Magneto-optical Kerr rotation spectra in Fe ultrathin film on noble metals

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We report on the Kerr effects of ultrathin Fe films on Au or Ag (100) substrates. In 3.5-4.5 eV, a new $\phi_K$ peak appears only in Fe/Au. The $\varepsilon_{xy}$ of Fe film below 8 Å deposited on Ag is different from that of bulk, and shows some structures in 2-3 eV. This is thought to be due to polarized Au atoms adjacent to Fe layer.

1. Introduction

It is supposed that an ultrathin film has an electronic structure which is different from the bulk state. So far many theoretical and experimental works have been done on the electronic structures of ultrathin films [1]. However only a few works have been reported in the field of the magneto-optical effect of thin ferromagnetic films except for SMOKE [2]. Recently, we found a new magneto-optical Kerr rotation peak in Fe ultrathin films below 8 Å. These films were deposited on Au buffer layers [3]. Himpsel found evidence for the existence of quantum well states in Fe ultrathin films deposited on Au using inverse photoemission spectroscopy (IPES) [4,5].

In this experiment, we prepared several kinds of Fe ultrathin films deposited on Ag(100) buffer layers. The magneto-optical Kerr rotation ($\phi_K$) spectra of these films were measured and compared with those deposited on Au buffer layers.

2. Experimental procedures

All the samples were deposited by means of a molecular beam epitaxy (MBE) technique using electron gun sources for Fe and Au and a Knudsen cell for Ag. During the deposition, the vacuum in the MBE chamber was better than $10^{-10}$ Torr. A (100) cleaved MgO single crystal was used as a substrate. After a thermal flashing of the substrate at 900°C, an fcc Ag(100) layer of 2000 Å was deposited on the substrate at room temperature (RT). This Ag film was annealed at 450°C for 1 minute. After cooling down to RT, a bcc Fe(100) layer was deposited on it and covered by an Au layer of 20 Å. The thicknesses of Au and Fe films were measured by a quartz thickness monitor and controlled by a shutter system. The growth modes were monitored by observation of reflective high energy electron diffraction (RHEED) patterns.

The $\phi_K$ spectra at RT were measured by a Kerr rotation spectrometer in the photon energy range from 1.55 to 5.3 eV. The angle of incidence was 10 degree from the film surface normal. The Kerr ellipticity ($\eta_K$) spectra were calculated from the value of $\phi_K$ by using the Kramers–Kronig (K–K) relation [3,6]. We calculated off-diagonal elements of the dielectric tensor ($\varepsilon_{xy}$) in Fe layers using the values of diagonal elements of the dielectric tensor ($\varepsilon_{xx}$) from the literature [7,8] under the assumption of no $\varepsilon_{xy}$ in noble metal layers.

3. Results

Fig. 1 shows the changes of the $\phi_K$ spectra as a function of Fe layer thickness ($d$) in Au(20 Å)/Fe (d Å)/Au(2000 Å)/Ag(2000 Å)/MgO(100) films. The vertical axis means a normalized value of $\phi_K$ by the Fe film thickness. A large peak, which is a plasma enhancement due to the Au buffer layer, is observed at 2.5 eV. A new $\phi_K$ peak appears in 3.5-4.5 eV for Fe films thinner than 10 Å. This peak shifts toward higher energies with increasing Fe thickness.

In fig. 2(a), (b) the changes of $\phi_K$ and $\eta_K$ spectra as a function of $d$ in Au(20 Å)/Fe(d Å)/Ag(5000 Å)/MgO(100) films are shown. A negative large enhanced $\phi_K$ peak is also observed at 3.8 eV. We cannot confirm a new peak in 3.5-4.5 eV contrary to the Au cases. But, there seem to exist in the 2-3 eV range some $\phi_K$ structures for Fe layers thinner than 8 Å. Such kinds of $\phi_K$ structures were not observed in the Fe layer above 10 Å.
Fig. 1. Magneto-optical polar Kerr rotation ($\phi_K$) spectra as a function of Fe layer thickness ($d$) in Au(20Å)/Fe(d Å)/Au(2000Å)/Ag(2000Å)/MgO(100) films at room temperature. The vertical axis means values of $\phi_K$ normalized by the Fe film thickness.

In fig. 3(a), (b) are shown the spectra of the real part ($\epsilon_{xy}$) and the imaginary part ($\epsilon'_{xy}$) as a function of $d$ in Au(20Å)/Fe(d Å)/Ag(5000Å)/MgO(100) films. The $\epsilon_{xy}$ and $\epsilon'_{xy}$ spectra of bulk Fe [9] are shown as a comparison. The $\epsilon_{xy}$ structures near 3.8 eV are thought to be due to an analytical error caused by errors of the optical constants of Ag [7]. The whole shape of the $\epsilon_{xy}$ spectrum has a tendency to approach towards that of bulk Fe with increasing Fe thickness. In the 2–3 eV range, there are some structures of $\epsilon_{xy}$ in Fe films thinner than 8 Å. We measured an $\epsilon_{xy}$ change as a function of the Au layer thickness ($x$) in Au(20Å)/Ag(10Å)/Fe(3Å)/Au($x$ Å)/Ag(4000Å)/MgO(100) films to investigate the effect of the Au layers. As a result, it is found that the $\epsilon_{xy}$ structure near 2–3 eV varies with changing $x$.

4. Discussion

As shown in fig. 1, a new $\phi_K$ peak is observed. This peak shifts to higher energies with increasing Fe thickness in Fe ultrathin film deposited on Au. The phenomenon is thought to be due to a formation of quantum well states in Fe ultrathin films [3,6]. In the case of an Ag buffer layer, the $\phi_K$ peak does not appear at the same photon energy region. As a possible reason why the new $\phi_K$ peak did not appear in the Fe layer deposited on Ag, we consider the following two reasons: (1) The influence of the large $\phi_K$ enhancement by the plasma edge of Ag. (2) The difference of crystal growth.

One of the reasons is that, since there is a large effect from $\phi_K$ enhancement due to the plasma edge of Ag near 3.5–4.5 eV, the appearance of a new peak may hardly be observed. It is found that this has not such a large effect upon the phenomenon from
5. Conclusion

We measured the magneto-optical polar Kerr effects on (100) ultrathin Fe film deposited on Au or Ag buffer (100) surfaces. In the photon energy region between 3.5 and 4.5 eV, a new $\phi_K$ peak appears in the Fe layers deposited on Au, whereas the new peak cannot be observed in Fe layers deposited on Ag. These phenomena are thought to be closely connected with the formation of quantum well states in Fe layers. The result of the RHEED intensity oscillation suggests that Fe layers deposited on Ag do not show a good layer-by-layer growth contrary to that of Fe layers deposited on Au. For this reason no quantum well states should be expected in Fe layers on Ag. The $\epsilon_{xy}$ spectra of Fe film less than 8 Å is different from that of bulk Fe. There are some structures of $\epsilon_{xy}$ in Fe films thinner than 8 Å, in the range of about 2–3 eV. These structures are tentatively attributed to spin-polarized Au atoms adjacent to the Fe layer.

References