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Direct observation of an oscillatory surface magnetization in Fe/Ni/Cu(100) films

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Introduction

The magnetic depth profile of Fe/Cu(100) films has been extensively studied[1–3]. It has been claimed that the surface two layers are ferromagnetically coupled, while the inner layers are in the antiferromagnetic or spin density wave state below ~200 K. If the Fe film is deposited on a ferromagnetic substrate, the interface (bottom) layer should interact with the substrate, and one can expect some magnetic coupling between the surface and interface via the inner layers. In the present study, we have investigated the magnetic structure of the surface and interface of Fe films grown on a Ni/Cu(100) film with the depth-resolved XMCD technique[3].

Experiments

All the experiments were performed at BL-7A in an ultrahigh-vacuum chamber. Fe and Ni were deposited on a clean and ordered Cu(100) single crystal at room temperature. A series of partial electron yield XMCD spectra with various probing depths were simultaneously recorded by separately collecting the emitted electrons at various detection angles[3]. All the spectra were taken at grazing x-ray incidence, since the present films exhibited an in-plane magnetization.

Results and Discussion

A series of XMCD spectra from Fe(4–11 ML)/Ni(6 ML)/Cu(100) films are given in Fig.1 with various probing depths, λ_e. All the spectra from the 4 ML film are almost identical independent of λ_e, indicating a simple ferromagnetic structure. In contrast, the XMCD intensity from the 4.5 ML film drastically decreases as λ_e increases. Moreover, the XMCD signal shows an opposite sign to that from the 4 ML film. These results unambiguously indicate that the surface of the 4.5 ML film has an opposite magnetization to the applied filed, and that its magnitude is larger than that of the inner layers.

As the Fe thickness increases, the XMCD signal is diminished, and almost vanishes at 6 ML. Then it increases with an opposite sign up to 9 ML, and vanishes at 10 ML. Thus, we have directly observed an oscillatory behavior in the surface magnetization as a function of Fe thickness. Note here that the Ni film exhibited a positive magnetization independent of the Fe thickness (spectra not shown).

We analyzed the obtained data by assuming that the surface two layers and interface (bottom) single layer have magnetizations, M_{surface} and $M_{\text{interface}}$, respectively, and that the rest inner layers are nonmagnetic. This simple model can be qualitatively justified by following reasons; (1) the magnitude of the surface magnetization is larger than that of the underlying layers, as directly suggested from the present data, (2) surface two layers of the Fe/Cu(100) film are ferromagnetically coupled, while the inner layers are nonmagnetic above 200 K[1–3], (3) the bottom layer is directly attached to the ferromagnetic Ni film. The analyses indicated that M_{surface} oscillates as a function of Fe thickness, while $M_{\text{interface}}$ stays almost unchanged between 5 and 11 ML, suggesting an oscillatory magnetic interaction between the surface and interface via the nonmagnetic inner layers.

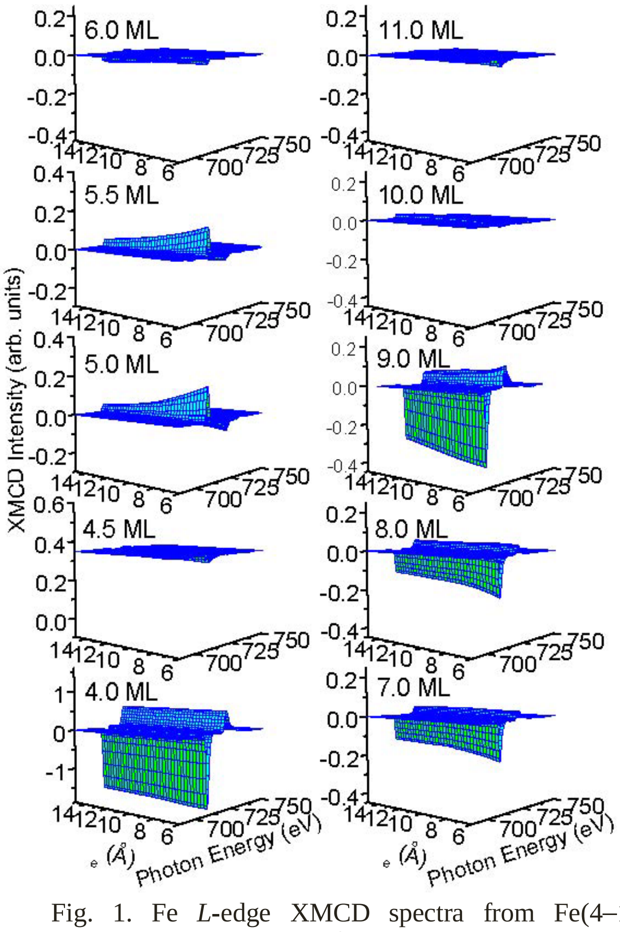

Fig. 1. Fe L-edge XMCD spectra from Fe(4–11 ML)/Ni(6 ML)/Cu(100) films with various probing depths, λ_e, taken at 200 K.

References

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