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Magnetization switching induced by in-plane current with low density in Pt/Co/Pt sandwich

W. W. Lin, H. Sang,[a] D. Liu, Z. S. Jiang, A. Hu, and X. S. Wu
National Laboratory of Solid State Microstructures, Department of Physics, Nanjing University, Nanjing 210093, China and Jiangsu Provincial Laboratory for Nanotechnology, Nanjing University, Nanjing 210093, China

G. Xiao
Department of Physics, Brown University, Providence, Rhode Island 02912

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We have observed that the extraordinary Hall resistance of Pt/Co/Pt sandwich with perpendicular magnetic anisotropy changes from positive to negative drastically as the current density increases in an applied field, indicating the magnetization switching induced by the current. There exists a critical current density that changes for the different applied field with the order of current density of 10^4 A/cm^2, which is much lower than that reported in literatures on the current-induced magnetization switching. The results of the extraordinary Hall effect of the sample in different in-plane current density show that the magnetization-switching field decreases with the increment of current density when the current density is larger than 10^4 A/cm^2. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2175822]

I. INTRODUCTION

Current-induced magnetic response is an interesting topic in physics, which has attracted much attention for many years. In 1984, Berger[1] proposed that there exists an interaction between a magnetic domain wall and an electric current. The ferromagnetic domain wall can be driven to move when a large pulsed current crosses it.[1–4] In 1996, Slonczewski[5] predicted another response, which was characterized as spin transfer. For a large electric current density flowing perpendicular to two magnetic layers spaced by a nonmagnetic layer, a steady precession could be driven, and even the magnetization switching could take place.[5] Spin wave emission[6] and magnetization switching[7–10] have been experimentally observed in magnetic multilayers,[6,7] spin valve,[8] and magnetic tunneling junction,[9] using point contact[6,10] or patterned structure.[7–9] All these experiments were carried out with magnetic field along the sample plane while the current is perpendicular to the plane with the current density above 10^6 A/cm^2 generally.[8]

Usually, the magnetoresistance (MR) effect has been used to detect current-induced magnetic response.[2,6–10] In the sample with perpendicular magnetic anisotropy (PMA), however, extraordinary Hall effect (EHE) is a good way to detect current-induced magnetic response due to its sharp and large changes at switching field. In this paper, we address the magnetic response induced by an in-plane dc in Pt/Co/Pt sandwich with PMA using EHE.

II. EXPERIMENTS

The Pt/Co/Pt sandwich samples were prepared at room temperature using a computer controlled dc magnetron sputtering system with high vacuum. The background pressure was 1.2×10^{-8} Torr and the operating Ar pressure was about 4 mTorr. A thin amorphous Ta layer with the thickness of about 20 Å was deposited onto the Si(100) substrate first against the affection of the orientation of Si. Then a 40 Å thick Pt bottom layer was grown in order to obtain (111) texture. As well known, (111) texture of Co/Pt multilayer favors PMA. Subsequently, 4.8–5.0 Å thick Co was deposited. Finally a 20 Å thick Pt layer capped the film. During deposition, the rates of both Co and Pt were 0.22 and 0.35 Å/s, respectively.

The extraordinary Hall effect of the sample was measured in physical properties measurement system (PPMS, Quantum Design) at low temperature with a sample size of 5 mm long and 1.5 mm wide. The magnetic field was applied along the normal of the sample plane with the dc in the plane.

III. RESULTS AND DISCUSSION

The extraordinary Hall effect of Pt/Co/Pt sandwich displays square loops when the applied field is perpendicular to the sample plane in all measured temperatures. At 5 K, the hysteresis loop measured using superconducting quantum interference device (SQUID) shows that the magnetization-switching field H_{sw} is about ±1735 Oe. When saturating the sample in the positive field and then demagnetizing it to a fixed field of −1710 Oe, which was a little bit smaller than its H_{sw}, we measured the Hall resistance with the current from 0.01 mA (current density $J\approx10^3$ A/cm^2) to 5 mA ($J=4.83\times10^4$ A/cm^2). From Fig. 1, one can find that the Hall resistance decreases slowly from its positive maximum with increasing the current in the region of 0.01–1.8 mA and then drops quickly to zero at about 2.8 mA. With further increment of the current, the Hall resistance goes down to its negative maximum. The result shows clearly that the Hall

[a]Author to whom correspondence should be addressed; electronic mail: haisang@nju.edu.cn

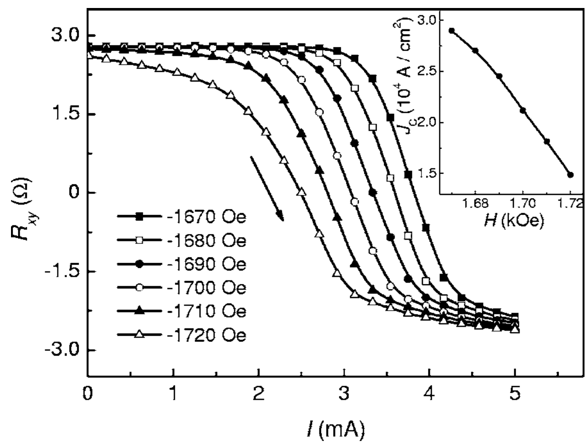

FIG. 1. The dependence of extraordinary Hall resistance of Pt/Co/Pt sandwich on the current in different applied fields at 5 K. Inset shows the critical current density as a function of the applied field. The solid line guides the eyes.

resistance varies with the current and changes its sign. The positive Hall resistance corresponds to a small current and negative one to a larger current in a fixed field. The sign change of the Hall resistance shows the reverse of magnetization in the sample because the Hall resistance is proportional to the magnetization, indicating that the dc can induce magnetization to switch. As shown in Fig. 1, the behavior of the extraordinary Hall resistance varying with the current in Pt/Co/Pt sandwich for different fixed fields is similar. One can see that there exists a critical current density J_C in which the Hall resistance begins to go down drastically, and J_C is reduced with the increment of a fixed field, as shown in the inset of Fig. 1.

Figure 2 shows a series of extraordinary Hall resistance of the Pt/Co/Pt sample measured in a different current at 5 K. When the sample was measured in a small current of 0.1 mA, magnetization switching appears in an applied field of −1735 Oe, which is consistent with its hysteresis loop measured at 5 K. However, magnetization switches at $H_{sw} = -1711$ Oe in the case that the current is 2 mA ($J = 1.93 \times 10^4$ A/cm^2), which is ahead of that in 0.1 mA. The results show that the magnetization-switching field is reduced with

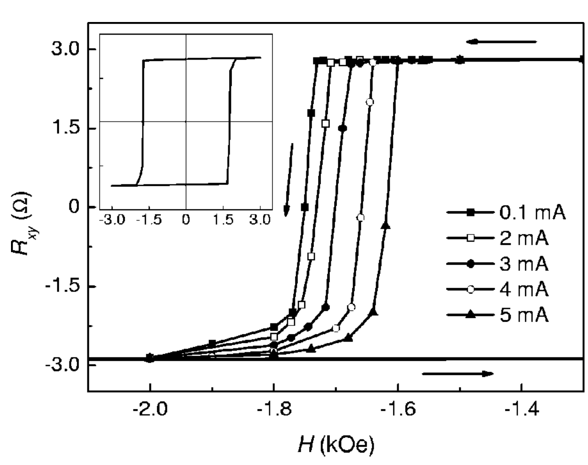

FIG. 2. The extraordinary Hall effect (a part of left half loop) of Pt/Co/Pt sandwich measured in different current at 5 K. The inset shows the whole loops of Hall effect measured at 0.1 mA.

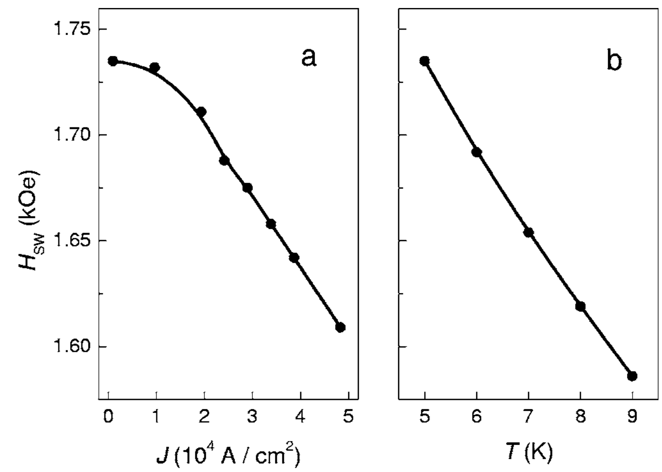

FIG. 3. The dependence of the magnetization-switching field on the current density (a) and temperature (b).

the increment of current density [shown in Fig. 3(a)], when the current density is larger than 10^4 A/cm^2. The variation in the magnetization-switching field is at the rate of about 27 Oe/mA. Those results are helpful to understand the behaviors shown in Fig. 1. As seen from Fig. 2, for example, in an applied field of −1700 Oe, the extraordinary Hall resistance has a positive maximum value when the current is 0.1 mA, but it changes its sign to a negative in 5 mA in the same field. So it shows that the extraordinary Hall resistance depends on the current for an applied field, indicating that the magnetizing state in the sample is different for the different current.

It is well known that the magnetization becomes unstable due to the thermal effect. When a large current flows in a very thin film, it is inevitable that a notable temperature rises due to the current. We have measured the extraordinary Hall effect in different temperatures. It can be seen from Fig. 3(b) that the value of magnetization-switching field is 1735 Oe in 5 K, but 1586 Oe in 9 K, indicating that the magnetization-switching field decreases with increasing temperature. It suggests that the behavior of current-induced magnetization switching in Pt/Co/Pt sample associates with the temperature rising induced by the current.

The decrement of magnetization-switching field with increasing temperature at a small current density is similar to its dependence on the current density at a fixed temperature. By comparing the dependence of magnetization-switching field on current density to that on temperature, we can estimate that the increment of temperature is about 3.5 K when the current density reaches 4.8×10^4 A/cm^2. The energy that comes from the current can make the temperature of the sample goes up, which leads the magnetization of the sample unstable due to the thermal effect.

It should be noted that the behaviors of current-induced magnetization switching in our Pt/Co/Pt sample are different from those of spin transfer effect. In spin transfer, current perpendicularly flows to two magnetic layers spaced by a nonmagnetic one and magnetic response is due to spin torque. The current density was more than 10^6 A/cm^2 (Ref. 8) in current-driven magnetization-switching experiments, mostly in the order of 10^7–10^8 A/cm^2. In our experiments, however, the behaviors of current-induced magnetization switching appear even in a single magnetic layer with the current density of 10^4 A/cm^2, which is two or three orders lower than that in current-driven magnetization-switching experiments.

IV. CONCLUSIONS

In summary, we have observed that the extraordinary Hall resistance of Pt/Co/Pt sandwich with perpendicular magnetic anisotropy changes from positive to negative drastically as the increment of current density in a fixed field, indicating the magnetization switching induced by the current. The critical current density varies for different field with the order of current density of 10^4 A/cm^2. The extraordinary Hall effect of the sample in different current density shows that the magnetization-switching field decreases as the increment of current density when the current density is larger than about 10^4 A/cm^2. In this current density, our results show that the current can lead a little bit increment of the sample temperature and affect the magnetization stability in the sample. Therefore, the change of sample temperature induced by the current should be taken into account for current-induced magnetization switching.

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[1] L. Berger, J. Appl. Phys. **55**, 1954 (1984); Phys. Rev. B **33**, 1572 (1986).
[2] C. Y. Hung and L. Berger, J. Appl. Phys. **63**, 4276 (1988); E. Salhi and L. Berger, *ibid.* **76**, 4787 (1994).
[3] A. Yamaguchi, T. Ono, S. Nasu, K. Miyake, K. Mibu, and T. Shinjo, Phys. Rev. Lett. **92**, 077205 (2004).
[4] G. Tatara and H. Kohno, Phys. Rev. Lett. **92**, 086601 (2004).
[5] J. C. Slonczewski, J. Magn. Magn. Mater. **159**, L1 (1996); **195**, L261 (1999).
[6] M. Tsoi, A. G. M. Jansen, J. Bass, W. C. Chiang, M. Seck, V. Tsoi, and P. Wyder, Phys. Rev. Lett. **80**, 4281 (1998).
[7] E. B. Myers, D. C. Ralph, J. A. Katine, R. N. Louie, and R. A. Buhrman, Science **285**, 867 (1999); J. A. Katine, F. J. Albert, R. A. Buhrman, E. B. Myers, and D. C. Ralph, Phys. Rev. Lett. **84**, 3149 (2000).
[8] Y. Jiang, S. Abe, T. Ochiai, T. Nozaki, A. Hirohata, N. Tezuka, and K. Inomata, Phys. Rev. Lett. **92**, 167204 (2004).
[9] Y. Liu, Z. Zhang, P. P. Freitas, and J. L. Martins, Appl. Phys. Lett. **82**, 2871 (2003).
[10] T. Y. Chen, Y. Ji, C. L. Chien, and M. D. Stiles, Phys. Rev. Lett. **93**, 026601 (2004).