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Electrical Control of Magnetic Properties in Pt/Co/AlOx films

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1. Introduction

Where methods of magnetization control by applied magnetic fields fall short in efficiency and power consumption for nanoscale devices, control via electric fields or currents has provided a promising alternative. Several experiments demonstrate the control of coercivity [1], curie temperature [2] as well as magnetization orientation switching by electrical methods [3], [4]. In this experiment we demonstrate changes in magnetic coercivity in a Pt (3 nm) / Co (0.6 nm) / AlOx (1 nm) film with an increasing applied current and applied gate voltage.

A ferromagnetic film consisting of a thin layer of Co deposited on a Pt layer exhibits a strong uniaxial perpendicular magnetic anisotropy (PMA), owing to the stress induced anisotropy between Pt and Co [5]. Another benefit of thin Co layers (< 1 nm) is preserving electric fields within the layer originating intrinsically by structural inversion asymmetry or extrinsically by gate voltage. One application of electric field based magnetization control is the Rashba effect where conduction electrons traveling through an electric field feel an effective magnetic field proportional to the vector product of its momentum and the electric field [6], [7]. The electric fields for the Rashba effect can be further enhanced by an applied gate voltage which also offers the flexibility of modulating the magnetization through the electronic structure of localized electrons [8], [9]. In this experiment we investigate the effects on magnetization in Pt/Co/AlOx films by the Rashba effect as well as a modulated electronic structure by the gate voltage.

2.) Experiment and Discussion

Pt 3 nm Co 0.6 nm and AlOx 1 nm were deposited in that order by ion beam sputtering onto an SiO_2 substrate. The film was shaped into an 80 μm × 20 μm rectangle through photolithography and several etching processes. An additional 20 nm of AlOx was deposited by atomic layer deposition before an Au electrode was deposited by electron beam evaporation directly on top of the Pt/Co Hall bar. A second device was fabricated into a 500 μm long and 2 μm width cross by electron beam lithography as lower dimensions are required to achieve a quasi 1D current to enhance the Rashba effect. No gate electrode was deposited on this device, thus the electric field re-

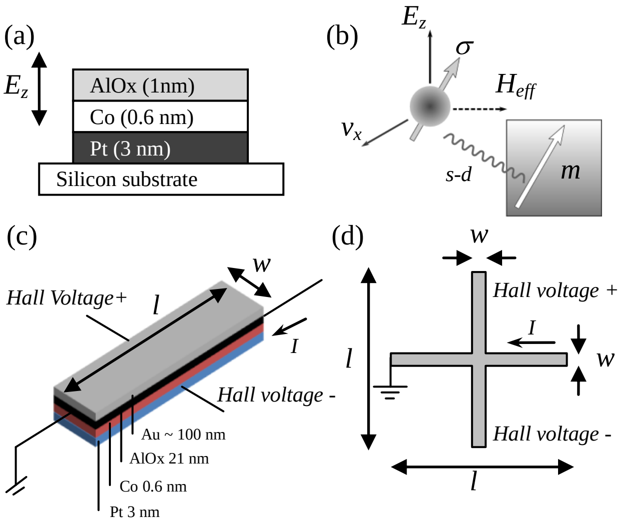

Fig 1: (a) Structure of the magnetic film by ion beam sputtering. Electric fields as well as magnetization exist normal to the plane. (b) Rashba effect and s-d exchange interaction coupling with local magnetization. (c) Hall bar structure used to measure the applied gate voltage effects. From bottom to top, the Hall bar is composed of the Pt (3 nm) Co (0.6 nm) AlOx insulating layer (20 nm) and an Au (100 nm) gate electrode. l = 80 μm, w = 20 μm. (d) Hall cross structure used to measure the Rashba effect as viewed from the top. with l = 500 μm, w = 2.5 μm.

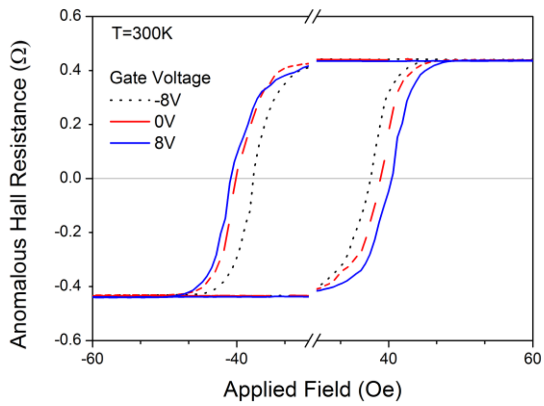

Figure 2: Magnetization measurement of the Hall bar structure.

quired for the Rashba effect would originate from intrinsically through structural inversion asymmetry. In all samples, a magnetic field was applied perpendicular to the film and magnetization was measured by anomalous Hall resistance.

The magnetization in the 20 μm × 80 μm Hall bar structure was measured by applying a 15 μA current at

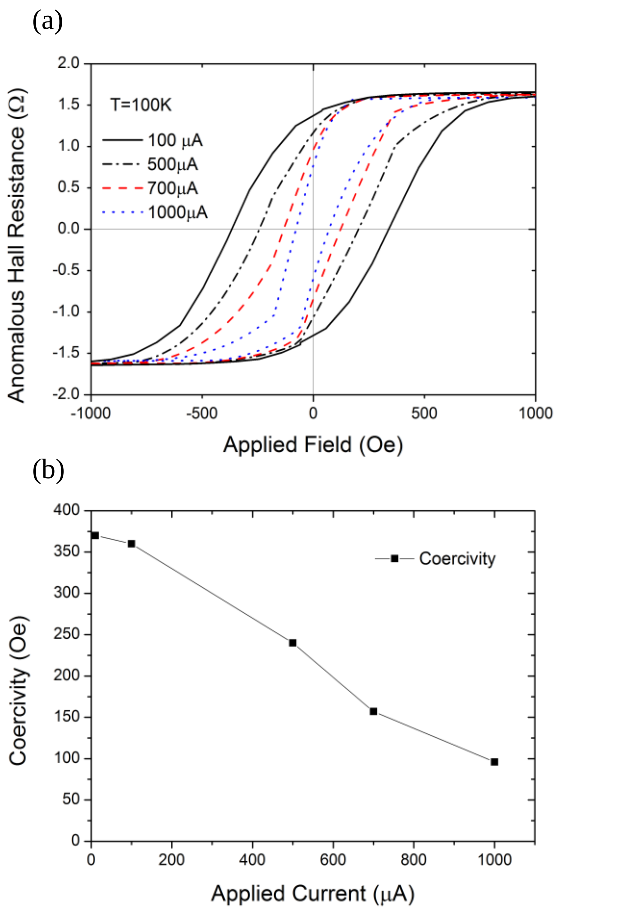

Fig 3: (a) Current dependent coercivity change from 100 μA to 1 mA. (b) Coercivity plotted against applied current for several measured values. Coercivity decreases almost linearly with increasing applied current.

room temperature. This current was sufficient to achieve a decent signal to noise ratio while minimizing effects of Ohmic heating. The electrode above the Pt/Co cross was applied with a positive and negative 8 V which was predetermined to be the maximum permitted voltage before internal discharged occurred. Magnetic coercivity decreased with -8V applied by an average of 1.8 Oe while +8V increased coercivity by 1.2 Oe. The application of a gate voltage alters the surface charge on the cobalt layer leading to a change in the occupied states in the 3d orbitals resulting in a change in perpendicular magnetic coupling [9]. The decrease in coercivity with a negative applied gate voltage is consistent with previous works involving similar films [1], [2], although to a smaller effect. The 1~2 Oe change in our experiment may be limited by the dielectric constant and maximum voltage permitted in a 20 nm layer of AlOx. In addition, previous experiments [1] demonstrate the importance of the interface between the metal and insulator for gate electrode modulation which may have been suppressed in the present study since no annealing was performed on any of the samples.

In the hysteresis measurement for the cross structure, a decrease in coercivity can be observed with increasing applied current from 100 μA to 1 mA (Fig. 3). One possible reason for this observed phenomena is the increase of the Rashba effect since it is proportional to applied current. In the Hall cross structure, the current is confined to a quasi 1D direction which results in an in-plane effective field perpendicular to the electric field and applied current. An in plane effective field contributes to the demagnetization of perpendicularly magnetized films which may account for the observed decrease in coercivity with increasing current. The decrease in coercivity appears to be linear with increasing applied current which agrees with results obtained in Ta/CoFeB/MgO films [10]. However, another possible cause for the decreases in coercivity is through ohmic heating by high currents which cannot be ruled out entirely by the measurements made to this point. We can distinguish the two causes with further experiments either by applying an electric gate field on the cross due to the dependence of Rashba effect with electric fields, or by performing a hysteresis measurement with a constant in-plane bias field. Furthermore various Hall cross widths and lengths can also be investigated where the Rashba effect is believed to be dependent on. Our next step is to investigate the combination both aspects of gate electrodes and the Rashba effect into a single device and exclusively confirm that the control of coercivity in the Hall cross structure is caused by the Rashba effective field.

3. Conclusions

We have investigated the effects of magnetization by applied gate voltage in a 20 μm × 80 μm Hall bar structure and applied currents in a 2 μm × 500 μm Hall cross structure both fabricated from Pt/Co/AlOx films. Further experiments will be required to confirm the origins.

5.) References

[1] T. Seki, M. Kohda, J. Nitta, and K. Takanashi, Appl. Phys. Lett. **98**, 212505 (2011).
[2] D. Chiba, S. Fukami, K. Shimamura, N. Ishiwata, K. Kobayashi, and T. Ono, Nature Mater. **10**, 11 (2011).
[3] I. M. Miron, *et al.* Nature Mater. **9**, 3 (2010).
[4] I. M. Miron, *et al.* Nature **3,** 8 (2011).
[5] B. Zhang, K. Krishnan, C. H. Lee, and R. F. C. Farrow, J. Appl. Phys. **73**, 6198 (1993).
[6] A. Manchon and S. Zhang, Phys. Rev. B, **79**, 094422 (2009).
[7] A. Manchon and S. Zhang Phys. Rev. B, **78**, 212405 (2008).
[8] C. Ast *et al.* (2007). Phys. Rev. Lett. **98**, 186807 (2007).
[9] M. Tsujikawa and T. Oda, Phys. Rev. Lett **102**, 247203 (2009).
[10] T. Suzuki, S. Fukami, N. Ishiwata, M. Yamanouchi, S. Ikeda, N. Kasai, and H. Ohno, Appl. Phys. Lett. **98**, 142505 (2011).