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Characteristics of perpendicular exchange bias in [Pt/Co]-IrMn multilayers

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1. Introduction

A ferromagnetic (FM) layer coupled with antiferromagnetic (AFM) layer typically exhibits a shift of the hysteresis loop along the magnetic field axis (exchange coupling field; H_{ex}), as well as an increase in the half-width of the loop (coercivity; H_c), when they are field cooled from above the blocking temperature of the AFM or deposited under the presence of the magnetic field [1]. For most FM/AFM bilayers, exchange bias is observed with in-plane anisotropy since this is usually the easy axis of the FM layer due to the strong shape anisotropy. However, recently, exchange bias effects have also been induced along the perpendicular-to-film direction, in both continuous and nanostructured multilayers (MLs). The perpendicular magnetic phenomenon can be quite useful for technological applications in magnetic sensors based on spin valves or magnetic tunnel junctions structure [2]. In this work, for [Pt/Co] ML perpendicular exchange coupled to IrMn, we report on the characteristics of H_{ex} and H_c with the Co thickness (t_{Co}) and with the applied measuring filed (H_a) rotated toward in-plane at angle (θ) from perpendicular-to-plane.

2. Experiment

MLs consisting of Si/SiO_2/Ta(50)/[Pt(15)/Co(t_{Co})]$_4$/IrMn(50)/Ta50 (in Å) were prepared by magnetron sputtering under typical base pressure below 2×10^{-8} Torr at room temperature. Magnetization measurements were performed on a vibrating sample magnetometer (VSM) or an extraordinary Hall voltage measurement system after cooling from 550 K under a field of 2 kOe applied along the perpendicular to film direction. During the angular dependence measurements, the positions of the sample and pick-up coils remained fixed while the H_a was rotated with angular precision better than 0.1°.

3. Results and discussion

Figure 1 shows typical hysteresis loops of the Ta(50)/[Pt(15)/Co(t_{Co})]$_4$/IrMn(50)/Ta50 (in Å) systems measured along the perpendicular to film direction by VSM. The usual inversely proportional relationship between H_{ex} and the FM thickness is only observed for intermediate values of t_{Co}, between 3 and 6 Å, where a relatively large perpendicular effective anisotropy is preserved. The magnitude of H_{ex} and H_c are also maximum for intermediate values of t_{Co}, i.e., H_{ex}=291 Oe for t_{Co}=3 Å and H_c=337 Oe for t_{Co}=4 Å. This is in contrast to most exchange bias systems, where, due to the interfacial character of the FM/AFM interactions,

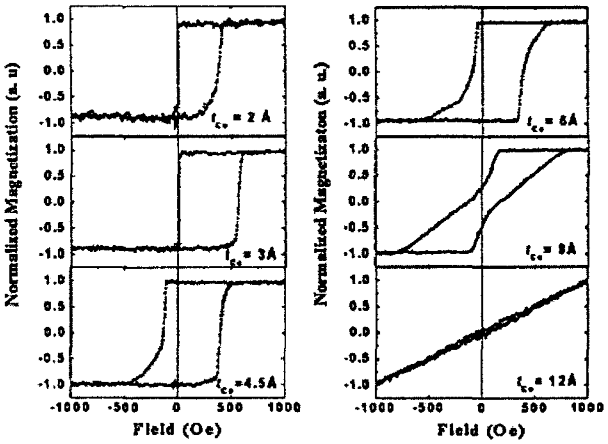

Fig. 1. Co thickness dependence of the hysteresis loops of Ta(50)/[Pt (15)/Co(t_{Co})]$_4$/IrMn(50)/Ta50 (in Å).

H_{ex} is larger for thinner FM layers. For either very thin (≤ 3 Å) or relatively thick (≥ 6 Å) t_{Co}, a decrease of the out-of-plane magnetic effective anisotropy occurs, which drastically reduces perpendicular exchange bias.

The values of the remanence to saturation magnetization ratio (M_R/M_S) are obtained after recentering the loops for the H_{ex}. For intermediate value of t_{Co}, M_R/M_S are also maximum (0.96 for t_{Co}=3 Å) and it drastically drops at larger t_{Co}=8 Å, confirming that the perpendicular anisotropy is lost for exceedingly thick Co layers.

The hysteresis loops were measured with the H_a rotated toward in-plane at an of angle θ (0°, 30°, 60°, 75°, 80°, 82°, 85°, 86° and 90°). The hysteresis loops become asymmetric at intermediate angles (75°~86°) with a shift both along the field axis and along the magnetization axis. At θ=90° only hard-axis hysteresis is observed with no loop shift along either axis. This angular dependence and the asymmetry of the loop with respect to magnetization axis (M=0) can be quantitatively attributed to the demagnetization field and the perpendicular anisotropy energy when the H_a is not in the field cooling direction. In that case, the magnetization aligns with the field direction when the H_a exceeds the saturation field. However, since magnetization easy axis is along the field cooling direction, the magnetization tends to rotate back to the easy axis when the H_a decreases. The perpendicular-to-plane field component of the H_a is $H\cos\theta$. H_{ex} and H_c are obtained at the center of the loop. Thus H_{ex} and H_c both have $1/\cos\theta$ dependence. In angular dependence of H_{ex} and H_c, the solid lines correspond to $H_{ex}(\theta)=H_{ex}(0)/\cos\theta$ and $H_c(\theta)=H_c(0)/|\cos\theta|$, respectively.

In summary, for [Pt(15)/Co(t_{Co})]$_4$/IrMn(50)] system, an unusual peak in FM thickness dependence of exchange bias properties is observed. This is ascribed to a reduction of the perpendicular effective magnetic anisotropy and the concomitant reduction of M_R/M_S for either very small or for large values t_{Co}. Both H_{ex} and H_c show a $1/\cos\theta$ dependence on the angle between the H_a and the perpendicular-to-plane cooling field.

4. References

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