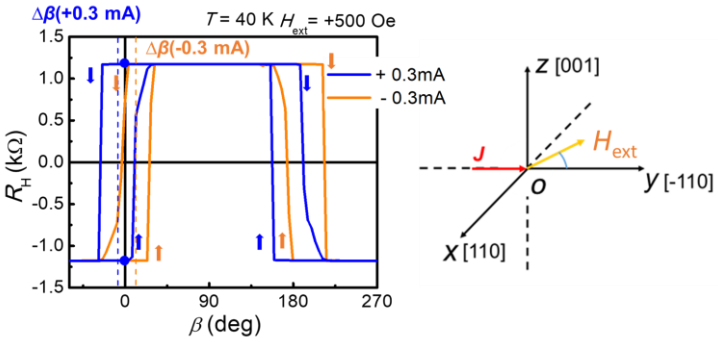

Fig. 1 Anomalous Hall effect measured with rotating H_y of 500 Oe in the *y*-*z* plane and applying *J* of ±0.3 mA at 40 K.

Our work demonstrated the high efficiency of the SOT switching in a perpendicularly-magnetized GaMnAs quantitatively, which will facilitate the development of SOT devices for practical applications.

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1. Y. Fan *et al. Nature Nanotech.* **11**, 352 (2016).
2. A. Chernyshov *et al. Nature Phys.* **5**, 656 (2009).
3. M. Jiang, H. Asahara, S. Sato, T. Kanaki, H. Yamasaki, S. Ohya and M. Tanaka, submitted; JSAP Fall Meeting, 20a-131-2, Nagoya, September 2019.
4. P. Zhang *et al. Phys. Rev. B* **97**, 214403 (2018).