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Exchange interaction in Co/Bi/Co thin-film systems with Bi interlayer

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ABSTRACT

The magneto-optical and magnetic properties of Co(5 nm)/Bi/Co(5 nm) samples and the peculiarities of exchange coupling between Co layers through the Bi spacer layer are studied. The magneto-optical investigations indicate that the shapes of Transverse Kerr effect (TKE) spectra are similar for all studied samples but the TKE values decrease at $t_{Bi} > 4$ nm as compared with TKE values of the single-layer Co thin film. The decrease in the volume ratio of the magnetic to nonmagnetic phases causes the reduction of the contribution of the magnetic phase to magnetooptical signals. Magnetic investigations show that the coercivity force, H_C, and saturation field, H_S, of the Co/Bi/Co samples increase with increasing t_{Bi}. The oscillatory behavior of H_C and H_S with various periods (short and long) is observed in a wide range of t_{Bi} values (from 0.2 to 50 nm). These data are explained by the dependence of Fermi energy on t_{Bi} and the changes in the Bi band structure with decreasing t_{Bi}.

1. Introduction

Physical properties of thin magnetic films of 3d-transition metals and magnetic multilayers are the most important area of the physics of magnetic phenomena and applied magnetism. It's connected with the rapid development of the fundamental knowledge related to phenomena such as quantum size effects [1,2], giant magnetoresistance [3,4] and oscillating exchange coupling between ferromagnetic layers (Fe, Co) through nonmagnetic (e.g., Cu, Cr, Ag and Au) spacers [4,5] and wide practical applications of these materials in devices of spintronics and micro- and nanoelectronics. Despite the huge amount of publications devoted to the study of aforementioned materials, the peculiarities of exchange interaction in thin-film magnetic nanostructures with a diamagnetic semimetallic Bi interlayer are far from complete understanding. Some aspects of the exchange interaction in thin-film systems with the Bi interlayer have been discussed in [6–8]. It was found, that there are the oscillatory exchange interactions in the NiFe(10 nm)/Bi(3–15 nm)/NiFe(10 nm) [6,7] and CoFe(15 nm)/Bi(1–60 nm)/Co(15 nm) samples [8]. The periods of oscillations, Λ, were 18–20 nm, which were significantly higher than those found for other thin-film systems with a metallic spacer, in particular, for the trilayer structures, consisting of two identical magnetic layers (Fe, Co) and different interlayers such as diamagnetic (Ag, Au), paramagnetic (Mo, Pt, Pd, Ta, Zr) and semiconducting Si [9–11]. Considering the above the study of thin film systems with bismuth deserves attention. The diamagnetic semimetallic bismuth has unusual physical properties [12]. In particular, it does not form compounds near interfaces in multilayer thin-film systems. The Fermi wavelength, λ_F, of semimetallic Bi is of the order of 40 nm. The value of the mean free path of bismuth electrons depends on layer thickness, temperature and applied magnetic field.

The aim of this work is the investigation of influence of Bi on the magneto-optical and magnetic properties of the Co/Bi/Co thin-film systems and also examination of the peculiarities of exchange coupling between Co layers through the Bi spacer layer.

2. Materials and methods

Co/Bi/Co samples were grown by magnetron sputtering at room temperature using Co and Bi targets. The surface roughness of the substrates was about 0.5 nm. The Ta seed layers of 5 nm thick were deposited on the glass substrates. The background pressure in the vacuum chamber was 4×10^{-7} mbar and the argon pressure during the film deposition was as high as 3.8×10^{-3} mbar. A constant magnetic field of 250 Oe was applied parallel to the substrate, H_{SUB}, in order to form an in-plane easy magnetization axis (EMA). The thickness of the Co layers, t_{Co}, in all samples was equal to 5 nm. The thickness of the Bi layer, t_{Bi}, varied from 0.2 to 50 nm.

The microstructure of the thin-film systems was studied by X-ray diffraction (XRD) using CuKα radiation. The deposition rate was 2.6 nm/min for Co and 2.0 nm/min for Bi. The surface morphology of samples was investigated by AFM. The domain structure (DS) was investigated by the High-Resolution Kerr microscope (HRM). The

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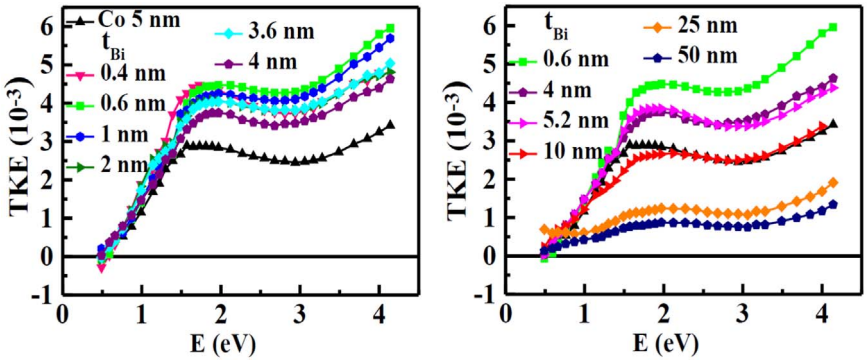

Fig. 1. Spectral dependences of TKE observed for the single-layer Co film of 5 nm thickness and Co/Bi/Co samples with the different thicknesses of Bi layer.

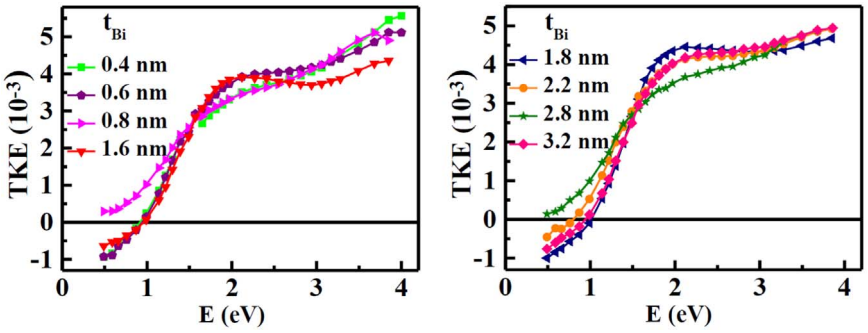

Fig. 2. Spectral dependences of TKE observed for the Co/Si/Co samples with the different thicknesses of Si layer.

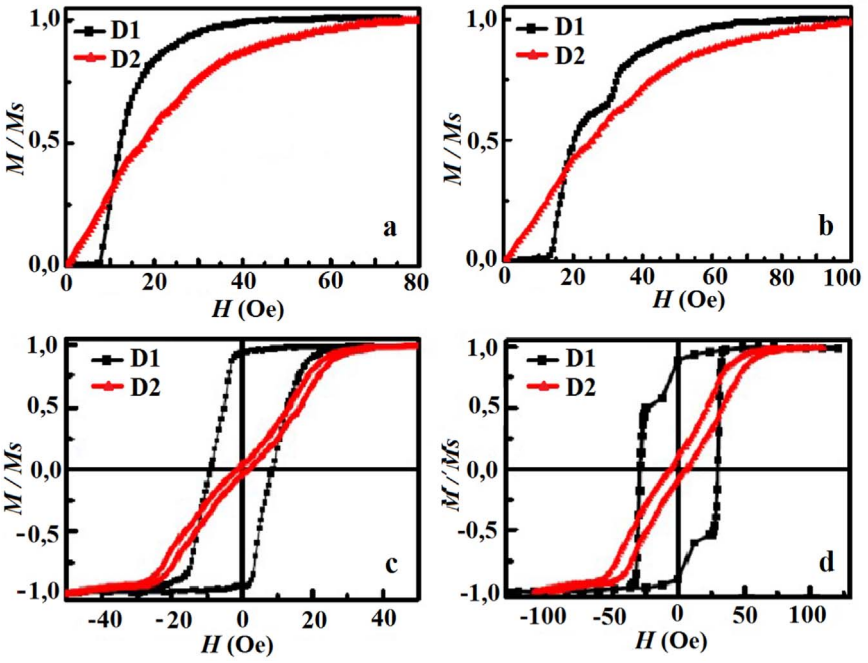

Fig. 3. Typical magnetization and hysteresis loops observed for the Co/Bi/Co samples with t_{Bi} =0.4 nm (a, c) and t_{Bi} =2.0 nm (b, d) in the magnetic field applied parallel to D1 and D2 directions.

magnetic characteristics and magneto-optical spectra of the Co/Bi/Co thin-film systems were measured employing a magneto-optical magnetometer and spectral magneto-optical equipment [described in 13,14] using the transverse Kerr effect (TKE).

The hysteresis loops of the studied samples were measured in two different directions of the external magnetic field. In one case H was parallel to the EMA direction (direction D1) and in the other–perpendicular to D1 (direction D2). The next dependences were measured: $\delta(H)/\delta_S \propto M(H)/M_S$, where δ_S is the value of TKE for $M = M_S$, M_S is the saturation magnetization of the sample. The value of H was changed from $-H$ to $+H$ and from $+H$ to $-H$.

3. Results and discussion

The results of XRD measurements showed that Co layers in the Co/Bi/Co samples have a nanocrystalline structure and no Bi–Co compounds are formed on the interfaces. The relative intensity of the diffraction peaks of Bi increases with increasing the Bi layer thickness.