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

M. Hayashi [a], T. Katayama [b], Y. Suzuki [b], M. Taninaka [a], A. Thiaville [c] and W. Geerts [d]

[a] *College of Science & Technology, Nihon University, Funabashi, Chiba 274, Japan*
[b] *Electrotechnical Laboratory, Umezono 1-1-4, Tsukuba, Ibaraki 305, Japan*
[c] *Université de Paris Sud, Lab. de Physique des Solids, 91405 Orsay, France*
[d] *University of Twente, MESA Institute, 7500 AE Enschede, The Netherlands*

We report on the Kerr effects of ultrathin Fe films on Au or Ag (100) substrates. In 3.5–4.5 eV, a new ϕ_K peak appears only in Fe/Au. The ϵ_{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 (ϕ_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 ϕ_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 (η_K) spectra were calculated from the value of ϕ_K by using the Kramers–Kronig (K–K) relation [3,6]. We calculated off-diagonal elements of the dielectric tensor (ϵ_{xy}) in Fe layers using the values of diagonal elements of the dielectric tensor (ϵ_{xx}) from the literature [7,8] under the assumption of no ϵ_{xy} in noble metal layers.

3. Results

Fig. 1 shows the changes of the ϕ_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 ϕ_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 ϕ_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 ϕ_K and η_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 ϕ_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 ϕ_K structures for Fe layers thinner than 8 Å. Such kinds of ϕ_K structures were not observed in the Fe layer above 10 Å.

Correspondence to: Dr. Toshikazu Katayama, Electrotechnical Laboratory, Umezono 1-1-4, Tsukuba-shi, Ibaraki 305, Japan. Tel: 0298-58-5426 or 5433, Fax: 0298-58-5434.

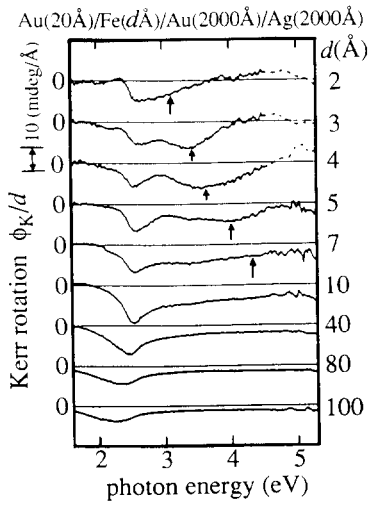

Fig. 1. Magneto-optical polar Kerr rotation (ϕ_K) spectra as a function of Fe layer thickness (d) in Au(20 Å)/Fe(d Å)/Au(2000 Å)/Ag(2000 Å)/MgO(100) films at room temperature. The vertical axis means values of ϕ_K normalized by the Fe film thickness.

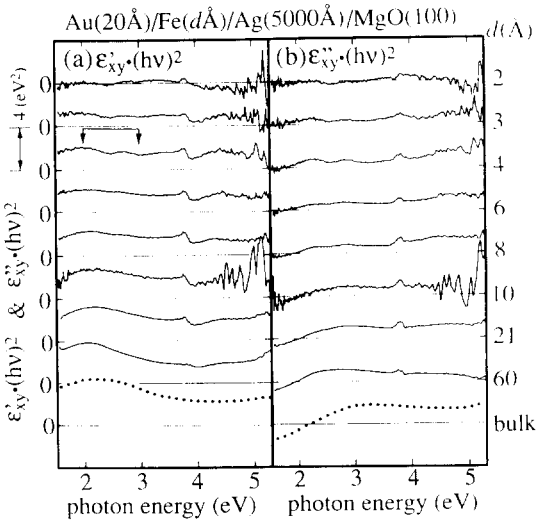

Fig. 3. Changes of the spectra of off-diagonal elements (ϵ_{xy}) of the dielectric tensor as a function of Fe layers thickness (d) in Au(20 Å)/Fe(d Å)/Ag(5000 Å)/MgO(100) films. The spectra of Fe bulk are shown as a comparison. (a) real part of ϵ_{xy}, (b) imaginary part of ϵ_{xy}.

In fig. 3(a), (b) are shown the spectra of the real part (ϵ'_{xy}) and the imaginary part (ϵ''_{xy}) as a function of d in Au(20 Å)/Fe(d Å)/Ag(5000 Å)/MgO(100) films. The ϵ'_{xy} and ϵ''_{xy} spectra of bulk Fe [9] are shown as a comparison. The ϵ_{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 ϵ'_{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 ϵ_{xy} in Fe films thinner than 8 Å. We measured an ϵ'_{xy} change as a function of the Au layer thickness (x) in Au(20 Å)/Ag(10 Å)/Fe(3 Å)/Au(x Å)/Ag(4000 Å)/MgO(100) films to investigate the effect of the Au layers. As a result, it is found that the ϵ'_{xy} structure near 2–3 eV varies with changing x.

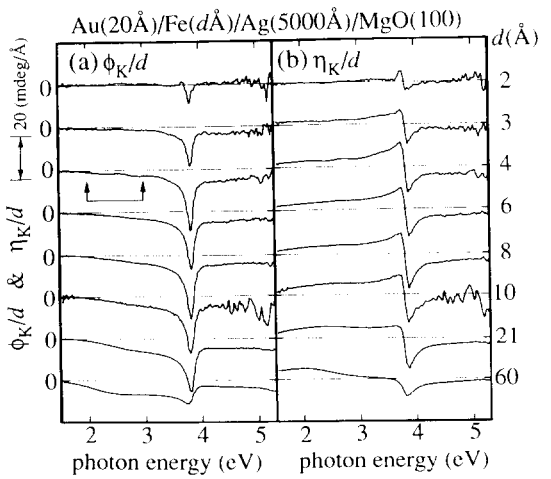

Fig. 2. Magneto-optical polar Kerr spectra as a function of Fe layer thickness (d) in Au(20 Å)/Fe(d Å)/Ag(5000 Å)/MgO(100) films at room temperature. (a) Kerr rotation (ϕ_K) spectra, (b) Kerr ellipticity (η_K) spectra. The vertical axis means values of ϕ_K and η_K normalized by Fe film thickness.

4. Discussion

As shown in fig. 1, a new ϕ_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 ϕ_K peak does not appear at the same photon energy region. As a possible reason why the new ϕ_K peak did not appear in the Fe layer deposited on Ag, we consider the following two reasons: (1) The influence of the large ϕ_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 ϕ_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

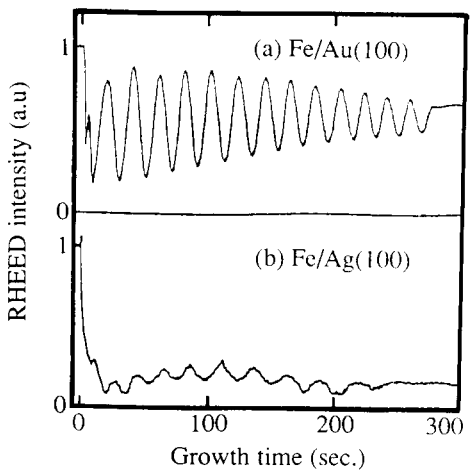

Fig. 4. The RHEED intensity oscillations during the growth of Fe layer deposited on (a) Au(100) and (b) Ag(100) buffer layers.

the results of difference of ϕ_K spectra between Au(20 Å)/Fe(3 Å)/Au(2000 Å)/Ag(2000 Å)/MgO and Au(20 Å)/ Fe(3 Å)/ Ag(10 Å)/ Au(2000 Å)/ Ag(2000 Å)/ MgO films [6]. Next, we investigated the influence of the difference of growth modes between Fe layers on Au and Ag buffer layers. In fig. 4 the RHEED intensity oscillations during the growth of the Fe layer on Au and Ag (100) surfaces are shown. In the case of a Fe layer on Au, the RHEED intensity oscillation continues for a long time. On the other hand for the growth of Fe on Ag the oscillation is not clearly observed. This result suggests that the Fe layer on Ag has a poor layer-by-layer growth different from that of Fe layer deposited on Au, which in turn suggests that quantum well states are not formed in a Fe layer on Ag.

The shape of the ϵ_{xy} spectra of Fe films less than 8 Å deposited on Ag are different from that of Fe bulk state. This suggests that the electronic structure of Fe film less than 8 Å is different from that of bulk Fe. And, in Fe films thinner than 8 Å on Ag, there are some structures of ϵ_{xy} in 2–3 eV. The ϵ'_{xy} structure is thought to be related with polarized Au atoms adjacent to the Fe layer from the following two reasons: (1) Schnatterrly reported a magneto-optical transition of polarized Au atoms near the plasma edge where an optical transition between s, p and d bands occurs in Au [10]. (2) The ϵ'_{xy} spectra change with Au layer thickness (x) in Au(20 Å)/ Ag(10 Å)/ Fe(3 Å)/ Au(x Å)/Ag(4000 Å)/MgO(100) films.

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 ϕ_K peak appears in the Fe layers deposited on Au, whereas we 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 ϵ'_{xy} spectra of Fe film less than 8 Å is different from that of bulk Fe. There are some structures of ϵ'_{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.

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