International Journal of Modern Physics B
Vol. 19, Nos. 15, 16 & 17 (2005) 2562–2567

World Scientific
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ANGULAR DEPENDENCE OF MAGNETIC PROPERTIES IN Co/Pt MULTILAYERS WITH PERPENDICULAR MAGNETIC ANISOTROPY

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Received 4 September 2004
Revised 1 December 2004

Dependence of magnetic properties on the angles between the applied magnetic field and the normal of the film plane in Co/Pt multilayer with easy magnetization direction perpendicular to the film plane have been studied. The results show that the sample exhibits unusual magnetization behaviors when an external magnetic field applied in different angle to the normal of the sample plane. The remanence decreases and the saturation field increases with increasing the angle, accompanying the magnetization-switching field and the coercivity enhance. These results suggest that the magnetization process in multilayers with perpendicular magnetic anisotropy (PMA) could not be described simply using coherent rotation model for uniaxial anisotropic ferromagnet.

Keywords: Multilayers; perpendicular magnetic anisotropy; magnetization-switching field.

1. Introduction

Perpendicular magnetic anisotropy (PMA) is an important property of some magnetic multilayers and alloys, which has attracted much attention in the last twenty years for fundamental researches and magnetic information storage applications.[1-15] It can be phenomenologically described as an interfacial magetocystalline anisotropy contribution due to the symmetry breaking at the interfaces.[16] It is known that the anisotropy of the orbital magnetic moment at the interface between ferromagnetic and non-magnetic layers, first suggested by Bruno,[17] contributes to the perpendicular magnetic anisotropy due to the spin-orbit interaction.[10] The spin and orbital magnetic moments at the interfaces have been directly determined using X-ray magnetic circular dichroism (XMCD) in several systems such as Co/Au, Co/Pt multilayer and CoPt alloy.[7-11,13,15]

PMA is known as uniaxial anisotropy. Usually, one can determine the easy magnetization direction by comparing the out-of-plane and in-plane hystersis loops. To

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our knowledge, however, the dependence of magnetic properties on the angle between an applied magnetic field and the normal of the sample plane in the multilayer with PMA has not been studied in details. It is not clear whether the magnetization process in multilayers with PMA behaves similarly as other uniaxial anisotropic system. In this paper, we investigated angular dependence of magnetic properties in Co/Pt multilayer with easy magnetization direction perpendicular to the sample plane. The results show that the sample exhibits unusual magnetization behaviors as changing the angle between an applied magnetic field and the normal of the sample plane.

2. Experiments

The $(Co/Pt)_N$ multilayer samples were prepared at room temperature using a computer controlled DC magnetron sputtering system. The base 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 30Å was deposited onto the Si(100) wafer against the affection of the orientation of Si wafer. Then a 100 Å thick Pt buffer layer were grown in order to obtain (111) texture. As well known, (111) texture of Co/Pt multilayer favors PMA in this system.[5] Subsequently, Co/Pt multilayers with the number of repetition $N = 5$ were deposited. Every period consists of 4.8 Å thick Co and 9 Å thick Pt. The layered structure of the multilayers is confirmed by the small angle X-ray diffraction (XRD). Finally another 20 Å thick Pt layer capped the film for protection. During deposition, the rates for Co and Pt were 0.22 Å/s and 0.35 Å/s, respectively. The magnetic properties were measured using vibrating sample magnetometer (VSM) at room temperature.

3. Results and Discussion

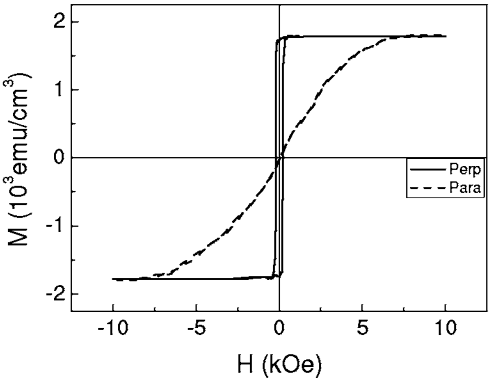

Fig. 1. Hysteresis loops of $[Co(4.8Å)/Pt(9Å)]_5$ at room temperature with applied magnetic field perpendicular (solid curve) and parallel (dashed curve) to the sample plane.

Figure 1 shows the hysteresis loops of the sample [Co(4.8Å)/Pt(9Å)]$_5$ at room temperature with applied magnetic field perpendicular and parallel to the film plane. The effective saturation magnetization of [Co(4.8Å)/Pt(9Å)]$_5$ multilayer at room temperature is 1780 emu/cm^3, which is obtained by dividing the saturation moment of the multilayer by the Co volume in the sample. The measured magnetization of the Co/Pt multilayer is larger than the bulk Co value (1420 emu/cm^3) because of the magnetization contributed by the polarized Pt atoms next to the Co layer.[5] As shown in Fig. 1, the saturation field out of plane is 340 Oe, and that in plane 8500 Oe. It indicates that the sample is easy to be magnetized perpendicular to the sample plane, and hard to be magnetized in plane, meaning the easy axis perpendicular to the sample plane. From the result, one can obtain the effective anisotropy energy constant amounts to about 7.4×10^6 erg/cm^3.

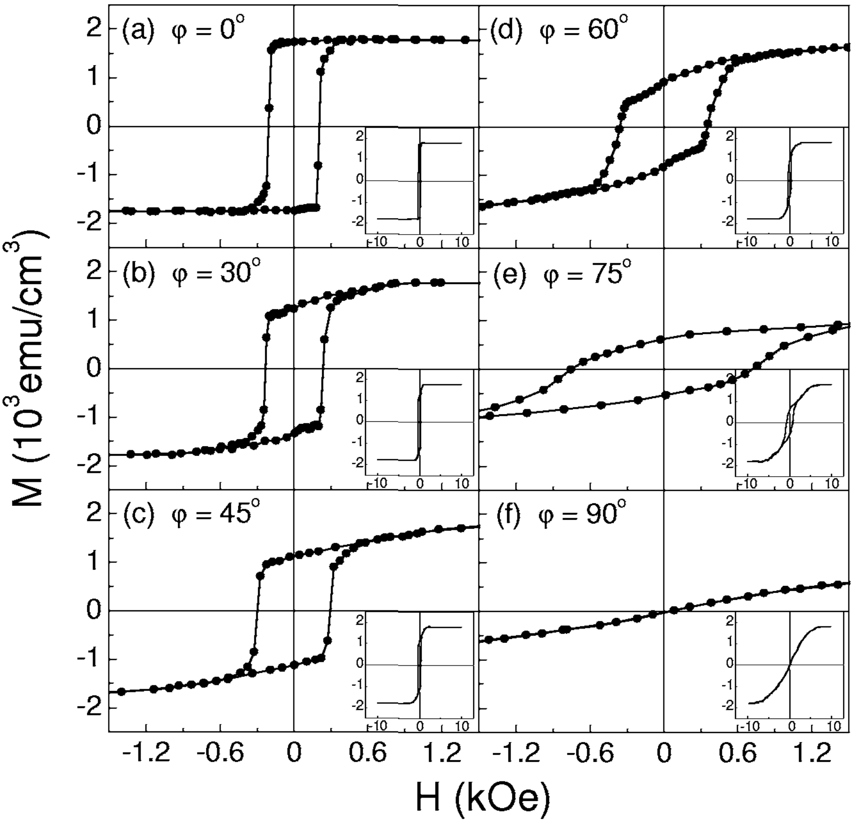

Fig. 2. Hysteresis loops of [Co(4.8Å)/Pt(9Å)]$_5$ measured in varied φ. The insets show the whole loops corresponding to φ.

Figure 2 shows a series of hystersis loops of the sample measured at different angles between the applied magnetic field and the normal of the sample plane, φ. One can see that the loops display different shape as φ increases. The loop is square when the field is applied along the normal of the plane (φ = 0°), as shown in Fig. 2(a). The remanence is nearly to its saturation magnetization, and the magnetization switches in the field of −180 Oe. The coercive field is 210 Oe. When the magnetic field is applied in φ = 30°, the magnetization falls down slowly in the demagnetization process from the saturated state, seeing the decedent branch of loop shown in Fig. 2(b), and the remanence decreases a little bit comparing to that in φ = 0°. However, the magnetization-switching field and the coercivity slightly enhance. As φ increases, a clear magnetization switching can be observed even in φ = 60°, seeing Fig. 2(d). There is no hysteresis as the magnetic field applied in plane, i.e. φ = 90°, shown in Fig. 2(f).

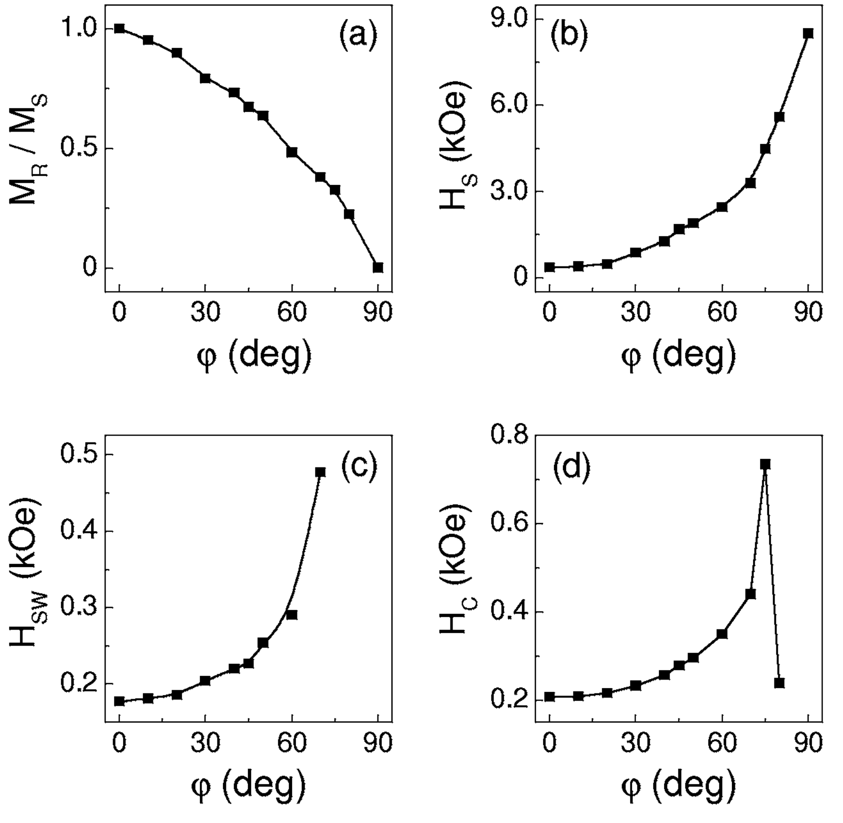

Fig. 3. The dependence of the ratio of the remanence and the saturation magnetization M_R/M_S (a), the saturation field H_S (b), the magnetization-switching field H_{SW} (c), and the coercivity H_C (d) on φ. All solid lines are the guides of eyes.

It is well known that the remanence and coercivity, usually, decreases when an applied field changes from the easy to the hard. Figure 3(a) shows the dependence of the remanence on the angle φ. The remanence monotonically decreases as φ increases. The saturation field H_S increases with the increment of φ, seeing Fig. 3(b). Fig. 3(c) shows the dependence of switching field H_{SW} on the angle φ. One can see that H_{SW} increases smoothly in the region from $\varphi = 0°$ to 45°, and a rapid change of H_{SW} can be found when $45° < \varphi < 70°$. Further increasing φ, the sample become hard to be magnetized and no obvious magnetization switching appears. Although the remanence decreases as φ increases, the coercivity H_C does not vary as the same behavior as that of remanence. From Fig. 3(d), one can see that H_C rises with the increment of φ, and reaches a maximum value of 740 Oe when $\varphi = 75°$. Then it drops quickly to nearly zero when the external field applied in plane.

The magnetic free energy per unit volume is composed of Zeeman energy and effective anisotropy energy, and is given by

$$E = -M_S H \cos(\varphi - \theta) + K_{eff} \sin^2 \theta , \tag{1}$$

where θ is the angle between the magnetization and easy axis, K_{eff} effective anisotropy constant. For the case of easy axis perpendicular to the sample plane, K_{eff} is positive. According to the coherent rotation model for uniaxial anisotropic ferromagnets, the critical field H_{SW} and the coercivity H_C should decreases with φ varies from 0° to 90°. One can find our experiment results in Co/Pt multilayer are not consistent with the existent model. It should be emphasized that the model is valid only to an isolated single-domain particle, assuming the magnatization is uniform and of constant absolute magnitude. Obviously, the magnetization mechanism of the multilayers with PMA cannot be explained simply by coherent rotation model for uniaxial anisotropic ferromagnets, which means that spin dynamical and magnetic reversal behavior is complex in this PMA system. It should be noted that the ferromagnetic layer in the multilayer structure contains only 2-3 atom layers and the effect of the interfaces is dominant in Co/Pt multiplayer with PMA,[5] which can be regarded as a two-dimensional magnetic system approximately. Because the orbital momentum remains largely unquenched, the strong spin-orbit interaction should be taken into account, which plays an important role at the interface between ferromagnetic and non-magnetic layers.[7-10,17] Meanwhile, there may exist some unusual domain structure in this PMA system. It is significant to pay much attention to the behavior of the unusual domain structure.

4. Conclusions

In summary, the Co/Pt multilayers with PMA exhibit unusual magnetization behaviors by changing the angle between an applied magnetic field and the normal of the sample plane. The remanence decreases while the saturation field increases as the angle varies from φ = 0° to 90°, but the magnetization-switching field and the coercivity are enhanced during φ = 0° through 75°. These behaviors suggest that the magnetization process in multilayers with PMA could not be described simply using coherent rotation model for uniaxial ferromagnets. Spin dynamical and magnetic reversal mechanism in ultrathin multilayers still remain unclear. Further studies are needed.

Acknowledgment

This work supported partly by CSKPOFR Grant No. 001CB610602, NSFC Grant No. 10128409 and No.10474038, JSNSF.

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