Formation of a NiO-Like Single Layer at the Surface of a Ni Thin Film

Depth-resolved X-ray absorption spectroscopy combined with circular and linear polarizations reveals that a NiO-like single layer is formed by growing a Ni thin film on an oxygen-precovered Cu(001) surface. The surface layer exhibits a NiO-like X-ray absorption spectrum, while the underlying layers show a spectrum typical of a metallic Ni film. A small magnetization is found for the surface NiO-like layer, which is antiparallel to that for the underlying Ni layers. On the other hand, no magnetic linear dichroism signal is observed. We have demonstrated a potential for fabricating a sharp interface between ferromagnetic and antiferromagnetic materials.

The interface between ferromagnetic (FM) and antiferromagnetic (AFM) materials has attracted much interest, since the magnetic interaction between FM and AFM layers is a key technology in spintronics devices. Although an atomically-flat interface is desirable in order to control and understand the interface effects, such a sharp interface cannot easily be obtained by just growing two thin films due to experimental difficulties such as intermixing and lattice mismatch at the interface. In the present study, we adopted another fabrication method, in which a Cu(001) substrate is first covered with atomic oxygen and then a Ni film is grown on the oxygen-covered surface. The oxygen atoms remain at the surface during the Ni deposition, leading to O/Ni/Cu(001) [1]. We have used the depth-resolved X-ray absorption technique [2] combined with circular and linear polarizations in order to reveal the formation of a NiO-like layer at the surface and to investigate the magnetic structure of the surface layer [3].

All of our experiments were performed in an ultra-high vacuum chamber, which was connected to the undulator beamline, BL-16A [4]. A Cu(001) single crystal was mounted with the [110] direction lying in the horizontal plane, and was rotated around the vertical axis to control the geometry between the sample and the X-ray polarization. The sample preparation procedure is schematically illustrated in Fig. 1. A clean and ordered Cu(001) surface was dosed with 5.2×10^{-4} Pa O_2 at 500 K for 300 s, yielding an atomic-O covered Cu(001) surface. Then, a 5.5 ML (monolayer) Ni film was grown on the O/Cu(001) surface by electron bombardment heating of a Ni rod. Since the oxygen atoms remain at the surface [1], the O/Ni/Cu(001) sample was obtained after Ni deposition. Circular dichroism measurements were performed at 100 K in the remanent state after the sample was magnetized along the [110] direction by a magnetic field of ~500 Oe for 1 s. We also applied the linear dichroism technique by using the horizontally and vertically polarized X-rays from the undulator combined with the sample rotation around the vertical axis. The depth-resolved X-ray absorption technique [2] was used to extract the surface and inner layer components of the X-ray absorption spectra.

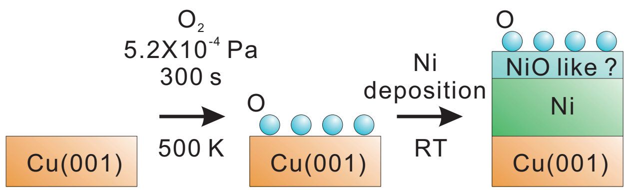

Figure 1
Schematic diagram of sample preparation.

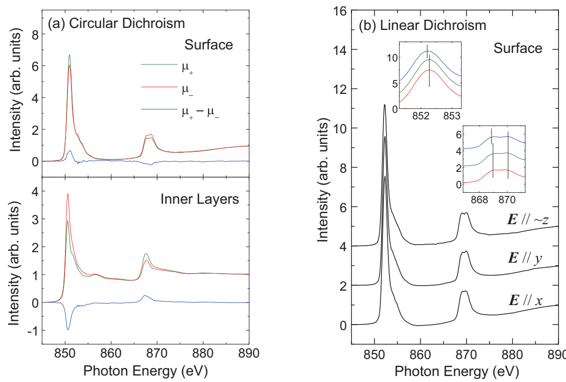

Figure 2
Extracted circular dichroism spectra for the surface and inner layers (a) and linear dichroism for the surface layer. ***E*** denotes the electric vector of the linear polarized X rays, and *x* corresponds to the magnetization direction of the inner Ni layers.

The extracted X-ray absorption spectra with circular polarization are shown in Fig. 2(a). The spectra for the surface single layer exhibit characteristic features of NiO, *i.e.* a shoulder structure at the L_3 peak and a double-peak feature at the L_2 edge, while those for the underlying inner layers show spectra typical of metallic Ni. In addition, a small magnetization, whose size is estimated to be 0.3 ± 0.2 μ_B/atom, is found for the surface NiO-like layer, which is antiparallel to that in the underlying Ni layers. This suggests an antiferromagnetic interaction at the FM/AFM interface. On the other hand, no linear dichroism is observed between the X-ray absorption spectra for the surface layer taken in the *E*//*x* and *E*//*y* configurations as shown in Fig. 2(b), suggesting that the spin moment has no preferential direction for either the *x* or *y* axis. Although a small difference can be seen between the *E*//(*x*, *y*) and *E*//~*z* configurations, this difference is attributed to geometric anisotropy of the single layer, *i.e.* different environments between the in-plane (*x*, *y*) and out of plane (*z*) directions, and therefore is not of magnetic origin. These results obtained from the circular and linear dichroism techniques are consistently interpreted by assuming a small rotation of the AFM spin moments in the surface NiO-like layer induced by an antiparallel coupling with the underlying Ni layers.

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