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SPIN-REORIENTATION TRANSITION IN ULTRATHIN CO FILMS ON Pt(111) AND Pd(111) SINGLE-CRYSTAL SUBSTRATES

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Pt(111)과 Pd(111) 단결정 기판 위에 증착된 Co 박막의 스핀 재배열 현상

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I. INTRODUCTION

Ultrathin magnetic films have a very novel property that the magnetic anisotropy prefers out-of-plane or in-plane magnetization depending on the film thickness or temperature. Perpendicular magnetic anisotropy (PMA) in ultrathin magnetic films has been one of the most attractive subjects due to its application to ultrahigh-density information storage. It is well known that Co films on Pt(111) and Pd(111) substrates exhibit PMA at the monolayers (ML) regime, where the magnetocrystalline anisotropy caused by a broken symmetry at the interfaces is sufficient to overcome the demagnetizing energy originated from the shape anisotropy. As the film thickness increases, the magnetic easy axis changes from perpendicular toward in-plane orientation, which is so called a thickness-driven spin-reorientation transition (SRT). In the present work, we compare SRT behavior in Co films grown on Pt(111) and Pd(111) single-crystal substrates, especially under the context of their 2nd- (K_2) and 4th- (K_4) order anisotropy constant flows.[1] Observed difference in the transition thickness between the two substrates is explained by differences in their interface anisotropy terms and likely by the polarization effects of Pt and Pd at the interfaces as well.

II. EXPERIMENTS

The Co films were grown on Pt(111) and Pd(111) single-crystal substrates at a rate of 0.4 ML/min by e-beam evaporation. The substrates were cleaned by a few cycles of 1 keV Ar^+ ion sputtering and annealing up to 1000 K. Well-defined terrace structures of the Pd(111) and Pt(111) surfaces were confirmed by a reflection high-energy electron diffraction (RHEED) and a scanning tunneling microscope (STM). The magneto-optical Kerr effect (MOKE) measurements as well as the Co growth were performed in an ultrahigh vacuum (UHV) chamber maintained under a base pressure of 1×10^{-10} Torr.

We have *in situ* measured the polar and longitudinal MOKE signals after every Co deposition of 0.5 ML coverage. For both substrates, the square loops start to appear at 2 ML coverage. Then, the loops become slanted from 10 ML for Pt(111) and 4.5 ML for Pd (111). The evolution of the hysteresis loops vs Co thickness, t_{Co}, clearly exhibits that perpendicular magnetization switches to in-plane one as t_{Co} increases through the transition region of spin reorientation. Overall trends in the SRT behavior vs t_{Co} are similar for both substrates, but the onset thicknesses from perpendicular to in-plan orientation and the thickness ranges of transition are different.

III. RESULTS AND DISCUSSION

In order to compare different SRT behaviors in both substrates, we first plot the canted angles, θ_z, from the film normal at the remanent state, *i.e.*, at zero field vs t_{Co}, as shown in Fig. 1 (a). Those angles are determined from $\cos^{-1}(m_z / m_x^2 + m_y^2 + m_z^2)^{1/2})$, where m_x, m_y, and m_z are the magnetization components along each axis. The vectorial determination of all the magnetization components from MOKE signals will be reported elsewhere.[2] In the plots of θ_z vs t_{Co} for Co/Pd (111) and Co/Pt (111), different transition onsets and ranges are evident, and also supported by the polar Kerr susceptibility, χ_r, defined by $dm_z/dH|_{H=0}$ as seen in Fig. 1 (b). The critical thickness, t^c_{Co}, where χ_r has a maximum, are determined to be ~ 5.5 ML Co on Pd(111) and ~ 12 ML Co on Pt(111). Before starting SRT, χ_r remains almost zero due to the square shapes of the loops, while the rapid increases up to t^c_{Co} and then decreases in the transition region represent the distinct SRTs.

The observed SRT behaviors in the Co/Pd(111) and Co/Pt(111) systems could be well explained under the context of the anisotropy flow. By adopting the fit values, in Fig. 2 we plot the anisotropy flows on the $\widetilde{K}_2 - K_4$ plane for the Co/Pd(111) and Co/Pt(111) systems with varying t_{Co} = 3 ~ 9 ML and 7 ~ 20 ML, respectively, where $\widetilde{K}_2 = \frac{1}{2}\mu_0 M^2 - K_2$. It is clean that the larger value of K_{2s} in the Co/Pt(111) than that in the Co/Pd (111) gives rise to the later onset and wider range of the SRT, while the negative small values of K_{4s} in the both systems yield a stable canted phase during the SRTs. As seen in Fig. 2, the SRTs in both the substrates proceed via a stable canted phase, *i.e.*, a typical second-order (smooth) SRT as t_{Co} increases. However, there is a large difference in the onset thicknesses of the transition between the two substrates. *The SRT from perpendicular to in-plane orientation starts at 4.5 ML Co for* Pd(111), and proceeds through the thickness range of 1.5 ML. On the other hand, the transition on Pt(111) substrate occurs in the range of t_{Co} = 10 ~ 15 MLs. Our results vividly witness that the contrasting behavior is essentially originated from the different interface anisotropies sensitively dependent on the substrate material. For instance, in the Co/Au(111) system with K_{2s} = 0.66 mJ/m^2 and K_{4s} = -0.12 mJ/m^2, Oepen *et al.*[3] reported an onset thickness of 3.7 ML and the transition via a coexistence phase within a 0.4 ML thickness.

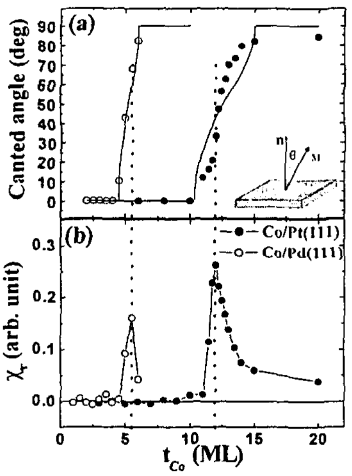

Fig. 1. (a) The canted angle, θ_c, of the magnetization vector from the film normal as a function of Co film thickness, t_{Co}. The solid lines indicate the fit curves. (b) Polar Kerr susceptibility at the remanent state (χ_r) as a function of t_{Co}.

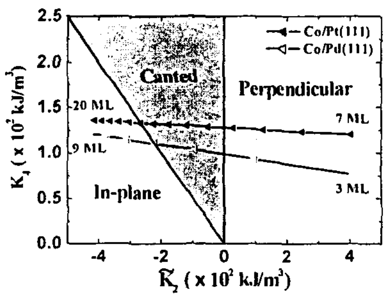

Fig. 2. Anisotropy constant flows on the $\widetilde{K}_2 - K_4$ plane with varying Co thickness. The perpendicular, canted, and in-plane phases are separated as noted in the figure.

IV. ACKNOWLEDGEMENT

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V. REFERENCES

[1] Y. Millev and J. Kirschner, Phys. Rev. B **54**, 4137 (1996).

[2] J.-W. Lee, J. Kim, S.-K. Kim, J.-R. Jeong, and S.-C. Shin, Phys. Rev. B, submitted (2001).

[3] H. P. Oepen, Y. T. Millev, and J. Kirschner, J. Appl. Phys. **81**, 5044 (1997).