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Magneto-Optical and Optical Properties of Polycrystalline Co–P Films with Nanometer Thickness

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Abstract—Features of the optical and magneto-optical properties of polycrystalline Co–P films with nanometer thickness are established experimentally. It is found that the spectra of optical parameters *n* and *k* and magnetic circular dichroism depend largely on film thickness, suggesting that magneto-optical activity is governed by different mechanisms in thin films and bulk materials.

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INTRODUCTION

Interest in studying Co–P films is mainly due to their possible application in different fields of engineering. From a fundamental viewpoint, Co–P alloy can be considered a model representative of the metal–metalloid class of materials [1]. The needs of nanotechnology require investigations of films with nanometer thickness (from one to tens of nanometers). This range marks the transition between two-dimensional systems and samples with near-bulk parameters. The contribution from surface effects becomes more pronounced as the films grow thinner, due to changes in the symmetry of the local environment on the surface, the coordination number, and so on. In addition, the effect of the oxide layer, the interfaces between layers, and the surface roughness start to play a more important role. Film thinness restricts the motion of electrons normal to the surface, and size effects arise when it is comparable to the free path. These features of the low-dimensional state are reflected in variations in the electronic structure, which are most effectively investigated using optical and magneto-optical techniques [2].

The measured optical and magneto-optical constants allow us to perform model calculations, compare their results to experimental dependences, and thus establish the effect film thickness has on the magneto-optical properties of Co–P and identify features of variationin the Co electronic structure upon the embedding of P.

Despite the great many works on the magnetic properties of Co–P films, their optical and magneto-optical properties in the nanometer thickness range remain poorly studied.

In this work, we report the measured optical and magneto-optical parameters of the Co–P films with nanometer thickness, prepared via chemical deposition.

EXPERIMENTAL

Polycrystalline Co–P films were fabricated via the chemical deposition of ions onto glass substrates containing 30 mg/L of cobalt sulphate, 10 mg/L of sodium hypophosphite, 80 mg/L of sodium citrate, and 30 mg/L of ammonia. The phosphorous content in the polycrystalline samples was 4.7 at % [3]. The degree of acidity of the solutions was pH 9 and their temperature was 95°C. In accordance with the procedure for chemical deposition, the samples under study were trilayers consisting of SnO_2 layers 1 nm thick, Pd layers 5 nm thick, and top Co–P film layers between 3 and 100 nm thick.

The spectral dependences of the optical parameters were measured by means of spectral ellipsometry, based on light polarization reversal: Light was reflected from a sample's surface and the ratio between the complex reflectances for light polarizations parallel (*p*) and perpendicular (*s*) to the plane of incidence was determined. The experimental data were interpreted for all three layers deposited onto the glass substrate. The first two layers (SnO_2 and Pd) were assumed to be optically homogeneous; the Co–P layer, optically heterogeneous. The sizes of the surface inhomogeneities used in our calculations were determined via atomic force microscopy (AFM) of films 3.2 to 70 nm thick.

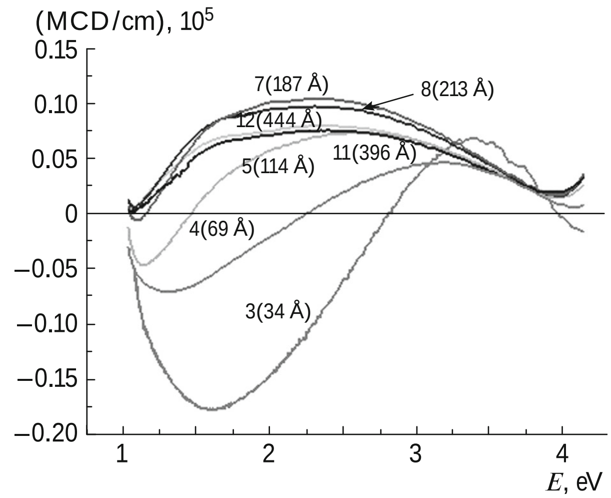

Fig. 1. MCD spectra of polycrystalline Co–P films reduced to thickness. The magnetic field was 1.2 T.

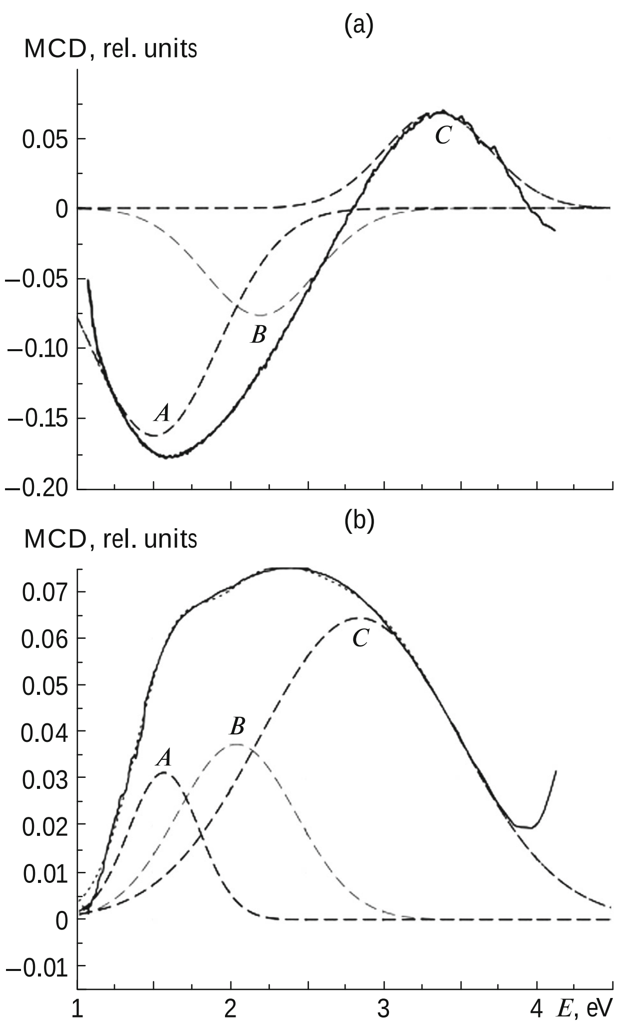

Fig. 2. Example of the decomposition of MCD spectra into Gaussian components for Co–P films with thicknesses of (a) 3.4 and (b) 44.4 nm.

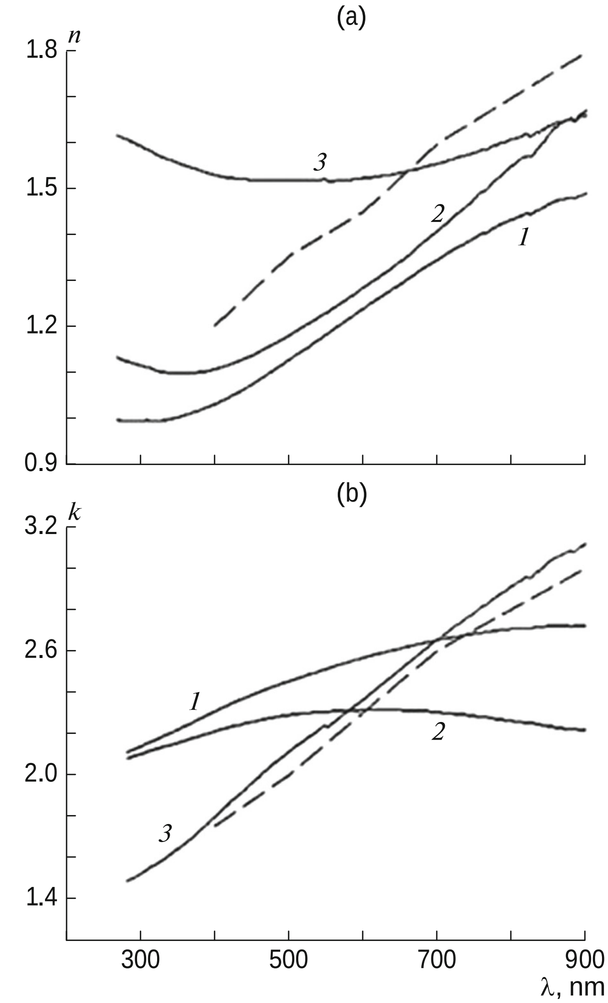

Fig. 3. Spectral dependences of refractive index n and absorbance k for Co–P films with thicknesses of (a) 11.4, (b) 21.3, and (c) 73.6 nm (solid lines). Dashed lines show the data from [5].

The magnetic circular dichroism (MDC) (i.e., the difference between the absorbances of the left- and right-polarized light) in the range of 1 to 4 eV was measured on a spectropolarimetric setup by means of light wave polarization modulation. The measurement error was 10^{-5} rel. units, and the spectral resolution was ~0.02 eV.

It can be seen in Fig. 1 that the MCD spectra of our thick samples (7, 8, 11, and 12) lie fully in the positive region and are similar in shape to the MCD spectra of the thick Co film. The spectra of the thinner samples (3, 4, and 5) made both positive and negative contributions. As these samples grow thicker, both the positive and negative peaks and the transitions of the curves through zero shift to the low-energy spectral region.

Figure 2 shows the MCD spectra as superpositions of Gaussian peaks A, B, and C, the positions of which lie near 1.5, 2.2, and 3.36 eV, respectively, and change slightly with the film thickness. According to the data in [4], these transitions correspond to interband transitions in Co. It should be noted that the amplitudes of these peaks change differently. The amplitude of peak *C* at all of the investigated Co–P film thicknesses is positive; the amplitudes of peaks *A* and *B* for thin films have conditionally negative values and reverse their signs as the films grow thicker.

Figure 3 shows the obtained refractive index *n* and absorbance *k* as functions of wavelength for films with different thicknesses. We can see (i) a pronounced thickness dependence that is indicative of variation in the electronic structure in this range of values and (ii) a considerable difference between the dependences and parameters for the thin film and the film 73.6 nm thick, which exhibits the properties of a bulk sample. The absorbance of the film 73.6 nm thick agrees with the literature data, due apparently to it lying in the range of 70–300 nm investigated in [5]. The discrepancy between the literature data and ours on the refractive index requires further investigation. We can try to explain this discrepancy using the differences between the sizes of surface inhomogeneities. In addition, an oxide layer that might exists on a Co–P film's surface can have an electronic structure different from that of the rest of the film and thus work as an additional interface [6], affecting mainly the refractive index.

CONCLUSIONS

Our data are indicative of specific optical parameters and different mechanisms of the magneto-optical activity of thick and thin Co–P films. More detailed clarification of the origin of features in the magneto-optical and optical properties of Co–P films requires further experimental and theoretical investigations.

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