

Suppression of 90° spin switching in Co nanomagnets grown on the Cu(110)- $\sqrt{2}\times\sqrt{2}$ O surface

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We report on the effect of oxygen on the CO-induced 90° spin switching in the Co/Cu(110) system [Hope *et al.*, Phys. Rev. B **57**, 7454 (1998)]. The epitaxial fcc Co films were grown on the unsaturated Cu(110)- $\sqrt{2}\times\sqrt{2}$ O surface and their magnetic properties have been studied with *in situ* magneto-optic Kerr effect. The easy axis switch of the Co(110) films is suppressed when Co is grown on O exposed Cu surfaces. Scanning tunneling microscopy images of the film surface reveals the growth of elongated nanostructures preferentially oriented along the [001] direction, providing step-like edges for gas adsorption. The density of steps is similar to the density developing during growth on the clean Cu(110) surface but the step edges now run in the perpendicular direction. The suppression of the easy axis switch can be attributed to subtle changes of the number and adsorption probability of the available atop adsorption sites along the step edges for CO chemisorption. Our experiments highlight the remarkable chemical sensitivity and adsorption site dependence of the easy axis switch of the Co(110) nanomagnets. © 2001 American Institute of Physics.
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The uniaxial anisotropy resulting from the reduced symmetry at surfaces, interfaces, and step edges¹ and the effect of the adsorption of nonmagnetic elements on its easy axis have recently received a great deal of attention.^{2,3} For thin fcc Co films grown on miscut Cu(001), a 90° rotation in the step-induced uniaxial anisotropy is caused upon adsorption of small amounts of different adsorbates, such as Cu, Fe, Ag, or O, irrespective of the adsorbate specific electronic structure.³ The mechanism behind this rotation is believed to be a change in the magnetic surface anisotropy of the step site atoms. However, in striking contrast with the vicinal Co/Cu(001) system, we have recently observed a chemically selective 90° spin switching in the Co/Cu(110) system, with only CO being able to induce the switch.⁴ Dosing experiments on the Co/Cu(110) system revealed that 0.08 monolayers (ML) of CO is required in order to switch the easy axis of a 15 ML Co film corresponding to one CO molecule switching the spins of ~ 180 Co atoms.⁵ The very small amounts needed for the switch indicate that the CO only adsorbs at specific sites probably along the island step edges. Scanning tunneling microscope images revealed the growth of elongated island structures preferentially oriented along the [1-10] direction that provide “step like” edges for gas adsorption. Furthermore, it was found that a Cu overlayer deposited before the easy axis switch will stop the switch from occurring, whereas once it occurred, it could be reversed by monolayer Cu coverages.⁶ It is likely that the Cu atoms occupy the specific adsorption sites preferred by the CO molecules in the first case while it displaces the CO gas in the latter. The question therefore arises as to the nature of the interaction between the adsorbed gas and the film morphology. In particular, to shed light on the role of the edge sites, it would be useful to investigate whether the same magnetization switch happens, if the island morphology were to be changed by growing on a modified surface.

In this article we present the magnetic properties of Co deposited on the unsaturated Cu(110)- $\sqrt{2}\times\sqrt{2}$ O surface. Although recent studies presented evidence that O acted as a surfactant to promote the growth of atomically flat fcc Co films on the Cu(110) surface,⁷ the quality of the films appears to be strongly influenced by the amount of oxygen present on the surface and during growth.⁸ The layer-by-layer growth observed is stabilized by an oxygen induced (3×1) surface reconstruction of the Co film, indicating that an oxygen coverage of at least $2/3$ ML is needed.⁸ Here, we have chosen to work with oxygen coverages of ~ 0.25 ML for which the effect on the film three-dimensional growth is expected to be small.

The experiments were carried out in a UHV chamber equipped with a Burleigh scanning tunneling microscope (STM), low energy electron diffraction (LEED) and reflection high energy electron diffraction (RHEED) for structural analysis, and *in situ* magneto-optic Kerr effect (MIKE) and Brillouin light scattering (BLS) for magnetic characterization. The base pressure was in the 10^{-10} Torr range and rising to 8×10^{-10} Torr during deposition. The single crystal Cu(110) substrate was prepared via cycles of 1.5 kV Ar⁺ sputtering and annealing to 730 K, until low energy electron diffraction measurements indicated a well-ordered surface. The unsaturated surface was prepared by exposing the clean surface to ~ 2.0 L of O at 625 K. The Cu–O atomic rows run along the [001] direction, with an inner-row periodicity of one lattice unit and inter-row periodicity of two lattice units. LEED measurements show the corresponding (2×1) reconstruction pattern Fig. 1(a). Upon heating the substrate to 625 K, the two-dimensional anisotropic Cu–O islands arrange themselves in a striped periodic supergrading [Fig. 1(b)]. The Cu–O strings appear as elevations for sufficiently high negative bias, otherwise they are imaged as depressions. In a typical case we observed ~ 40 Å wide (2×1) Cu–O stripes, ~ 60 Å apart, corresponding to ~ 0.25 ML of oxygen. The sample temperature was held at room temperature (RT) dur-

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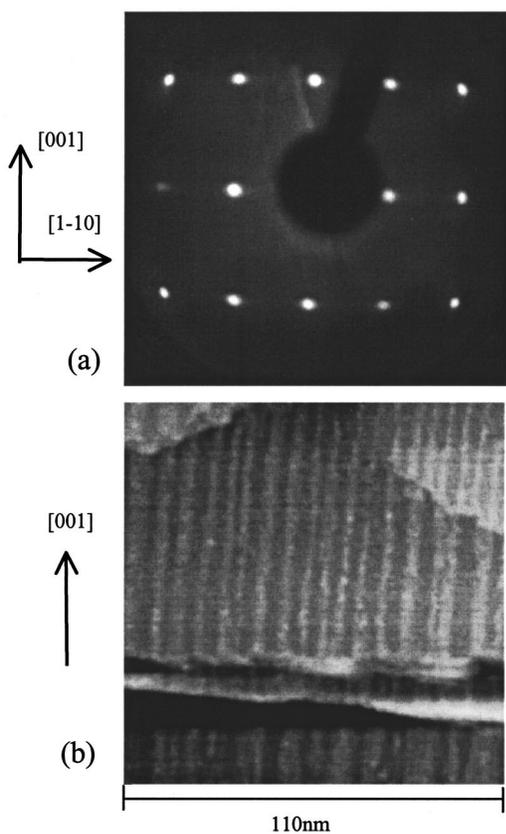


FIG. 1. (a) LEED pattern from the O exposed Cu(110) surface, $E=101$ eV and (b) STM image of the same surface, $B=1.64$ V (positive with respect to sample) and $I=1$ nA, the dark stripes are the Cu-O strings.

ing evaporation. *In situ* MOKE measurements were performed at RT with the longitudinal geometry and a maximum field of 2 kG. The sample was subsequently transferred to the STM stage for morphology measurements at selected thicknesses.

MOKE measurements of a 6 ML Co film grown on the unsaturated Cu(110)-{2×1}O surface are shown in Fig. 2. Angle-dependent studies (top panel) show that a dominant uniaxial anisotropy is present resulting in the [001] and the [1-10] directions being the magnetic easy and hard axis, respectively. The bottom panel shows the coercive field H_c as a function of time for the 6 ML Co film taken from M - H loops with the field parallel to the [001] direction. A square loop with unity remanence is observed along [001] even after almost 24 h in vacuum. This data clearly indicates that the 90° magnetic easy axis switch does not occur in this system. In order to investigate the stability of the easy axis direction we have dosed with both CO and O after growth. CO dosing of up to 40 L was found to have no effect on the magnetization of the film. This is contrary to the case of the Co films grown on the clean Cu(110) surface in which, as the residual CO gas/Co interface grows, H_c for the [001] direction reduces almost linearly over the first 60 min as is consistent with a linearly changing in-plane anisotropy strength, before changing sign, thereby switching the easy axis to the [1-10] direction.⁴ However, dosing with O was found to initially increase the coercivity by a factor of 2 at a dose of ~2.5 L, indicating that the strength of the uniaxial anisotropy is in-

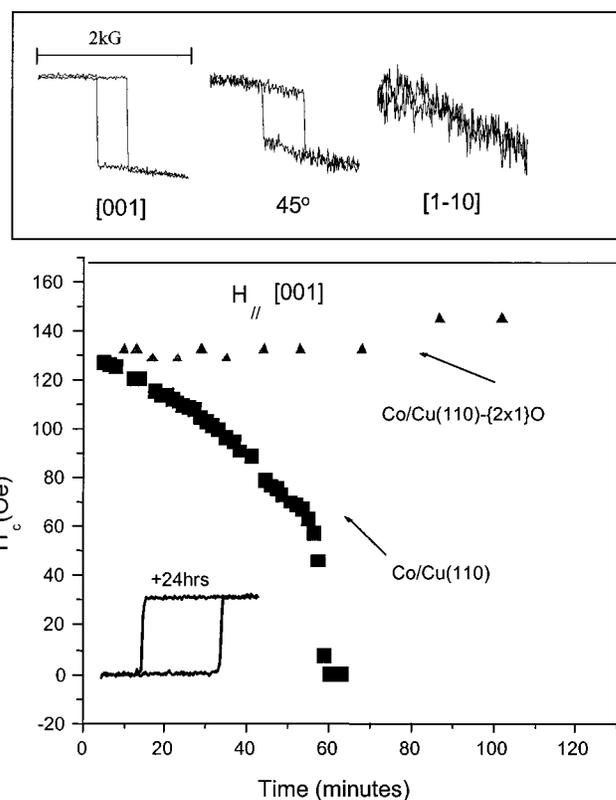


FIG. 2. (a) Angle-dependent MOKE loops of 6 ML Co film. The sample exhibits an in-plane uniaxial anisotropy with the easy axis parallel to the [001] direction. (b) The evolution of the coercive field H_c as a function of time for a 6 ML Co film grown on the Cu(110)-{2×1}O surface and the Cu(110) surface.

creasing as a result of O adsorption.⁹ Interestingly this change in the coercivity is not observed when the film is grown incrementally in order to reach the same 6 ML thickness and then exposed to O.

We have performed STM measurements on the films grown on the oxygen preadsorbed surface to see whether morphology changes are responsible for the suppression of the switch. Fig. 3(a) shows the STM image for the 6 ML film measured above. The growth on the Cu(110)-{2×1}O surface proceeds via the formation of three-dimensional islands along the [001] direction. Differences in the morphology of the films at the initial stages of growth compared to the growth on the clean surface will be reported elsewhere.¹⁰ The morphology revealed by the STM images is in agreement with previous studies in which it was reported that when preadsorbing less than 0.5 ML of oxygen, the shape and the intensity of the Co thermal helium atom scattering growth oscillations was degraded, indicating three-dimensional growth for this coverage regime.⁸ Figure 3(b) shows an image from 6 ML of Co film grown on the clean Cu(110) surface for comparison. It can be seen that the nanoscale morphologies in the two systems are very similar. An average island length and width of 9.2×2.7 nm² and of 9.6×3.6 nm² have been estimated from the STM images for the 6 ML Co film grown on the O exposed surface and on the clean surface, respectively. The presence of island step edges has been shown to be an important factor in explaining the

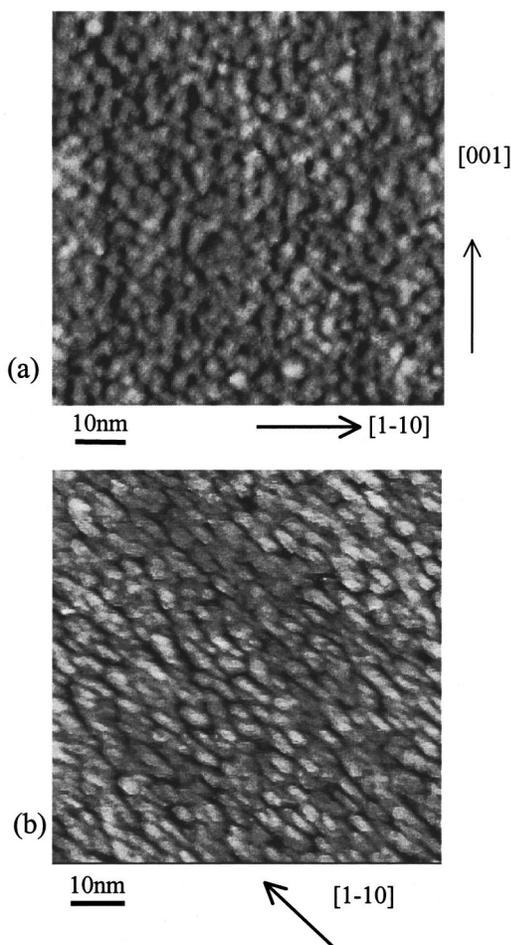


FIG. 3. STM images from (a) 6 ML thick Co film grown on the Cu(110)-{2×1}O surface and (b) 6 ML thick Co film grown on the Cu(110) surface.

easy axis switch in both the stepped Co/Cu(001) (Ref. 3) and the Co/Cu(110) system.⁴ Figure 3(a) indicates that elongated Co structures in the case studied here do provide “step like” edges for the gas adsorption in analogy with the clean Cu(110) surface. In general, due to lateral interactions between the adsorbate molecules, the adsorbates occupy different surface sites depending on the coverage. Although there have been relatively few studies on the adsorption of CO on Co (and those are mainly concerned with hcp Co), support for adsorption on step edges in the low coverage regime can be found in the literature on the adsorption of CO on other fcc surfaces such as the vicinal Ni(001) surfaces.¹¹

Assuming that the preferred adsorption sites are indeed along the step edges, the main difference between the two surfaces is that the longest step edge is running along the [001] direction on the Cu(110)-{2×1}O substrate, i.e., there are two preferred growth orientations for the Co depending on which surface it was grown on. There are two possible reasons for the suppression of the easy axis switch in the Co/Cu(110)-{2×1}O system: (i) the morphological changes evident by the change of this preferred growth direction and (ii) the more direct effect of oxygen adsorption on the Co nanomagnets. The difference in the orientation of the long axis of the nanomagnets will affect the number and nature of

available sites for CO adsorption. Assuming that CO adsorbs on the atop and/or long-bridge sites, as is the case for the Cu(110) surface,¹² the total number of atop and long-bridge sites around the island edges will be different for the two orientations due to the twofold symmetry of the Co(110) surface; there will be more (less) atop sites (long-bridge sites) available when the islands are elongated along the [1-10] direction than when elongated in the [001] direction. It is reported in the literature that at the hcp Co(0001) surface the atop site is first populated with the subsequent adsorption in bridge position.¹³ Assuming that CO adsorbs on the atop sites for the fcc Co(110) surface as well, this suggests that the number of occupied atop sites is important in order for the easy axis switch to occur. Recent tight-binding studies of the CO chemisorption effect on hcp cobalt magnetization indicate that the CO molecule in the atop position is effective in local moment quenching whereas adsorption on the bridge site leaves the magnetic moments intact.¹⁴ A corresponding effect on the anisotropy can be expected.

Alternatively, it is also very likely that the CO can no longer adsorb on the sites it prefers at room temperature due to the presence of the oxygen. For example, repulsive interactions between atomic oxygen and CO on low index Ni surfaces, to which both gases readily adsorb at the step edges, result in coadsorption-induced changes in the distribution of CO adsorption sites. When oxygen fully saturates sites along the step edge, the steps are completely blocked from CO adsorption and virtually all the CO population on the terraces shifts from atop to bridge sites.^{11,15}

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