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Faraday rotation in annealed granular Co-SiO_2 films

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Granular Co_x-$(SiO_2)_{1-x}$ films with composition x=0.09～0.46, or volume fraction of Co f=0.06～0.31, were prepared by rf-diode co-sputtering. They were annealed at T_a=500-900°C, by which the Co particles increased in size from ～5 to 130nm as observed by TEM. Faraday rotation measured at wavelength λ=400-900nm varies sensitively on the Co composition x (or volume fraction f), and increases when annealed at T_a=500-700°C. However, rotation decreases slightly when T_a is further raised to 900°C. Faraday rotation of the annealed samples in specified wavelength range (especially in longer range 700<λ<900nm) exceeds the value calculated from Bruggeman's effective medium theory for the respective volume fractions. The enhancement of the magneto-optical effect is ascribed to the change in granular structure (size and distribution of Co particles), which may be related to the weak localization of light in the granular structure.

Key words: granular magnetic film, Faraday effect, Bruggeman's effective theory, weak localization of light

1. 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 have been involved in theoretical and experimental studies on magneto-optical properties of composite magnetic films [4-6]. We discovered that the Ni-PVC granular films exhibit magneto-optical Faraday rotation 2～3 times stronger than that calculated from theory [4]. Kerr rotation in the Co-Au and Co-AlO_x granular films enhances in magnitude, exceeding the calculation, as the Co particles increases in size by the annealing at 400-600°C, even though the magnetization of the films are kept constant by the annealing [6].

In this study we measured Faraday rotation in granular Co_x-$(SiO_2)_{1-x}$ films, as deposited and annealed at 500-900°C. Changes observed in Co particles size and in the magnetic properties induced by the annealing are reported.

2. EXPERIMENTAL

Granular films, 270～300nm in thickness, of Co_x-$(SiO_2)_{1-x}$ were deposited on substrates of glass (Samples #3～#12) and rock-salt crystal (Sample #5') by rf-diode co-sputtering under 10mmTorr of Ar pressure. We used as target a SiO_2 disk (74mmϕ) on which Co sheets (10×10mm^2) were placed. Composition of Co in films were varied by changing the number of the Co sheets. A film sample deposited on the glass substrates (26×76×1.1mm^3) was cut into several pieces, 5×5mm^2 in area, which were annealed at temperatures T_a=500, 600, 700, 900°C, for 3 hours in a mixed gas of H_2/N_2 (=1/9). On these samples, thickness was measured by using a styrus machine and chemical composition x of Co by inductively coupled plasma (ICP) method, from which volume fraction f of Co particles was calculated assuming that the constituent materials, Co and SiO_2, have densities equal to those reported for bulk samples [7,8]. Magnetic measurement was performed with a vibration sample magnetometer applying magnetic field up to 15kOe, and Faraday effect measurement by a polarization modulation method in wavelength range of λ=400-900nm, applying magnetic field up to 15kOe. Size and dispersion of the Co particles were observed by transmitted electron microscope (TEM) on the films deposited on the rock salt substrate.

3. RESULTS

Table I shows composition, volume fraction f, and thickness of the samples. Fig. 1 shows the saturation magnetization measured perpendicular to film plane plotted as a function of annealing temperatures T_a. The magnetization increases with increasing T_a, reaching to (and kept at) a value which is equal to that reported for bulk Co when heated at above 700°C. This is because the Co particles change from superparamagnetic to ferromagnetic by the annealing; M-H hysterisis loops typical for ferromagnetic materials were obtained when $T_a \geq 700$°C, while those typical for superparamagnetic materials were obtained when $T_a \leq 600$°C. Fig. 2 shows TEM images for the sample #5' (x=0.23 , f=0.16) . The Co particles grow in size with increasing T_a, from 5 (as-deposited) to 130nm (T_a=900°C) in average.

Fig. 3 shows Faraday rotation spectra obtained for these Samples #5, 8, 12 annealed at various temperatures. In the figures spectra calculated for respective values of f of samples based on the Bruggeman's effective medium theory [5] are shown.

Sample #3 (x=0.09) as-deposited does not exhibited appreciable Faraday rotation (Fig. 3(a)). This agrees with the calculation, because the Co particles are very small in composition (x=0.09, f=0.06) and therefore in grain size. However, rotation increases prominently when annealed at 500-700°C, which slightly reduces when annealed at 900°C.

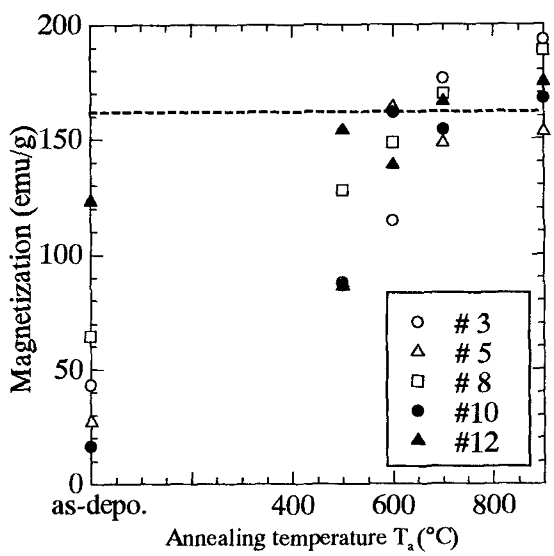
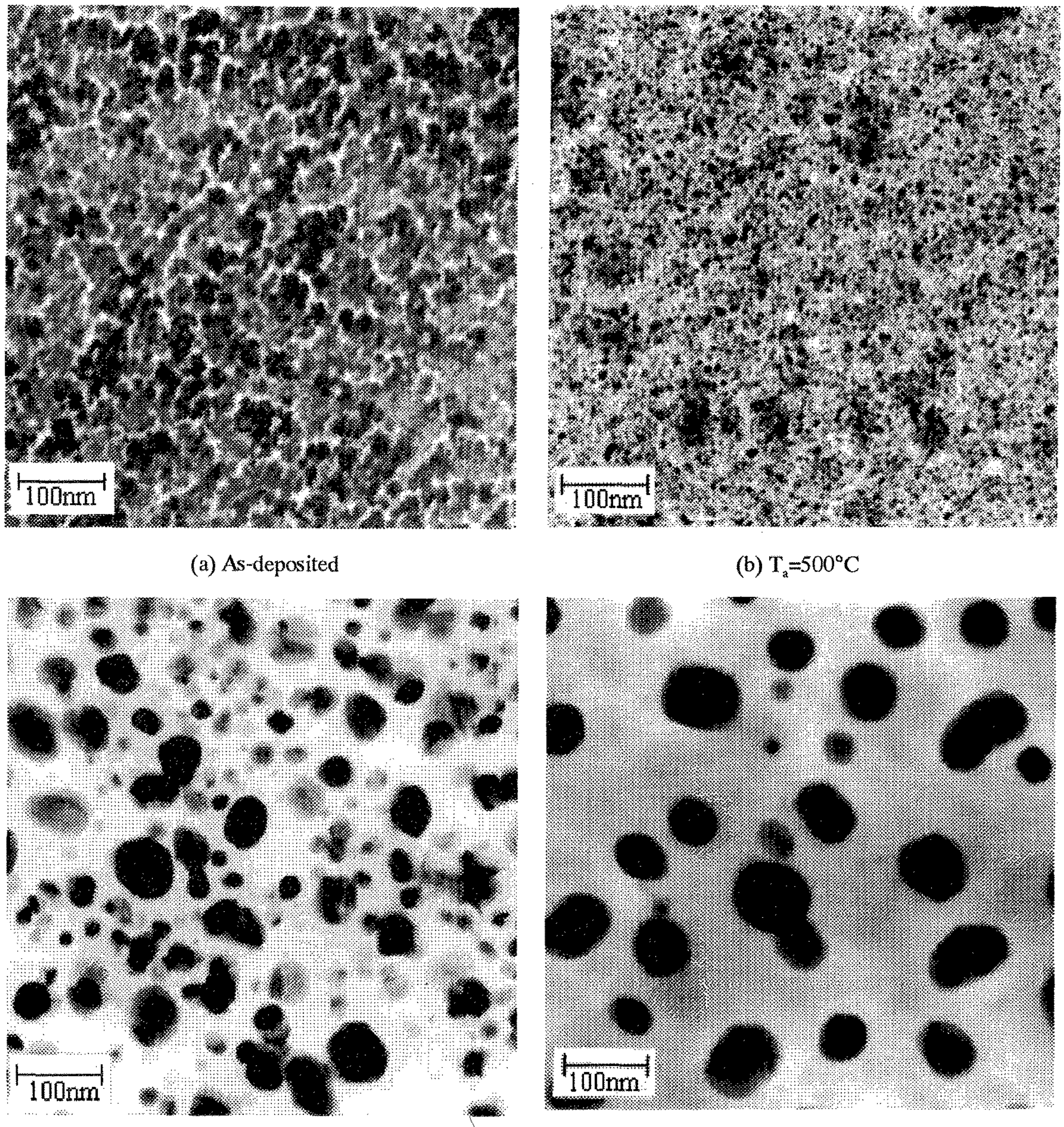


Fig. 1 Magnetization versus annealing temperature T_a in granular Co_x-$(SiO_2)_{1-x}$ films.

Table I Various parameters and substrates of Co_x-$(SiO_2)_{1-x}$ granular

Sample	Composition x	Volume fraction f	Thickness (nm)	Substrate
#3	0.09	0.06	285	glass
#5	0.21	0.14	270	glass
#5'	0.23	0.16	280	rock-salt
#8	0.25	0.17	321	glass
#10	0.41	0.28	300	glass
#12	0.46	0.31	282	glass



(a) As-deposited (b) T_a=500°C

(c) T_a= 600°C (d) T_a=700°C

Fig. 2 TEM observation on granular Co_x-$(SiO_2)_{1-x}$ films, as deposited and annealed at various values of T_a.

In Fig. 3(b) Faraday rotation of Sample #8 having greater amount of Co (x=0.25) increases in magnitude when annealed at 500-600°C. Again Faraday rotation decreases slightly when annealed at 900°C. In Fig. 3(c) Faraday rotation of Sample #12 having much greater Co concentration (x=0.46) does not show a systematic change in magnitude and in sign with annealing temperature. However, we can say that rotation at longer wavelength side (λ>600nm) increases when annealed at

4. CONCLUSIONS

Faraday rotation in Co_x-$(SiO_2)_{1-x}$ composite films varies sensitively on the Co concentration x, and increases in magnitude as the films are annealed at T_a=500-700°C, which is followed by a slight decrease when T_a is raised further to 900°C. Faraday rotation in the annealed Co-SiO_2 composite films exceeds the calculation, though in limited wavelength range. The marked increase in the magneto-optical effect is related to the changes induced by annealing in the granular structure (i.e. size and distribution of the Co particles). It may be related to the weak localization of light in the granular structure [9,10], as we described in the previous paper [6].

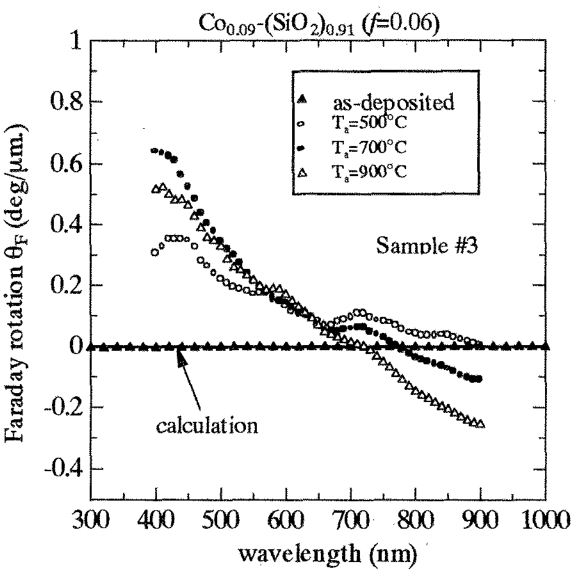


Fig. 3(a) Faraday rotation spectra for $Co_{0.09}$-$(SiO_2)_{0.91}$ (f=0.06) films, as deposited and annealed at various temperatures T_a.

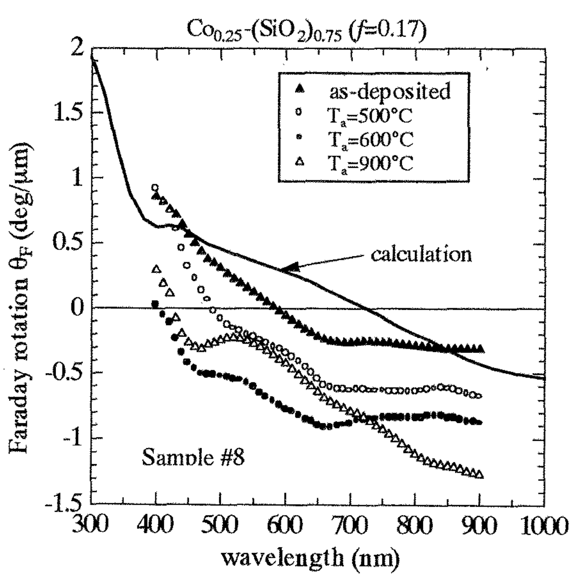


Fig. 3(b) Faraday rotation spectra for $Co_{0.25}$-$(SiO_2)_{0.75}$ (f=0.17) films, as deposited and annealed at various temperatures T_a.

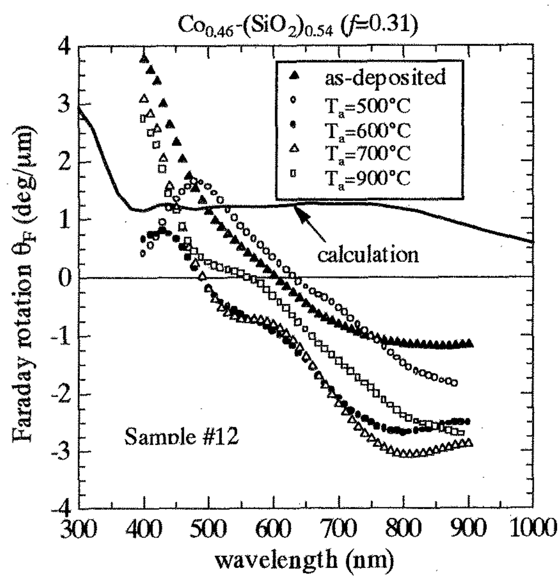


Fig. 3(c) Faraday rotation spectra for $Co_{0.25}$-$(SiO_2)_{0.75}$ (f=0.31) films, as deposited and annealed at various temperatures T_a.

5. REFERENCES

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