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Enhancement of Magneto-Optical Kerr Effect in Annealed Granular Films of Co-Au and Co-AlO$_x$

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Co fine particles were dispersed in Au metal and AlO$_x$ amorphous matrices by vacuum evaporation and rf-sputtering, respectively, thus forming granular composite films having chemical compositions of $Co_{0.59}$-$Au_{0.41}$ and $Co_{0.52}$-$(AlO_x)_{0.48}$. The films were annealed at 200~500°C to increase the size of the Co particles, from 30Å to 180Å in the Au matrix and 40Å to 180Å in the AlO$_x$ matrix, as revealed by X-ray diffraction analysis. The Co metal in as-deposited films have saturation magnetization equivalent to that of bulk Co, which is unchanged by the annealing, showing that the Co metal is not oxidized by the annealing. Magneto-optical Kerr rotation measured at λ=400-900 nm for the $Co_{0.59}$-$Au_{0.41}$ film as deposited is larger than that calculated for the composition. The rotation increases as the film is annealed at 200°C and 300°C, approaching to that of bulk Co. The Kerr rotation for the $Co_{0.52}$-$(AlO_x)_{0.48}$ film as deposited is smaller than that calculated for the composition based on Bruggeman effective medium theory. However, the rotation increases much, exceeding the rotation of the bulk Co as annealed at 300°C and 400°C. As a possible origin of the marked magneto-optical enhancement a weak localization of light in granular structure is suggested.

Key words : Granular film, Magneto-optical enhoncement, Kerr effect, Co-Au composite film, Co-AlO composite film

I. Introduction

Magnetic granular composite films, in which ferromagnetic ultra-fine particles are dispersed in non-magnetic matrices, have attracted much interest lately because of their potential applicability to ultra-high density magnetic recording media[1] and to high-performance GMR (giant magneto-resistance) materials.[2,3] We[4-6] have been involved in theoretical and experimental studies on magneto-optical (MO) properties of composite magnetic films. When the size of the granular structure of a composite is much smaller than wavelength of light, light propagates in the composite as if it is a continuous media having so-called effective dielectric tensor. The off-diagonal elements of the effective dielectric tensor, which are responsible for magneto-optical effects, were formulated by one of the authors.[4,6] He first based on Maxwell-Garnet's effective field approximation which is applicable only when volume fraction, f ($0 \leq f \leq 1$), of the particles is small ($f \approx 0$)[4] and later based on Bruggeman's symmetrized effective medium theory which is free from the restriction on f.[6]

II. Experimental

Granular films of Co-Au and Co-AlO$_x$ were deposited on quartz glass substrates (~$(5\ cm)^2 \times 1$ mm in volume) by vacuum evaporation at Ben-Gurion University[7] and by rf-sputtering at Research Institute of Electric and Magnetic Materials,[8,9] respectively. The substrates were neither heated nor cooled during deposition, left to increase in temperature during film deposition. Each granular film of Co-Au and Co-AlO$_x$ was cut into several pieces (1 cm^2 in area), which were annealed at temperatures T_a=200, 300, 400 and 500°C, for 3 hours in H_2/N_2 mixed gas for Co-Au and in vacuum for Co-AlO$_x$.

On these films crystallographic properties were analyzed by X-ray diffractometry (XRD) using Cu-Ka radiation, and magnetic properties by a vibrating sample magnetometer applying magnetic field up to 20 kOe. The chemical compositions of the films were analyzed by an inductively coupled plasma (ICP) method. From the compositions the volume fraction f of the Co particles was calculated assuming that the constituent metals, Co and Au, have densities equal to those reported for bulk samples[10] and also AlO$_x$ has a density equal to bulk Al_2O_3.[10]

The MO polar Kerr effect was measured by a polarization modulation method in a wavelength range of λ=400-900 nm not only on the samples of the Co-Au and Co-(AlO$_x$) granular films but also on that of pure Co film which was prepared by rf-sputtering for comparison.

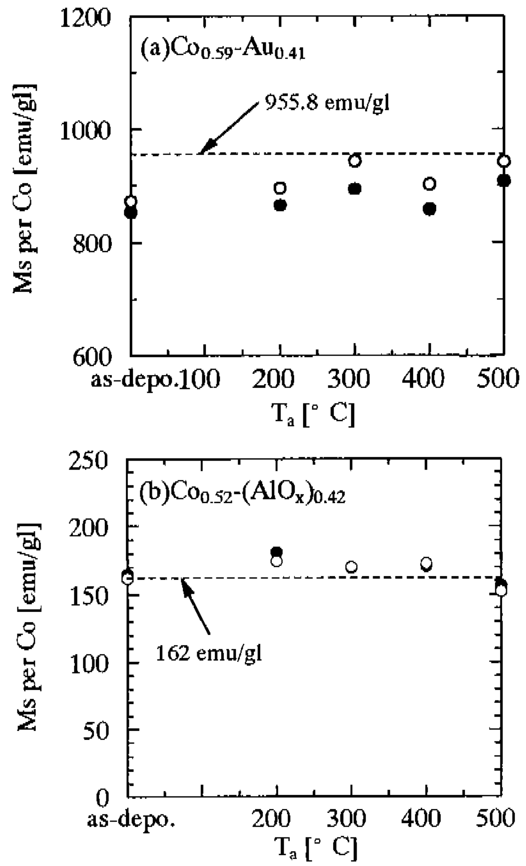

Fig. 1. Saturation magnetization Ms per Co in the (a) $Co_{0.59}$-$Au_{0.41}$ and (b) $Co_{0.52}$-$(AlO_x)_{0.48}$ films, measured parallel (closed circles) and perpendicular (opend circles) to the film plane, which is plotted as a function of annealing temperatures T_a. Dashed lines show the value for bulk Co.

III. Results and Discussion

The Co-Au and Co-AlO$_x$ films are 0.11 μm and 1.98 μm, respectively, in thickness which is large enough to measure Kerr rotation for reflected light without being perturbed by superimposed Faraday rotation from transmitted light. The films have composition (volume fraction) of $Co_{0.59\pm0.02}$-$Au_{0.41\pm0.02}$ (f=0.48) and $Co_{0.52\pm0.03}$-$(AlO_x)_{0.52\pm0.03}$ (f=0.41).

As shown in Fig. 1 the saturation magnetization per Co atom in the both films does not change appreciably by the annealing, but remains nearly equal to the value reported for bulk Co. This means that the Co metal in the films is not oxidized even by the annealing at high temperatures up to 500°C. However, the Co particles increase in size as revealed by the change in the width of the XRD scattering peak by (001) plane of hcp Co at 2θ (Cu-Kα)≈44°. (We neglected fcc (220) scattering which may superimposes on the hcp (001) scattering, because the films were deposited at relatively low temperatures where fcc Co can be hardly grown). The average size of the Co particles in the Co-Au (or Co-AlO$_x$) films increases roughly from 30 Å to 180 Å (or 40 Å to 150 Å) by the annealing.

Fig. 2(a) shows the Kerr rotation spectra for the $Co_{0.59}$-$Au_{0.41}$ films. The rotation for the film as deposited is 1.5~2 times larger than that calculated for the composition (or *f* of the film) based on the Bruggeman effective medium theory.[6] The rotation increases as annealed at T_a=200°C and 300°C, which is, when T_a is further increased to 400°C and 500°C, followed by a decrease down near to the original value obtained for the as-deposited film. The most enhanced rotation spectrum (T_a=300°C) is close to that obtained for our bulk Co film, which is in good agreement with the that reported in literature.[11]

Fig. 2(b) shows the Kerr rotation spectra for the $Co_{0.52}$-$(AlO_x)_{0.48}$ films. The rotation for the film as deposited is much smaller than the calculation, especially in the higher wavelength region. However, as the film is annealed at 300°C and 400°C the Kerr rotation increases greatly, exceeding the calculation for the composition. We could not measure Kerr rotation on the sample annealed at T_a=500°C because the surfaces of the film was roughened by the annealing.

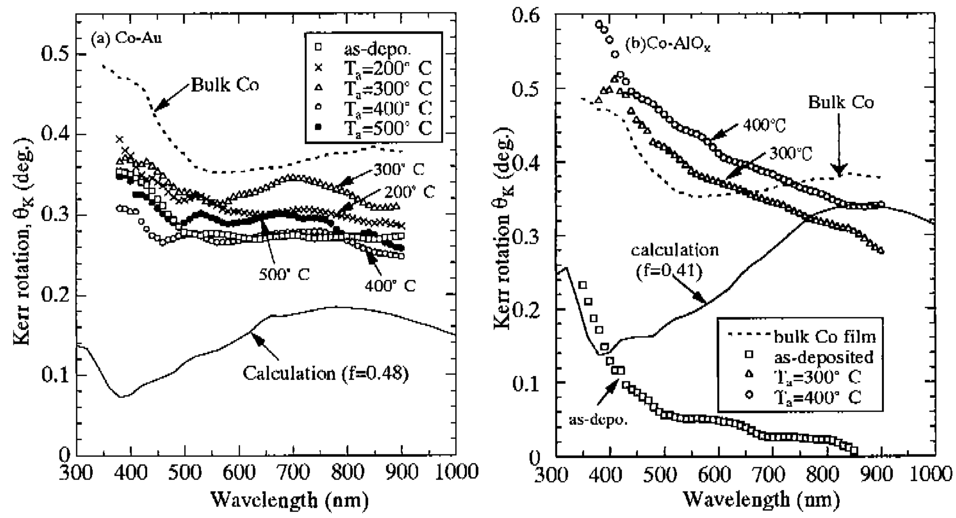

Fig. 2. Kerr rotation spectra for granular $Co_{0.59}$-$Au_{0.41}$ (a) and $Co_{0.52}$-$(AlO_x)_{0.48}$ (b) films as deposited and annealed at T_a of various values. Spectra for bulk Co (dotted line) and that calculated for respective films (solid line) are shown for comparison.

IV. Concluding Remarks

The MO Kerr effect in the $Co_{0.59}$-$Au_{0.41}$ film as deposited is much stronger than that calculated for this composition. The Kerr rotation increases as the film is annealed at T_a=200°C and 300°C, which is, when T_a is further increased to 400°C and 500°C, followed by a decrease down near to the original value obtained for the as-grown film. The Kerr rotation of the $Co_{0.52}$-$(AlO_x)_{0.48}$ film as deposited is smaller than that calculated for the composition. However, the rotation increases much, exceeding that obtained for bulk Co as the film is annealed at 300°C and 400°C.

The marked enhancement of the Kerr rotation is related to the change induced by the annealing in the granular structure, i.e. the increase in size of the Co particles and in average distance between neighboring particles. A possible mechanism for the origin of the MO enhancement in the granular structure is proposed as follows: As has been shown by theory[12] and experiment[13,14] light is weakly localized in the vicinity of metal particles in a granular material when the size of granular structure satisfies specified conditions. In our films the granular structure may become to satisfy the conditions as the films are annealed, and MO Kerr effect is enhanced because interaction between the light and the Co metal particles is strengthened by the weak localization of light.

V. References

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