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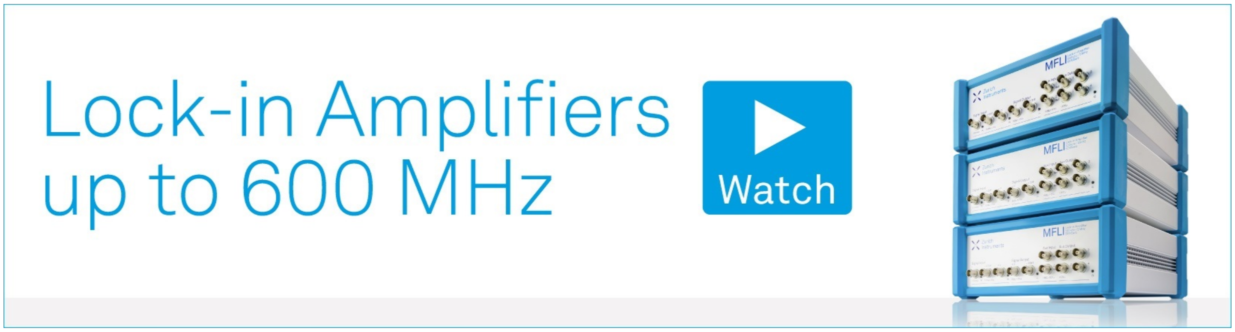

The Structure, Electrical and Magnetoresistance Properties of Heterogeneous Films $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$

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Abstract. The $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films were obtained by ion beam sputtering. X-ray and TEM studies of the structure and phase composition showed that the $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ films characterized by multilayer structure, where $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposite layers and In_2O_3 spacers are amourphous. It is shown that the introduction of In_2O_3 spacers in $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposite leads to decreasing in specific resistance due to creation continues conductivity layers of low-resistance In_2O_3. All investigated samples characterized by the presence of magnetoresistance both at 77 K and at room temperature, which is characteristic of ferromagnetic metal-dielectric nanocomposites.

INTRODUCTION

Composite materials, containing ferromagnetic nanogranules randomly distributed in insulator or semiconductor matrix are widely studied both as fundamental and practical applications points of view. The increasing interest to such composites is due to unique physical properties: giant magnetoresistance [1-3], high magneto-optical characteristics [4], good absorption of electromagnetic radiation at RF and microwave bands [5], a wide range of electrical resistivity, magnetorefractive effect [6]. However, the magnetic and electrophysical properties of these nanocomposites strongly depend on the preparation method, particle size, concentration and chemical bond between the nanoparticles and the matrix. As a rule, metal dielectric/semiconductor composites are produced by ion-beam or magnetron sputtering of complex target, containing sputtering metal parts distributed on insulator surface. A nanogranular structure is formed on the substrate surface as a result of self-assembly processes. Thus, there are significant limitations in the composition of the heterogeneous system: low temperature of deposition, non-solubility or it low value and absence of chemical interaction between components at deposition temperatures. The part of these limitations can be removed by creation of multilayer nanogranular structures using ion-beam sputtering. Therefore, in this work, the effect of In_2O_3 semiconductor spacers on the structure, electrical and magnetoresistance properties of $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposite was studied under multilayer structure condition.

EXPERIMENTAL

The $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films were obtained by the ion beam sputtering method [7]. To deposition multilayer systems, we used a composite target consisting of a metal alloy ($Co_{40}Fe_{40}B_{20}$) with uniformly distributed ceramic plates of SiO_2 on its surface and In_2O_3 ceramic target. A V-shaped screen was placed between the semiconductor target and the substrate to obtain the different thickness of the semiconductor layer during the single deposition process.

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The resulting multilayer system had 92 bilayers, what is displayed in the notation $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films. Sample thicknesses (h) were measured using an MII-4 interferometer, and changed from 0.20 to 0.60 μm. The bilayer thickness (h_1+h_2) is varied from 1.6 to 6.3 nm.

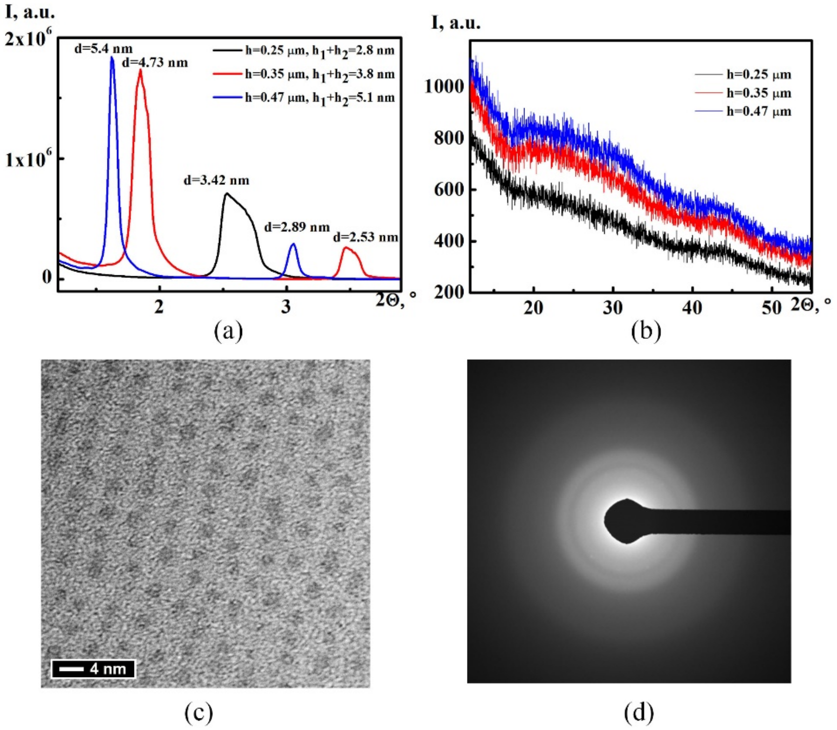
X-ray diffraction was carried out on D2 PHASER diffractometer (BRUKER). To decipher the diffraction patterns obtained a licensed software was used. Transmission electron microscopy (TEM) studies were carried out using a Hitachi HT7700 TEM (acceleration voltage 100 kV, W source). The cross-sectional samples on the sitall substrates for TEM studies were prepared by focused ion beam (single-beam FIB, Hitachi FB2100) at 40 kV to a thickness of about 40-50 nm.

The temperature, magnetic field strength and resistance of the samples were recorded using a B7–78/1 voltmeter and the original software. The magnetoresistance of the films was measured in the external magnetic field with magnitude varied from 0 to 8 kOe. The relative error of the measuring did not exceed 10%.

RESULTS AND DISCUSSION

Structural Properties

X-ray diffraction pattern of the $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ multilayered thin-films with different thicknesses, measured at small Bragg angles showed peaks, that indicated that the multilayer structure was successfully formed under ion-beam deposition conditions (Fig. 1a). A wide diffraction halo at middle Bragg angles (Fig. 1b) shows that structure of the layers is X-ray amorphous. It is known that metallic granules and matrix of $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposite thin films have amorphous structure, if it prepared by ion-beam sputtering [8]. Thus, the resulting dependence of $I(2\Theta)$ shown on Fig. 1b is the summation of diffractions from amorphous $Co_{40}Fe_{40}B_{20}$, SiO_2 and X-ray amorphous In_2O_3.



(a) (b)

(c) (d)

FIGURE 1. X-ray diffraction pattern of the $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ film with different thicknesses measured at small (a) and middle (b) Bragg angles. TEM micrographs of the cross section (c) and electron diffraction pattern (d) for $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films with bilayer thickness h_{bl} = 5.97 nm (h_{In2O3}= 1.94 nm)

In order to establish the structure of the In_2O_3 interlayers (truly amorphous or nanocrystalline), the cross section investigation was carried out using TEM (Fig. 1c, d). An analysis of TEM micrographs confirmed the formation of a layered structure in the $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ films. The presence of three wide halos in the electron diffraction pattern confirms the conclusion that the structure of In_2O_3 interlayers is amorphous (Fig. 1c). It is important to note, that the $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ composite is formed by non-overlapping metal granules and the percolation metallic network does not form (Fig. 1c).

Electrical and Magnetoresistance Properties

The indium oxide band gap ~ 3 eV [9]. Its conductivity at room temperature substantially depends on the concentration of various kinds of structural defects, which create impurity electronic levels in the band gap. Such defects include oxygen and indium vacancies, impurity atoms, defects at the crystal boundaries, surface defects and adsorbed atoms of various gases [10].

A comparative analysis of the specific resistance for $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposite films and $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ layered structures revealed, that the electrical resistivity of the multilayer structure increases and tends to ρ of the bulk composite with a decrease of the In_2O_3 monolayer thickness h_{In2O3} (Fig. 2). The value of the specific resistance of $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films does not reach the values of the electrical resistivity of the In_2O_3 film. The increase in ρ can be explained by the decrease of the semiconductor layer thickness to 0.4 nm, where continuous conducting In_2O_3 layer is not form. Therefore, the electrical transfer is carried out by the composite medium. When the thickness of the semiconductor layer becomes sufficient for the formation of a conducting medium, a significant difference from the ρ of the In_2O_3 film is related to the presence of poorly conductive composite inclusions. Thus, it has been established that the introduction of the In_2O_3 semiconductor spacers decreases the value of specific electrical resistance.

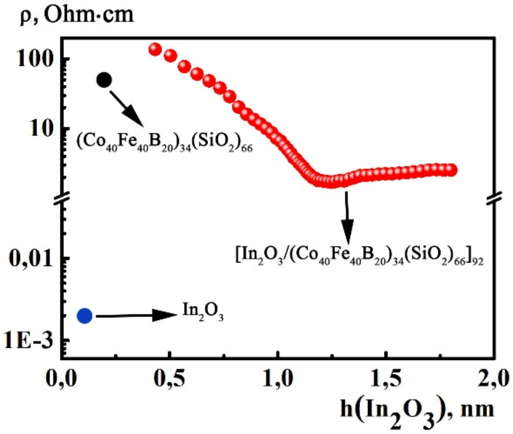


FIGURE 2. The dependences of the specific resistance for $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ multilayer structures versus In_2O_3 monolayer thickness h_{In2O3}

It is very good known, that ferromagnetic metal – insulator nanocomposites can characterized by spin-dependent tunneling magnetoresistance at under percolation regime [11]. In order to established the effect of In_2O_3 spacers on the magnetoresistance of $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposites, the magnetic field dependencies of magnetoresistivity for $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films has been investigated (Fig. 3). The value of magnetoresistance MR was determinated according to the equation:

$$MR(H,T) = [(\rho(H,T) - \rho(0,T))/\rho(0,T)] \cdot 100\% \tag{1}$$

where $\rho(H, T)$ and $\rho(0, T)$ are the resistivity at a given temperature T in the presence and absence of magnetic field H, respectively.

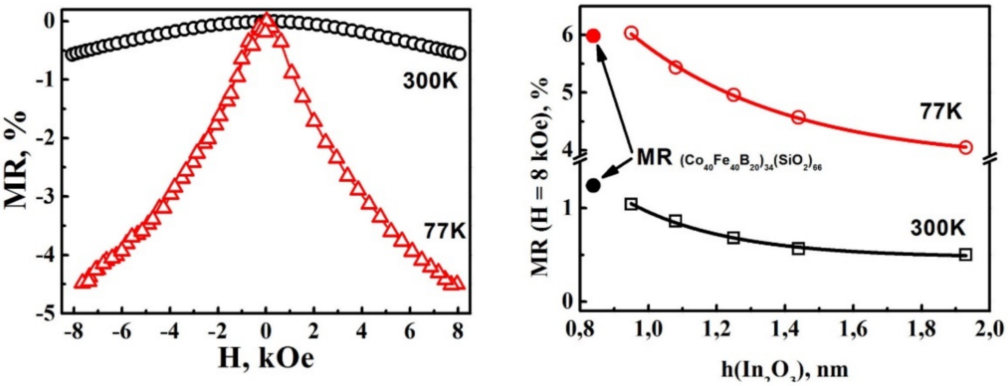


FIGURE 3. The magnetic field dependencies of magnetoresistivity for $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films (h_{bl} – 5.52 nm; h_{In2O3} = 1.44 nm) (a) and dependencies of magnetoresistivity versus In_2O_3 monolayer thickness h_{In2O3} (b), measured at 77 and 300 K

As it seen on Fig. 3a, the magnetoresistance of the investigated $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films was negative. It is mean, that the value of specific resistivity is decreased with increasing in magnetic field strength magnitude. The decreasing in temperature from 300 to 77 K leads to the increasing of the maximum value of the magnetoresistivity, obtained in 8 kOe. Such field dependences of the magnetoresistance for the $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films are typical for systems of ferromagnetic metal-dielectric, indicating that it's a spin-dependent tunneling mechanism, as a determinative a magnetoresistance of those samples. The introduction of the In_2O_3 semiconductor spacers and it's following increasing decreases the value of magnetoresistance for $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films both at room (300 K) and at low temperatures (77 K) (Fig. 3b). This is may be due to an increase in the distance between the ferromagnetic metal $Co_{40}Fe_{40}B_{20}$ granules in the adjacent layers of the $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ composite. Thus, the magnetoresistance of the $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films is determined by the processes of spin-dependent tunneling not only between granules within the layers of the $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ composite, but also by the processes of tunneling between the granules of the neighbor layers through In_2O_3 amorphous spacers.

SUMMARY

The $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films were obtained by ion beam sputtering. X-ray and TEM studies of the structure showed that the $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ films are multilayers, where $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposite and In_2O_3 layers are amorphous. It is shown that the introduction of In_2O_3 spacers in $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposite leads to decreasing in specific resistance due to creation continues conductivity layers of low-resistance In_2O_3. For all investigated samples the presence of magnetoresistance both at 77 K and at room temperature was found. It was established, that the nature of the magnetoresistance is a spin-dependent tunneling, which is characteristic of ferromagnetic metal-dielectric nanocomposites. The introduction of the In_2O_3 semiconductor spacers and it's following increasing the distance between the granules of the neighbor $(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}$ nanocomposite layers. It leads to the decreases in the value of magnetoresistance for $[In_2O_3/(Co_{40}Fe_{40}B_{20})_{34}(SiO_2)_{66}]_{92}$ thin films.

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