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Magnetic circular dichroism measurement of Co films on Pd(111) substrate

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Abstract

We measured x-ray magnetic circular dichroism of Co films on Pd(111) surface with and without Pd capping layer at the Co $L_{2,3}$ edges. Perpendicular magnetization and orbital-moment enhancement are induced by the capping layer. The increase of perpendicular magnetic anisotropy induced by capping layer is considered to result from the increase of surface anisotropy due to the hybridization at the surface.

1. Introduction

In recent years, researches on magnetic thin film systems and multilayers has been very active because of their interesting magnetic properties and usefulness for practical devices. In particular, a number of experimental investigation have been performed on Co/Pd and Co/Pt systems because they show perpendicular magnetic anisotropy(PMA) [1] and large Kerr rotation at short wavelength, which make them promising candidates for the high-density magneto-optical storage media. Theoretical calculations [2,3] of magneto-crystalline anisotropy(MCA) of Co/Pd multilayer showed that a strong perpendicular Co-Pd interface MCA arises from the hybridization between the out-of-plane Co-boding xy(yz) states with the Pd atoms at interface. The large *d-d* boding strength and high energy of the Pd *d* states shift substantial component of these Co states above the Fermi energy. Co/Pd bilayer system also shows perpendicular magnetization when Co coverage is below 9 monolayers[4].

Theoretically, the enhancement of orbital-moment is predicted in Co/Pd(111) [5] and the magnetic moment enhancement is also expected at the interface of Pd/Co/Pd(111) [6]. Indeed, the enhancement of magnetic moment has been observed experimentally in Co/Pd multilayers [7]. The orbital-moment is considered to be important in PMA because the microscopic origin of magnetic anisotropy is thought to be originated from the spin-orbit interaction. A simple picture for the microscopic origin of magnetocrystalline anisotropy was proposed by Bruno [8], which is in large part supported by experiment [9]. Usually in 3d transition-metal thin films, the spin-orbit coupling energy is large compared to the anisotropy energy, so the orbital-moment can redirect the total moment. The orbital magnetic moment can be enhanced due to the modification of density of states(DOS). For example, at the surface d bands become narrower and can carry larger magnetic moment. The change of crystal fields and hybridization also affect the DOS. There are many reports supporting enhanced orbital moments in

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several film systems theoretically [5] and experimentally [7], although in some cases reduced orbital moments have been also measured [10]. The hybridization effect was emphasized in Co/Cu(100) [10] and Co/Pt [11,12] systems, and the lowering of symmetry was considered as important in Co/Cu(100) [13].

In this paper we present the magnetic properties of Co films on Pd(111) with and without Pd capping layer using x-ray magnetic circular dichroism (MCD) to investigate the effect of interface and the magnetic properties of Co thin films. MCD is now used widely for measuring element-specific local magnetic moment [2]. By using sum rules, orbital and spin magnetic moments can be obtained separately [14]. Although sum rules have some limitations and uncertainties, it is useful to study magnetic property and understand its microscopic origin.

2. Experiment

MCD experiment was performed at U4B beamline in National Synchrotron Light Source, USA. The base pressure of the vacuum chamber was 2×10^{-10} Torr. The Pd(111) single crystal substrate was cleaned by repeated cycles of sputtering at 2 keV and annealing at 900 K, and the formation of smooth surface was checked by low energy electron diffraction. The surface contamination was checked by measuring oxygen absorption spectra. The Co and Pd layers were evaporated by heating the Co and Pd wires with electron beam keeping the pressure under 1×10^{-9} Torr, and the deposition rate was maintained at 1 Å/min. The thickness of films was determined by a thickness monitor. The thickness of Pd capping layer was fixed at 5 Å for all bilayer systems studied here. We obtained the x-ray absorption and MCD spectra in opposite remanent magnetic field directions with a fixed incident photon polarization. Absorption spectra were obtained by measuring the total electron yield current. The external magnetic field ($\pm$40 kA/m) was applied with a pulsed driven electromagnet *in situ* which is 45° off from the photon incidence direction. For measurement in the in-plane magnetization, we set the sample plane parallel to the magnetic field direction and photon incidence angle at 45° to the sample normal. The parallel setting between the surface of sample and the magnetic field only gives the in-plane magnetization. For measurement in perpendicular magnetization, we rotated the sample plane to 45° off-normal and photon incidence angle was changed to 0°.

The perpendicular setting between the photon incidence and the surface of sample gives the information on the perpendicular magnetic property.

3. Results

We studied Co films of thickness from 4 Å to 24 Å deposited on a smooth Pd(111) surface with or without Pd capping layer. In our experiment, Co films without capping layer show in-plane remanent magnetization for all thickness larger than 6 Å. On the other hand, the films with Pd capping layer show perpendicular magnetization. This is consistent with previous results [4]. In Fig. 1 and Fig. 2, we present the x-ray absorption and MCD spectra of 6 Å Co film and 24 Å Co film with and without Pd capping layer, respectively. The X-ray absorption spectra are normalized to have the same edge jump. The MCD signal is the difference spectra between the absorption curves I^+ and I^-, where I^+ (I^-) means the absorption cross section measured with polarized light parallel(antiparallel) to the magnetization of sample. In Fig. 1, we can see that the easy axis of Co film rotates from in-plane to out-of-plane due to the capping layer. While, in the thick 24 Å Co film, the easy axis of Co film remains in-plane direction(Fig. 2).

In Fig. 3, we plotted the MCD signals of the Co films without capping layer depending on the film thickness. There is a small perpendicular signal at 4 Å, but no signal above 6 Å. Hence, we can say that the perpendicular magnetization exists only below 6 Å. On the other hand, the MCD intensities above 6 Å are nearly the same with each other. Because the MCD intensity indicates the magnetic ordering, it implies that the Co films grown on Pd(111) have similar magnetization

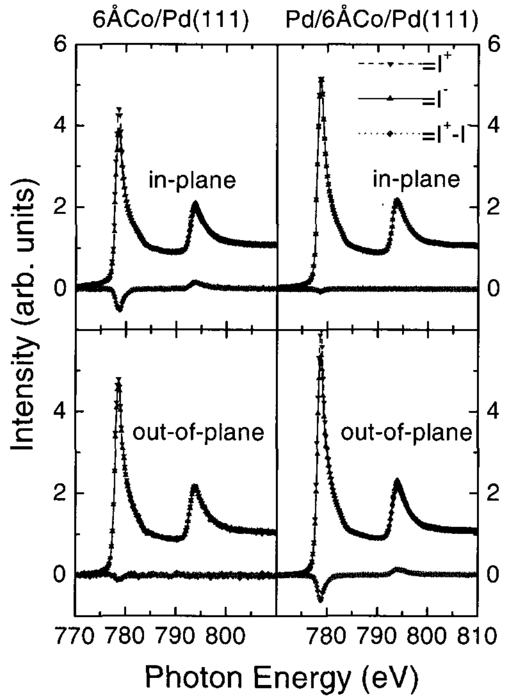

Fig. 1. X-ray absorption and MCD spectra of Co films of 6 Å with Pd capping layer(right) and without capping layer(left).

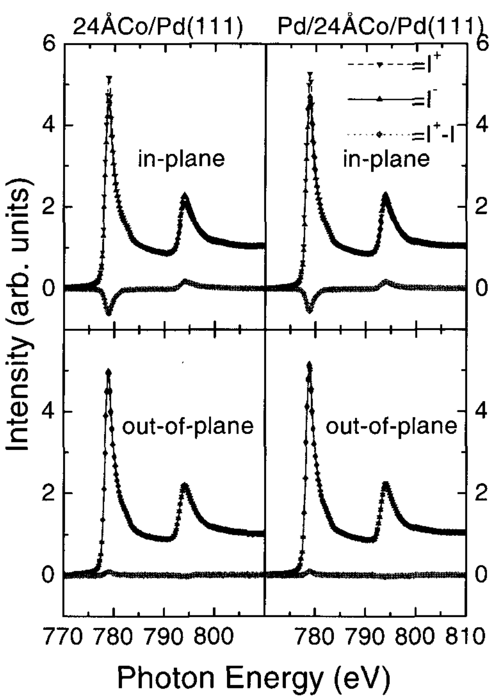

Fig. 2. X-ray absorption and MCD spectra of Co films of 24 Å with Pd capping layer(right) and without capping layer(left).

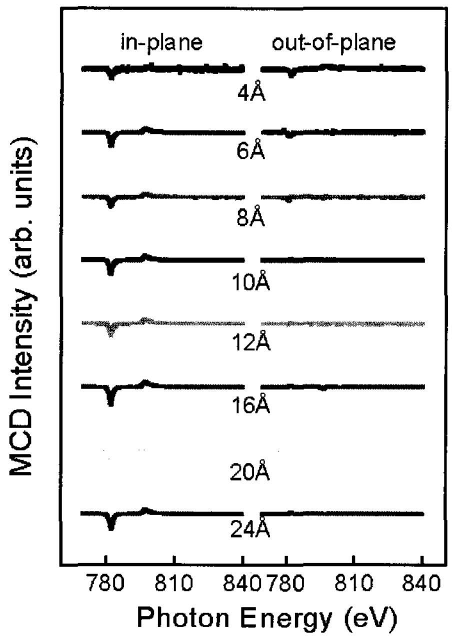

Fig. 3. MCD signals of Co films on Pd(111) without capping layer.

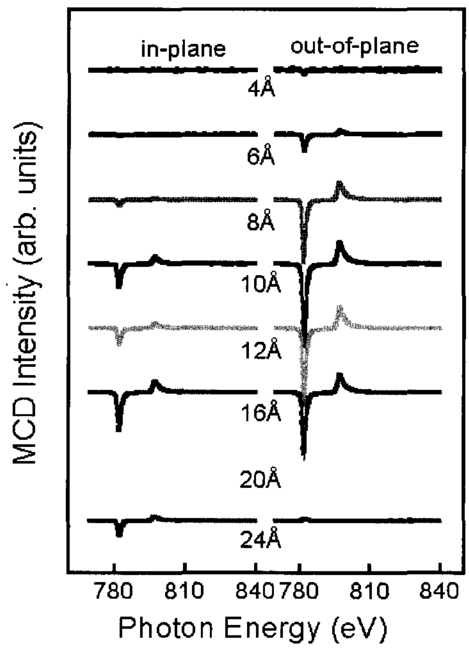

Fig. 4. MCD signals of Co films on Pd(111) with capping layer.

above 6 Å. Note that the small MCD signals measured in perpendicular direction above 6 A are caused by the experimental limitations. Small change of angular setting led to the change of the polarity of MCD signal, so the signal can be thought to be from the longitudinal component.

In Fig. 4, we plotted the MCD signals of the Co films with capping layers. After Pd capping layer is deposited on Co/Pd(111), the perpendicular MCD signal shows up from 6 Å, which persists up to 20 Å thickness. This is consistent with a previous result measured by surface magneto-optical Kerr effect [15]. The increase of perpendicular anisotropy must be induced by the new Pd/Co interface with the capping layer. Therefore, the perpendicular magnetization of Co films on Pd(111) can be understood to arise dominantly from hybridization effect. The MCD intensities of Co films with capping layer vary very much with Co thickness and have a maximum in contrast to those of bare Co films. The maximum intensity occurs near 16 Å for in-plane direction, and at near 10 Å for out-of-plane direction. If we want to get large remanent magnetization, we should choose these thickness. The coexistence of both in-plane and out-of-plane signal indicates that the easy axis may be in a canted direction or the existence of higher order term of magnetic anisotropy. The perpendicular MCD intensities are very large compared to the MCD intensities of bare Co film, which indicates that magnetization is quite enhanced in perpendicular direction with the capping layer. Also the in-plane MCD intensities are rather large, so we can conclude that the magnitude of the magnetization is generally enhanced by capping layer. Note that the MCD signals from capped and uncapped films are the same for 24 Å in Fig. 2. This indicates that the effect of capping layer is valid only films thinner than 24 Å.

We obtained orbital moment to spin moment ratio from the MCD spectra by applying sum rules. Orbital or spin moments can be calculated separately using sum rules, but we only show their ratio here because we measured the remanent magnetization and some canted easy axis region exists. The result is represented in Fig. 5, which shows that the ratio between orbital and spin moments(m_{orb}/m_{spin}) is larger for our Co film samples than that of bulk Co, which is about 0.09 [14]. This implies an orbital-moment enhancement of Co films on Pd(111). We can say that the effect of orbital-moment enhancement is enlarged by capping layer, although there is some exceptional region. The orbital-moment enhancement is very large in the thinnest region near 5 Å, which is comparable to that of theoretical calculation [5].

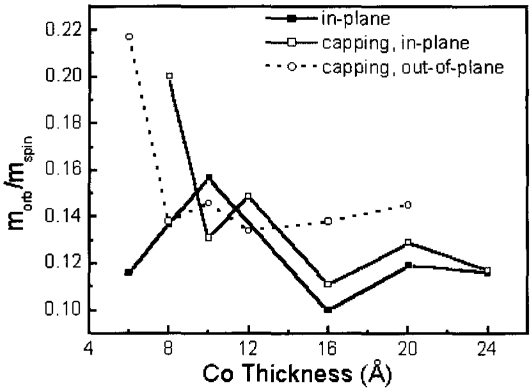

Fig. 5. Orbital to spin moment ratio of Co films on Pd(111) with and without capping layer.

In 10~12 Å region, the values do not show much orbital-moment enhancement. At this thickness, it seems that the capping layer does not induce orbital moment enhancement either.

The orbital-moment enhancement can be caused by hybridization and structural change, and they can differ depending on the directions. Moreover, the direction of orbital moment can be different from that of spin moment. Therefore some thickness region can exist, where capping layer cannot enhance orbital moment in a specific direction. For a thickness larger than 12 Å, the orbital-moment enhancement is obviously enhanced by capping layer, and it is larger in perpendicular direction than in the parallel direction. Nevertheless, the values are not so large as those of thinner films. This is in contrast to the phenomenon occurring in Co/Pt(111) [12].

4. Conclusions

In summary, we show in this paper that Co/Pd(111) interface and Pd capping layer induce large remanent magnetization and perpendicular magnetization using MCD. We conclude that the local structure of magnetic film and the hybridization between Co 3*d* and Pd 4*d* are very important in PMA. The increase of PMA induced by capping layer is explained to be due to the increase of surface anisotropy arising from the hybridization at the interface. The orbital-moment enhancement was observed in Co/Pd(111) film. We conclude that the hybridization between Co and Pd atoms is important in the orbital-moment enhancement.

Acknowledgments

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