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Magneto-optical and optical properties of Fe-Au alloy films in a wide composition range

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Abstract

Fe-Au alloys are characterized by the complete solubility, and exhibit an *fcc-bcc* structural transformation at the Fe-rich side. The magneto-optical(equatorial Kerr effect : EKE) and optical properties of $Fe_{1-x}Au_x$ $(0 < x < 1)$ were investigated in the 0.5 - 5.0 eV energy range. The x-ray diffraction study shows the structural *fcc-bcc* transformation about 80 at.% of Fe. Noticeable changes in the optical properties caused by the *fcc-bcc* structural transformation was observed. The shape and intensity of the EKE spectra as well as the field dependence of the magneto-optical response were also significantly changed. It is thought that these changes are mainly comes from the induced magnetic monent in Au(and/or the emhanced magnetic moment of Fe). The nature of the prominent structure observed in the UV range of the magneto-optical Kerr effect of Au/Fe multilayered films are disscussed in connection with the above results.

1. Introduction

Artificially made metallic multilayered films(MLF) which are made of magnetic and nonmagnetic substances have attracted wide interest due to their novel physical properties such as enhanced magnetoresistance, long-range exchange coupling, and large perpendicular magnetic anisotropy [1]. Among the various MLF systems, Au/Fe MLF have been studied intensively during the recent years experimentally and theoretically. But the nature of the prominent structure observed in the UV range of the magneto-optical Kerr effect(MOKE) spectra is still disputable. According to Suzuki *et al.* [2] and Takanashi *et al.* [3] this structure results from the formation of quantum well states in the very thin Fe layers. On the other hand, theoretical calculation of the magnetic properties of Au/Fe MLF revealed enhancement in the magnetic moment at the Fe sites and an induction of small and oscillating(with Au sublayer thickness) magnetic moment of the Au atoms [4]. It is well known that the MOKE is caused by the simultaneous occurrence of spin polarization and spin-orbit coupling in a magnetic solids. Therefore, the enhancement in the UV region of the Kerr response of the Au/Fe MLF can also be induced by the enhanced magnetic moment at the Fe sites, a strong spin-orbit coupling of Au atoms, or the induced magnetic moment of Au atoms. Moreover, owing to their complete solubility, Au/Fe MLF may contain Au-Fe alloy layers in interface regions between sublayers. Hence, the induced magnetic moment of the Au atoms or the enhanced magnetic moment of the Fe atoms can be thought as the common phenomena for the Au/Fe MLF as well as Au-Fe alloy films. There is no doubt that the study on the Au-Fe alloy film should be performed to understand the nature of prominent feature in the MOKE spectra of in the UV

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region as well as magnetic properties of Au/Fe MLF.

In this study, magneto-optical and optical properties as well as magnetic properties of Au-Fe alloy films were investigated. Since the Fe-Au alloy .exhibits structural transformation from *fcc* to *bcc* at the Fe-rich side, special concentrations were devoted to understand the changes in physical properties due to *fcc-bcc* structural transformation.

2. Experimental

$Au_{1-x}Fe_x$ ($0 < x < 1$) films of about 100 - 150 nm in thickness were fabricated by using face-to-face sputtering technique onto a glass substrate at room temperature. The chamber was evacuated down to 1×10^{-6} mbar before sputtering, and Ar pressure during sputtering was 6.5×10^{-3} mbar. The $Au_{1-x}Fe_x$ alloy films were made by simultaneous deposition of Au and Fe onto a substrate of 30×120 mm^2, located parallel to the "line" connecting the Au and Fe targets. Then, this film was cut by 12 pieces along the short side of substrate, 12 alloy samples with different compositions were obtained. Finally each samples were numbered from 1 to 12 according to the increase of Fe content. The composition of each alloy sample was determined at its central part by x-ray fluorescence and the Fe content of the films are shown in Table. 1. The structures of Au-Fe alloy films were analyzed by using the high-angle XRD. The details of the MO [equatorial Kerr effect(EKE : δ_p)] and opical conductivity(OC : σ) measurements can be found elsewhere [5].

Table 1. Fe content of $Au1-x_{Fex}$ alloy films.

sample number	Fe content
1	0.015
2	0.011
3	0.035
4	0.038
5	0.074
6	0.160
7	0.314
8	0.590
9	0.771
10	0.863
11	0.926
12	0.978

3. Results and Discussion

According to the XRD spectra of Au-Fe alloy films shown in Fig. 1, *fcc* and *bcc* types of structures are formed in $Au_{1-x}Fe_x$ alloy films for $x < 0.70$ and $x > 0.85$, respectively. A range of $0.70 < x < 0.85$ is the transition region from fcc to bcc type of structure. The lattice parameters of the films marked as 1 and 12 are very close to those of pure Au and Fe, respectively, and the lattice spacing sharply decreases at the the transition region as shown in Fig. 2. The shift and broadening of diffraction peaks at the Au-rich side is thought to be caused by the strain of lattice. When the Fe content is low, the Fe atoms can be thought as existing in the Au matrix as a solid solution state. Due to the difference in atomic radius of Fe and Au atoms, the presence of Fe atoms in Au matrix can exert strains on the *fcc* lattice of Au. The increased strain as Fe content increases result in the shift and the broadening of diffraction peaks. The breadth of peaks in this region also reflects the multiformity of

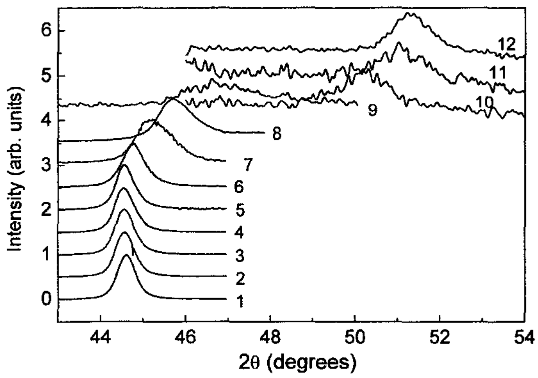

Fig. 1. X-ray diffraction patterns for $Au_{1-x}Fe_x$ alloy films. Alloy films are labled from 1 to 12 according to the Fe content(See Table. 1).

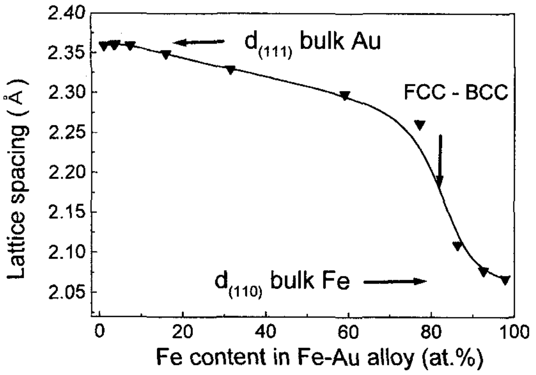

Fig. 2. Change in lattice parameter along with the Fe content in $Au_{1-x}Fe_x$ alloy films. The structural *fcc-bcc* transformation occur at about 80 at.% of Fe.

grain size. The optical conductivity, σ, spectra for the $Au_{1-x}Fe_x$ alloy film with bcc type of structure have a pronounced maximum near the energy range of 1.9 - 2.0 eV, which has the same nature as the main absorption peak of pure Fe, while for the $Au_{1-x}Fe_x$ alloy films with *fcc* type of structure this maximum is absent as shown in Fig. 3. A shift of this peak at the Fe-rich side to the low-energy side can be caused by narrowing of the Fe 3*d* band due to a reduction of the nearest Fe atoms in the *bcc* $Au_{1-x}Fe_x$ alloys.

The prominent changes caused by the *fcc-bcc* structural transformation were also observed in the EKE spectra for the $Au_{1-x}Fe_x$ alloy films. Magentic field dependence of the MO response(not shown here) reavealed that the $Au_{1-x}Fe_x$ alloy films lose ferromagnetic properties as Fe content decreases, and exhibit a non-magnetic behavior when the Fe content is less than 69 at.%. The EKE spectrum of $Au_{1-x}Fe_x$ thin films with bcc-type of structure exhibit the pronounced peak near 1.9 eV and 4.1 - 4.6 eV. A maximum at 1.7 eV in the EKE spectrum for pure Fe is transformed into a maximum at about 1.9 eV for the *bcc* $Au_{1-x}Fe_x$ alloy films with decreasing x, and then nearly disappears for the *fcc* $Au_{1-x}Fe_x$ alloy films. The high energy maximum in the EKE spectra of $Au_{1-x}Fe_x$ alloy films decreases in the intensity and shifts to the low energy side with decreasing the Fe content. No peak was observed in the spectrum of pure Fe film with bcc-type structure in this energy range. It should be mentioned here that the MO responses for the Fe-rich $Au_{1-x}Fe_x$ alloy films in an energy range of $h\nu < 3$ eV are noticeably larger than that for the pure Fe film. It is thought that the appearence of a new peak and the enhanced MO response of bcc $Au_{1-x}Fe_x$ alloy films in UV region reflect the induced magnetic moment in Au(and/or enhanced magnetic moment of Fe). Even though further study is required to estimate the magnetic moment of Fe and Au atoms in bcc $Au_{1-x}Fe_x$ alloy films, we can conclude that the prominent feature observed in the UV range of MO response of Au/Fe MLF result not from the quantum

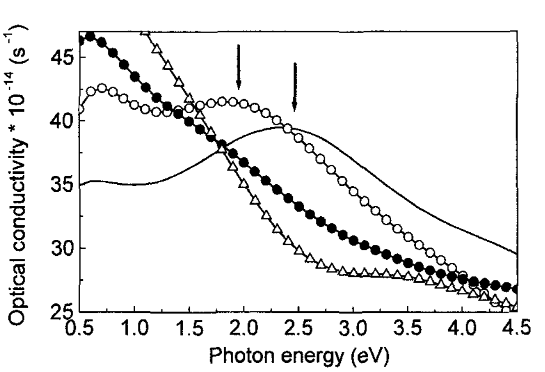

Fig. 3. Optical conductivity spectra for pure Fe(solid line), $Fe_{0.863}Au_{0.137}$(open circle), $Fe_{0.771}Au_{0.229}$ (solid circle), and $Fe_{0.590}Au_{0.410}$(open triangle) alloy films.

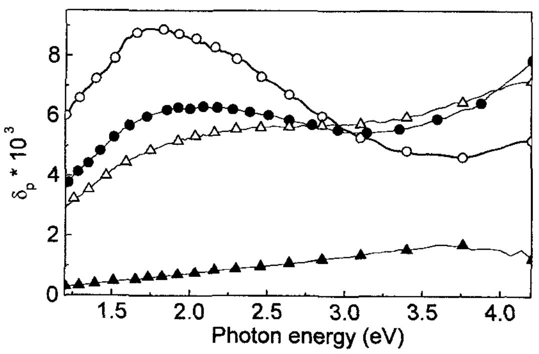

Fig. 4. Equatorial Kerr effect spectra(EKE) for pure Fe(open circle), $Fe_{0.863}Au_{0.137}$(solid circle), $Fe_{0.771}Au_{0.229}$(open triangle), and $Fe_{0.590}Au_{0.410}$(solid triangle) alloy films.

confinement, but probably from the induced magnetic moment in Au(and/or enhanced magnetic moment of Fe).

Acknowledgments

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