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Magnetic Properties of Fe–Ti–O Composite Films Obtained via Solid-Phase Synthesis

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Abstract—The results from investigating the magnetic and magneto-optical properties of Fe–Ti–O composite films with compositions above the percolation threshold, prepared via a solid-phase reaction with oxygen exchange in layered FeO/Ti structures, are presented. Features of the magneto-optical spectra of prepared films are compared to the spectra of continuous metal films.

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INTRODUCTION

Composite films with a nonuniform distribution of components in the film plane (nanogranulated films) that consist of ferromagnetic granules arranged in the dielectric matrix have some interesting properties. These include tunnel magnetoresistance, the magnetorefractive effect, and the enhancement of the magneto-optical effect. Most investigations so far have been devoted to granulated films in SiO_2 and Al_2O_3 dielectric matrices.

Compared to continuous films, the magneto-optical spectra in nonuniform systems depend on the filling coefficient in terms of the magnetic fraction (or relative volume) and type of the dielectric matrix [1–3]. The magneto-optical properties of granulated films in a TiO_2 matrix [4–6] with a dielectric constant exceeding the corresponding values for SiO_2 and Al_2O_3 are therefore of great interest.

EXPERIMENTAL

It was shown earlier that the products of the solid-phase reaction

$$2CoO + Ti \rightarrow 2Co + TiO_2$$

are Co granules in a matrix of titanium dioxide [4]. Taking into account high chemical activity of titanium with respect to oxygen, we used the following reaction to prepare granulated Fe films in the titanium dioxide dielectric matrix:

$$2FeO + Ti \rightarrow 2Fe + TiO_2.$$

The reaction reagents here can be FeO and Ti layers on a substrate. To change the ratio of the volumes of the magnetic and dielectric phases in the reaction products, we must not only vary the ratio of thicknesses of reagent layers but also the pressure of the residual gases. The volume concentration of the magnetic phase was found to be $X = V_{Fe}/(V_{Fe} + V_{Ti})$, while solid-phase reactions in the FeO/Ti layered structures were conducted in the isothermal annealing mode.

The FeO films were prepared via the oxidation in air at 620 K of iron films deposited by thermal evaporation in a vacuum of $\sim 10^{-6}$ torr on plates of coating glass at 470–520 K. The titanium layers were deposited via the ion-plasma sputtering of a massive titanium target in argon at a pressure of $(4–5) \times 10^{-4}$ torr and a substrate temperature of ~320 K. The solid-phase reaction was conducted in the isothermal annealing mode at 570–600 K in a vacuum of 10^{-6}–10^{-5} torr. Below, we present the results from investigating the magnetic properties of composite films with volume concentrations of 0.5, 0.56, and 0.63.

The chemical composition and thickness of the films were monitored by X-ray spectral fluorescence analysis. The crystal structure was analyzed via X-ray structural phase analysis. The magnetic properties of the prepared films were measured using a Nano MOKE 2 magneto-optical magnetometer. The magnitudes of the Kerr magneto-optical effect (θ_k) and their spectral dependences were recorded following the zero-analyzer procedure with double modulation of the plane of the incident light's polarization along the azimuth on a magneto-optical stand in fields of up to 14 kOe. The measurements were made at room temperature in the wavelength range of 400–1000 nm. The accuracy of measurement was 0.2 nm.

RESULTS AND DISCUSSION

The results from our X-ray structural investigations of films prepared by annealing the FeO/Ti film structures revealed a reduction of Fe in the reaction products.

Resistivity $\rho = 5 \times 10^{-3}$ Ω m for $X = 0.5$ corresponded to nanogranulated films in a nonconductive matrix.

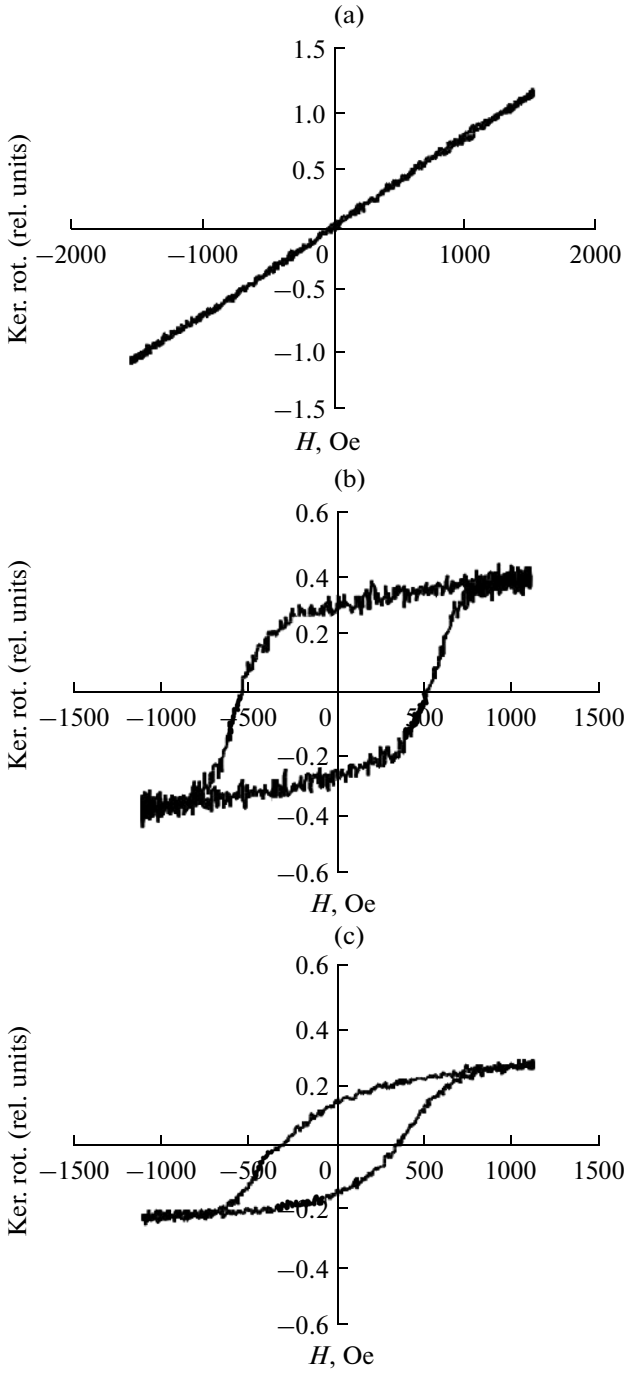

Fig. 1. Remagnetization curves of the Fe–Ti–O films with volume concentrations (a) $X = 0.35$, (b) $X = 0.6$, and (c) $X = 0.63$.

Our investigation of the magnetic properties of the prepared Fe–Ti–O composite films showed that the shape of the remagnetization curves in the planes of films with volume concentrations $X = 0.4$ and higher testified to the ferromagnetic character of the interaction between the magnetic granules. Figure 1 shows the remagnetization curves of the films with $X =$ (a) 0.35, (b) 0.56, and (c) 0.63. The values of the coercive force for the films with concentrations of 0.5, 0.56, and 0.63 are 600, 500, and 350 Oe, respectively. It can be seen that as the volume concentration of the magnetic phase increases, the coercive force of the films decreases. Both similar and inverse concentration dependences of the coercive force were observed for granulated films [7].

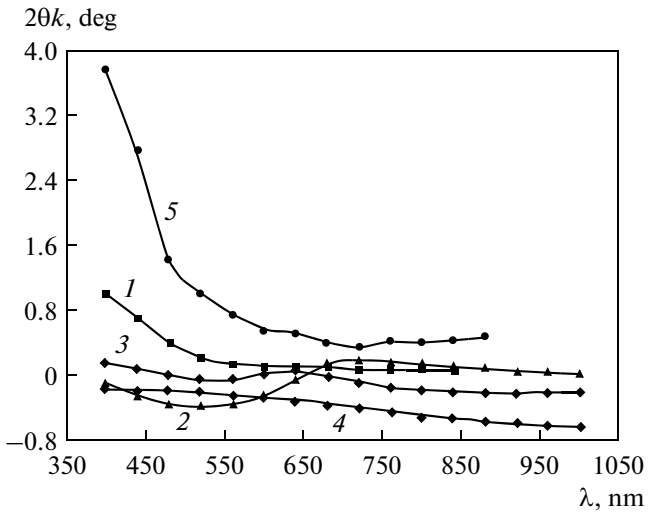

Fig. 2. Spectral dependences of the Kerr rotation angle for the Fe–Ti–O films with (curve *1*) $X = 0.5$, (curve *2*) $X = 0.56$, (curve *3*) $X = 0.63$, (curve *4*) uniform Fe films, and (curve *5*) film prepared from the Ti–O/Fe/Ti–O layered structure.

The magneto-optical spectra of the prepared films were investigated in the visible spectral region in magnetic fields of up to 14 kOe.

The spectral dependences of the Faraday effect were measured for the films with $X = 0.5$. The spectrum of the Faraday rotation was a nonmonotonic dependence with a broad maximum in the wavelength range of 750–800 nm. The Faraday rotation angle reached a maximum of 9 deg μm^{-1}.

Figure 2 shows the dependences of the rotation angle ($2\theta_k$) of the Kerr polar effect on wavelength (λ) of the films with $X = 0.5$, 0.56, and 0.63; and for a uniform Fe film 30 nm thick. It can be seen that the dependences are nonmonotonic. In contrast with the Co–Ti–O granulated films studied in [5], the spectra of the Fe–Ti–O films have no clearly pronounced resonant character, although they do show considerable enhancement (fivefold) of the rotation angle in the short-wavelength spectral region for concentration $X = 0.5$, compared to the homogeneous iron films. Figure 3 shows the dependence of the absolute value of the maximum Kerr rotation angle on the volume concentration at a wavelength of 400 nm. An increase in the magneto-optical rotation in a short-wavelength region is observed for $X = 0.5$. An even larger (20-fold) increase in the Kerr rotation is observed for the composite films with the same concentration that we pre-

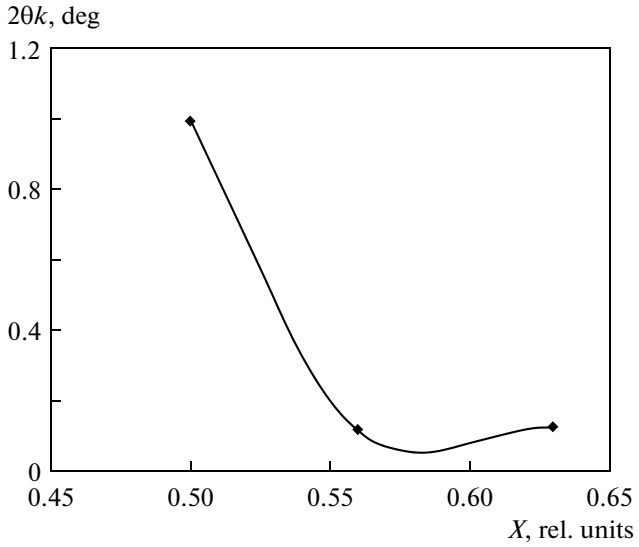

Fig. 3. Dependence of the absolute value of the maximal Kerr rotation angle on the volume concentration of the magnetic phase at a wavelength of 400 nm.

pared using the traditional method, most notably in the sequential deposition of Fe and Ti–O layers and subsequent annealing (Fig. 2, curve *5*).

CONCLUSIONS

The features observed in the Kerr effect spectrum of our composite films were characteristic of nonuniform metal–dielectric media [5, 6, 8, 9]. It is clear that the results from investigations of the magneto-optical properties of prepared films are of a preliminary character and cannot be interpreted in terms of this experiment.

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