Formation of a NiO-like surface single layer by deposition of Ni on O/Cu(001) revealed by depth-resolved X-ray absorption spectroscopy

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The interface between ferromagnetic (FM) and antiferromagnetic (AFM) materials has attracted much interest, since the magnetic interaction between the FM and AFM layers leads to a key technology in spintronics devices. Although an atomically-flat interface is desirable in order to enhance and investigate the interface effects, such a sharp interface can hardly be obtained by just growing FM and AFM thin films. On the other hand, although it might be possible to oxidize only around the surface of a FM film in order to form the AFM/FM interface, e.g., NiO/Ni, the amount of oxidation must be carefully controlled to avoid excess oxidation. 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 always stay at the surface during the Ni deposition, leading to O/Ni/Cu(001). Thus, the thickness of the surface oxide-like layer is expected to be limited to 1 ML. We have adopted the depth-resolved X-ray absorption spectroscopy (XAS) technique [1] in order to reveal the formation of a NiO-like layer at the surface [2].

All the experiments were performed *in situ* in an ultrahigh vacuum chamber at the beamlines BL-7A and 16A of the Photon Factory, Japan. A clean and ordered Cu(001) single crystal was first dosed with O_2 at 500 K, leading to saturated adsorption of atomic oxygen on the surface. The Ni film was then grown on the oxygen-precovered Cu(001) surface at room temperature by the electron bombardment evaporation of a Ni rod. The depth-resolved XAS was measured in the partial electron yield mode by using an imaging-type detector, in order to obtain a set of spectra with different electron detection angles, which correspond to different probing depths.

The XAS spectra for the surface and inner layers are separately obtained by analyzing a set of XAS spectra at different probing depths [1]. The extracted XAS spectrum for the surface single layer exhibits spectral features characteristic to NiO, while that for the underlying layers shows a typical spectrum for metallic Ni. We have thus demonstrated a potential to fabricate a sharp interface between FM and AFM materials. In addition, X-ray magnetic circular dichroism (XMCD) measurements were performed. It is revealed that the surface NiO-like layer has a small uncompensated spin moment, which is antiparallel to that in the underlying Ni layers, suggesting an antiferromagnetic interaction at the interface. On the other hand, no X-ray magnetic linear dichroism (XMLD) is found for the surface layer. A possible magnetic structure in the surface layer will be shown, which does not contradict with the XMCD and XMLD results.

[1] K. Amemiya, et al., Appl. Phys. Lett. 84, 936 (2004).
[2] K. Amemiya and M. Sakamaki, Appl. Phys. Lett. 98, 012501 (2011).