II-F Controllable Magnetic Anisotropy of Ultrathin Magnetic Films and Nanowires Using Surface Chemical Techniques

In recent years noble properties of magnetic thin films have extremely attracted scientific and technological interests. Magnetic anisotropy is one of the most important subjects in this field since the origin of perpendicular magnetization is not well understood but is useful for high-density recording media. We are investigating the microscopic mechanism of perpendicular magnetic anisotropy that is stabilized by gaseous adsorption on magnetic film surfaces by means of the synchrotron radiation x-ray magnetic circular dichroism (XMCD) and the visible-light magneto-optical Kerr effect (MOKE) techniques. A goal of these works is spin engineering by which the magnetization of ultrathin metal films and nanowires can be controlled artificially.

II-F-1 X-Ray Magnetic Circular Dichroism Study on NO Adsorbed Co and Ni Ultrathin Films on Cu(001)

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NO is well known as an effective magnetic killer since NO interacts with magnetic metal surfaces very strongly and the unpaired electron couples with the metal spins antiferromagnetically. In this work, we have investigated the effect of NO adsorption on ultrathin Co and Ni/Cu(001) films from the view point of magnetic anisotropy.

Figure 1 depicts the Ni *L*-edge x-ray magnetic circular dichroism (XMCD) of 5.5 and 9 monolayer (ML) Ni on Cu(001), taken at Beamline 4B in UVSOR. In the case of in-plane magnetized 5.5 ML Ni/Cu(001), both $\theta = 30°$ (close to the in-plane easy axis) and $\theta = 90°$ (along surface normal, hard axis) spectra were taken at a magnetic field of 1000 G and at a temperature of ~100 K. The $\theta = 30°$ spectra show noticeable reduction of the magnetization on NO adsorption, while less prominent suppression is found in the $\theta = 90°$ spectra. This finding is similar to the NO/Co/Cu(001) case (not shown). The 9 ML spectra (perpendicular magnetization both before and after NO adsorption) show much less change between clean and NO-adsorbed Ni along the easy axis, being different from the 5.5 ML case.

From the quantitative analysis, it is found that in the in-plane magnetized films of 5.5 ML Ni and 3 ML Co (not shown), the in-plane orbital moments are significantly suppressed on NO adsorption, while perpendicular orbital moments show much less change. The Ni 9 ML films give again almost no change in perpendicular orbital moments. These results imply that NO suppress the in-plane orbital moment drastically, while the perpendicular orbital moment is much less influenced. Consequently, NO relatively stabilizes perpendicular magnetization effectively.

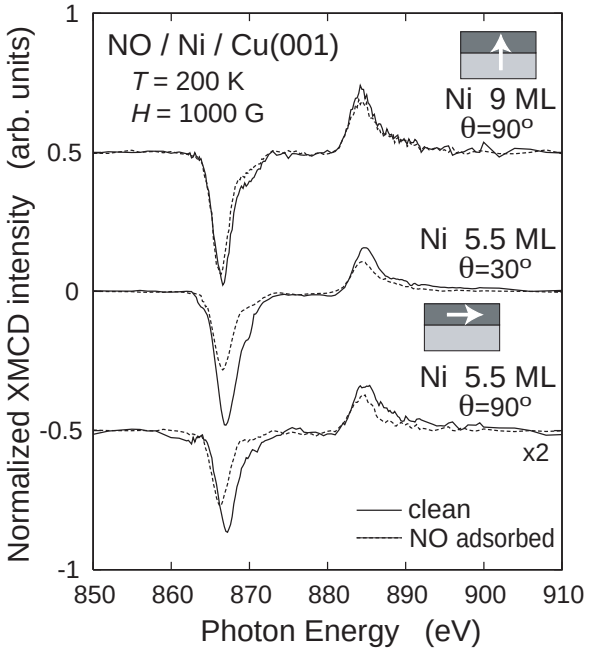

Figure 1. Ni *L*-edge XMCD of 5.5 and 9 ML Ni/Cu(001) before and after NO adsorption. The x-ray incidence angles were $\theta = 30°$ and 90° for 5.5 ML Ni and $\theta = 90°$ for 9 ML Ni.

II-F-2 Is the Perpendicular Magnetic Anisotropy in Ni/Cu(001) Stablized by the Cu Capping ?

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The effect of the Cu capping on Ni/Cu(001) films has been investigated by different research groups, and essentially contradictory results were reported. In this work, we have examined the Ni films grown on clean and preoxidized Cu(001) surfaces by means of the MOKE and XMCD. These films consequently show completely different properties concerning the spin reorientation transition, leading to a consequent definite answer for the previous contradictions.

For the Cu-capped Ni films grown on clean Cu(001), the MOKE measurement shows that the critical thickness for the spin reorientation transition of ~ 9 ML before Cu capping is significantly reduced to ~ 6.5 ML after > 0.4 ML Cu capping. The XMCD results clarifies that the in-plane orbital magnetic moment is correspondingly suppressed after Cu deposition, while the perpendicular orbital magnetic moment does not vary

irrespective of the presence or absence of the Cu overlayer. On the contrary, for the Cu-capped Ni films grown on preoxidized Cu(001), the opposite trends were basically concluded. MOKE shows that the critical thickness of ~ 5 ML before Cu capping is significantly enlarged to ~ 6.5 ML after Cu capping. The XMCD results clarifies that the in-plane orbital magnetic moment is correspondingly enhanced after Cu deposition. Figure 1 shows the orbital magnetic moments from XMCD and the relative hysteresis loss from MOKE, which are in good acoordance with each other.

Such different nature originates from the behavior of adsorbed oxygen. Although Ni was deposited onto oxidized Cu(001) in the latter case, the oxygen atoms act as a surfactant and comes up to the surface of the Ni films. Adsorption of oxygen suppresses surface magnetic anisotropy that favors in-plane magnetization much more effectively than clean Ni and even than the Cu/Ni interface. Furthermore, when depositing Cu, oxygen again comes up to the Cu overlayer and locates at the surface, in spite that the O–Ni bond is much stronger than the O–Cu bond. Since no O–Ni interaction remains any more, the Cu-capped Ni films shows similar magnetic properties. The present finding clearly concludes that the modification of the in-plane orbital moment drives the spin reorientation transition.

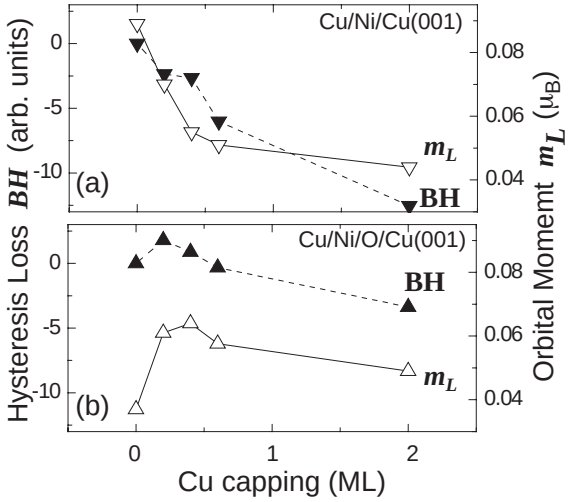

Figure 1. Comparison between the hysteresis losses (open symbols) from MOKE and the orbital magnetic moment (filled symbols) from XMCD for (a) Cu/Ni(5.5 ML)/Cu(001) and (b) Cu/Ni(4.8 ML)/O/Cu(001). The plots demonstrate a one-to-one correspondence between the hysteresis loss and orbital magnetic moment.

II-F-3 Switching of the Magnetic Easy Axis in Pseudo-Nanowire Co on Vicinal Cu(1 1 41) Surface *via* Ag and NO Adsorption

NAKAGAWA, Takeshi; WATANABE, Hirokazu; YOKOYAMA, Toshihiko

It is well known that rod magnets are likely to be magnetized along its axis due to shape anisotropy. Metal thin films grown on stepped surfaces can be regarded as pseudo-nanowires, which are connected at the step edges with each other. These films are found to exhibit strong uniaxial magnetic anisotropy along the step direction. Weber *et al.* [*Phys. Rev. B* **52**, R14400 (1995)] reported surprising results whereby Ag capping induces the switching of the easy axis of Co on a vicinal Cu surface. In this work, we have tried to confirm the findings on 10 ML Co on Cu(1 1 41) and moreover have investigated the effect of NO adsorption on 7 ML Co on the same substrate by means of the MOKE experiments.

Figure 1 depicts the hysteresis loops recorded by the longitudinal MOKE measurements of 10 ML Co on Cu(1 1 41) (a) before and (b) after 0.2 ML Ag deposition. On clean Co, a normal hysteresis loop was observed along the step, while a double hysteresis with a shift filed can be found in the direction perpendicular to the step. This implies that the magnetic easy axis, which was along the step as in the usual case, rotates by 90° and is perpendicular to the step direction within the surface plane. The previous experiments were confirmed and more detailed information was derived.

Figure 1(c) shows the hysteresis loops of 7 ML Co before and after NO adsorption. Before NO adsorption, clear uniaxial anisotropy is again seen, implying that the easy axis is along the step. After NO adsorption, the hysteresis loop is dramatically changed. There can be found no angular dependence and both the loops taken parallel and perpendicular to the step are identical. Correspondingly, the coercive field is drastically reduced. This implies that the easy axis disappears and the pseudo-nanowire behaves as if it had a fourfold symmetry. The XMCD measurements are in progress.

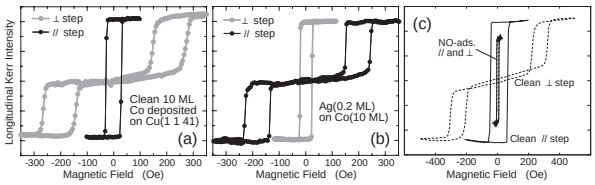

Figure 1. (a,b) Hysteresis loops of 10 ML pseudo-nanowire Co on Cu(11 41) (a) before and (b) after Ag deposition with the magnetic field parallel (black) and perpendicular (gray) to the step; (c) Hysteresis loops of 7 ML pseudo-nanowire Co on Cu(11 41) before and after NO adsorption with the magnetic field parallel (solid) and perpendicular (dashed) to the step.