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The Spin Reorientation Transitions and Magnetic Anisotropy Energies of Fe/Ni/Cu(001) films studied by depth-resolved XMCD technique

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Introduction

It has been reported that the Ni films on Cu(001) exhibit an in-plane magnetization below 8 ML, and a perpendicular one between 9-37 ML [1]. It is also known that the magnetic anisotropy is sensitive to surface or interface structures. For instance, H or CO adsorption stabilizes the perpendicular magnetic anisotropy [2].

In the present study, we investigated Fe/Ni/Cu(001) magnetic films to clarify the magnetic anisotropy and the depth profiles of the nickel orbital magnetic moment.

Experiments

XMCD experiments were performed at BL-7A. Fe and Ni films were deposited on a cleaned Cu(001) by an electron-beam evaporation. The thickness was monitored by a RHEED observation. To obtain the magnetic anisotropy phase diagram, wedge-shaped Ni samples were prepared, which slopes were 1-2 ML/mm. The sample was magnetized by a pulsed current through a coil.

Circularly polarized(~80%) x-rays were obtained by using the light emitted downwards from the electron orbit of the storage ring. In order to reveal the depth profiles of the Ni orbital magnetic moment, depth-resolved XMCD study [3] was performed in the partial electron yield mode by using a microchannel plate detector. XMCD spectra were obtained by reversing the film magnetization. The direction of the magnetization was examined by measuring XMCD spectra at normal (90º) and grazing (30º) x-ray incidences, which are referred to "NI" and "GI", respectively.

Results and discussion

Fig. 1a shows a series of XMCD spectra taken during a stepwise Fe deposition on a Ni(7.5 ML)/Cu film. The spectra show in-plane, perpendicular, and in-plane magnetization as the Fe thickness increases. From a series of XMCD measurements for the wedged Ni samples, a magnetic anisotropy phase diagram of Fe/Ni/Cu was obtained (see Fig. 1b). Note here that in-plane magnetized Ni films (<9 ML) undergo twice spin reorientation transitions (SRTs). The first one to perpendicular occurs even with a small amount (<0.5 ML) of Fe deposition. In contrast, the perpendicularly magnetized Ni/Cu film (< 16 ML in the present experiment) shows a SRT to in-plane magnetization by 1-2 ML Fe film deposition.

The depth-resolved XMCD spectra were analyzed to obtain probing depth dependences of the Ni orbital magnetic moment(not shown). The magnetic anisotropy energy(MAE) should be proportional to the orbital moment difference between perpendicular and in-plane magnetization[4,5]. Then MAE values can be estimated by this relationship and the magnetic moment data. The obtained MAEs of nickel are listed in table 1.

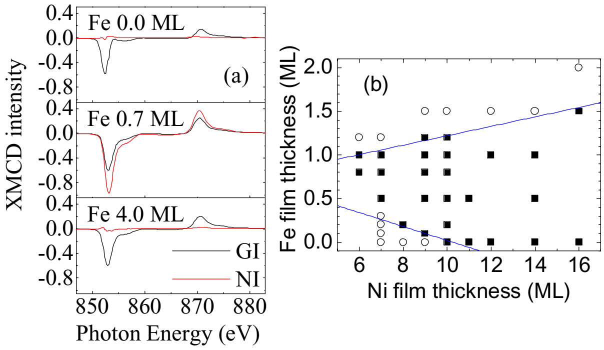

Fig. 1. (a) Ni *L*-edge XMCD spectra of Fe(x ML)/Ni(7.5 ML)/Cu(001). (b) The magnetic anisotropy phase diagram of Fe/Ni/Cu(001). The open circle represents in-plane magnetization, the solid square perpendicular.

According to table 1, the MAE of the top layer is significantly reduced upon iron deposition, while that of the inner layer almost remains.

The MAEs of iron were also estimated to be 210 (< 1 ML) and 13 μeV/atom (2 ML). This means that the single layer iron favours perpendicular magnetization strongly, while the 2 ML-thick iron does not.

The two boundary lines which can be obtained from the data such as the MAEs are depicted in Fig.1b as blue lines. These are in good agreement with the points experimentally obtained. Thus, the SRTs can be understood at the depth-resolved point of view.

Table 1: The magnetic anisotropy energy values of Ni

(μeV/atom)	Bare Ni	Fe covered Ni
Top layer	-177	-36
Inner layer	33	34

References

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