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Highly efficient spin-orbit torque switching in a single GaMnAs thin film with perpendicular magnetic anisotropy

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Abstract

Spin-orbit torque (SOT) enables an innovative method of manipulating the magnetization of ferromagnets by means of current injection, which is facilitating the development of high-density information storage devices with low power consumption. In this work, we demonstrate highly efficient full SOT switching achieved by applying a current in a *single layer* of perpendicularly magnetized ferromagnetic semiconductor GaMnAs with an extremely small current density of ~3.4×10^5 A/cm^2, which is two orders of magnitude smaller than that needed in typical metal bilayer systems. The switching efficiency obtained by measuring the equivalent magnetic field is estimated to be 99 [Oe/(10^6 A/cm^2)], which is almost *two orders of magnitude lager* than that in Pt/Co bilayer systems. Our results offer a new possibility for achieving more efficient electrical control of magnetism, which advances the development of SOT switching devices for practical applications[1].

1. Introduction

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, there are basically two functional layers, one of which is the ferromagnetic layer and the other one is the paramagnetic layer with a large spin Hall angle to generate spin current and inject it into the adjacent magnetic layer. Then the spin current exerts a torque on the magnetic moment and reverses it[2, 3]. Therefore, the switching efficiency should be strongly limited by the interface quality between the two layers and the intrinsic character of the non-magnetic layer. In the typical metal systems, the critical switching current density is usually in the order of 10^7 A/cm^2 [3-5]. To increase the switching efficiency, the achievement of interface-free SOT switching in a single layer is one of the options.

2. Results

Here, we report a highly efficient full SOT switching by applying a current with a density J_c of 3.4×10^5 A/cm^2 in a *single* layer of perpendicularly magnetized ferromagnetic semiconductor GaMnAs[1], as shown in Fig. 1. With the intrinsic bulk inversion asymmetry of the zinc-blende crystal structure, the intrinsic spin-orbit interactions couple the hole spin with its momentum. This generates the Dresselhaus effective magnetic field[6], which induces an in-plane component of hole's spin in the GaMnAs thin film. Then, the in-plane spin component exerts a torque on the magnetic moment of the GaMnAs thin film. We have achieved the magnetization reversal just by driving a current in a single ferromagnetic GaMnAs layer, with two orders of magnitude smaller J_c than that reported so far in metallic bilayer systems.

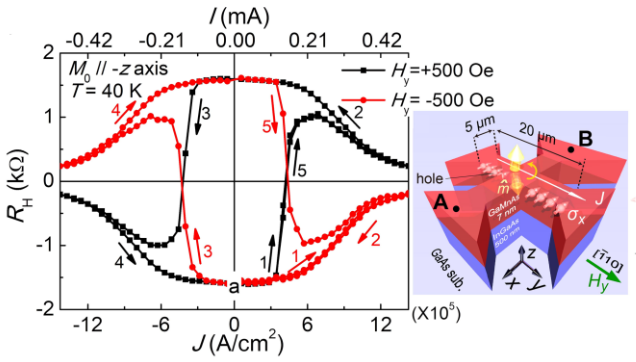

Fig. 1 SOT switching with a magnetic field H_y of ±500 Oe along the current direction, $[\bar{1}10]$, at 40 K and schematic illustration of the device structure. Here, R_H is the Hall resistance.

The SOT strength in the GaMnAs single layer is evaluated with the equivalent magnetic field ($\boldsymbol{H}_{equi}$)[7] as shown in Fig. 2. 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 ($\boldsymbol{H}_{ext}$) 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 $\boldsymbol{H}_{ext}$, there appears an obvious opposite horizontal shift for the positive and negative currents. Based on this horizontal shift, the magnitude of $\boldsymbol{H}_{equi}$ is estimated to be 84.6 Oe and the efficiency of the equivalent field, $\chi = H_{equi} / J_c$, 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 systems, indicating that very efficient magnetization switching is realized in GaMnAs.

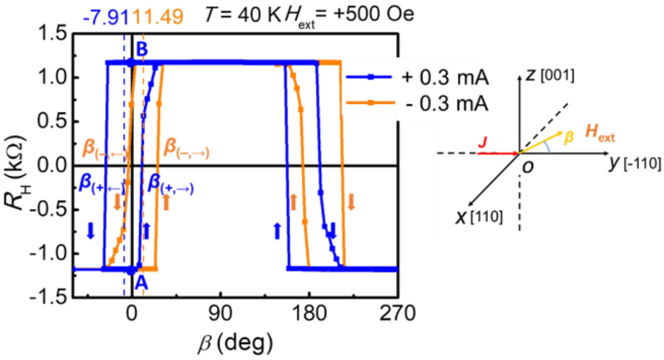

Fig. 2 Anomalous Hall effect measured with a current of ±0.3 mA and an external field of 500 Oe applied at an angle β from the $[\bar{1}10]$ direction in the *y-z* plane.

3. Conclusions

We have found that SOT switching can be achieved in a single-crystalline ferromagnetic semiconductor GaMnAs layer with an extremely small current density of ~3.4×10^5 A/cm^2. The high switching efficiency, which is *two orders of magnitude lager* than that in the Pt/Co bilayer systems, has been obtained. Our results provide us with guidance in selecting appropriate materials and offer a new possibility for achieving more efficient electrical control of magnetism, which will facilitate the development of SOT switching devices for practical applications.

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