THE FEATURES OF STRUCTURAL AND MAGNETIC CHARACTERISTICS OF Co/Cu/Co THIN-FILM SYSTEMS

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Structural and magnetic characteristics of Co/Cu/Co thin-film systems fabricated by magnetron sputtering are investigated. The Co thickness in all samples was 5 nm and the Cu thickness was varied from 0.5 to 4 nm. It was found that the saturation field, oscillates in magnitude with increasing Cu layer thickness with the period of the order of 1 nm. The obtained data are explained by the presence of exchange coupling between the ferromagnetic layers through the Cu spacer.

1. Introduction

Magnetic thin films have attracted the attention of researchers since the mid of the XX century due to the peculiarities of their physical properties. For example, the giant magnetoresistance and oscillating exchange interaction between ferromagnetic (FM) layers containing nonferromagnetic (NFM) spacers were discovered in multilayer systems consisting of alternating FM and NFM layers of submicron thicknesses [1–3]. Moreover, the multilayer systems (MS) are widely used in devices of micro- and nanoelectronics [4,5]. Despite the huge experimental data accumulated [6–8], the study of the influence of NFM layer on the magnetic properties of the thin-film magnetic systems is still relevant. This work is devoted the study of the influence of copper interlayer on the structural and magnetic properties of Co/Cu/Co thin-film systems.

2. Materials and methods

The Co/Cu/Co samples were grown by magnetron sputtering using Co and Cu targets and corning 2845 glass substrates. The Ta seed layers of 5 nm thick were deposited onto the glass substrates. The background pressure in the vacuum chamber was 4×10^{-7} mbar and the argon pressure was as high as 3.8×10^{-3} mbar. A constant magnetic field of 250 Oe was applied parallel to the substrate surface, H_{SUB}, in order to form an in-plane easy magnetization axis (EMA). The thickness of the Co layers, t_{Co}, was equal to 5 nm, and the Cu layer, t_{Cu}, was varied from 0.5 to 4 nm.

The structure of the Co/Cu/Co samples was studied by X-ray diffraction (XRD) method using CuKα radiation, and the surface morphology by atomic force microscope (AFM). The magnetic characteristics of the thin-film systems were measured employing a magneto-optical magnetometer by means of the transverse Kerr effect (TKE) and the vibration sample magnetometer (Lake Shore VSM 7400) with the sensitivity up to 10^{-7} G·cm^3. The hysteresis loops were recorded for two directions of the magnetic field, *H*. In particular, the orientation of *H* was parallel or perpendicular to the EMA (designated, respectively, as D1 and D2 directions).

3. Results and discussion

The results of XRD analysis of Co/Cu/Co samples and reference Co thin film deposited directly on the glass substrate are presented in Fig. 1.

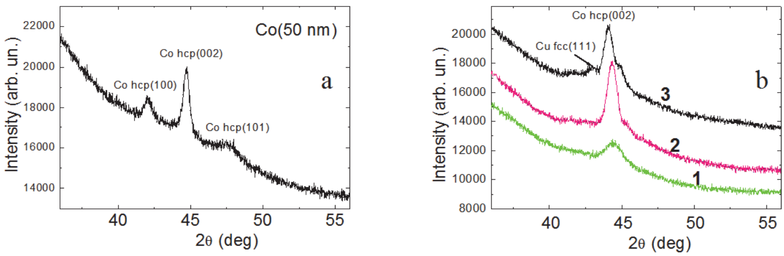

Figure 1. X-ray spectra observed for the reference 50 nm Co film (a), and the samples contained Ta, Co and Cu (b): curve 1 – Ta/Co(5 nm)/Ta, curve 2 – Ta/Co(5 nm)/Cu(1 nm)/Co(5 nm), curve 3 – Ta/Co(5 nm)/Cu(4 nm)/Co(5 nm).

The X-ray spectra obtained for the trilayer samples do not have peaks corresponding to the lines of Ta. The line fcc (111), corresponding to the lattice of Cu, becomes more noticeable on the spectrum of the sample with the thicker layer of copper. It was found that the size of the crystallites in the Co film is of the order of its thickness. According to AFM data, the average surface roughness, R_a, of the studied samples does not exceed 0.5 nm that confirms high quality of the samples surface.

The typical results of magnetic measurements are presented in Fig. 2. All measurements were carried out in open air at room temperature. The results of magnetic measurements of hysteresis loops allowed to receive the dependences of the saturation field H_S on t_{Cu} (Fig. 2e). The hysteresis loops measured in the magnetic fields, applied along the D1 and D2 directions, differ. It was observed for all samples, measured both by using magneto-optical and vibration techniques. This fact shows the presence of induced magnetic anisotropy with

EMA, parallel to the direction of the magnetic field, applied during the deposition process.

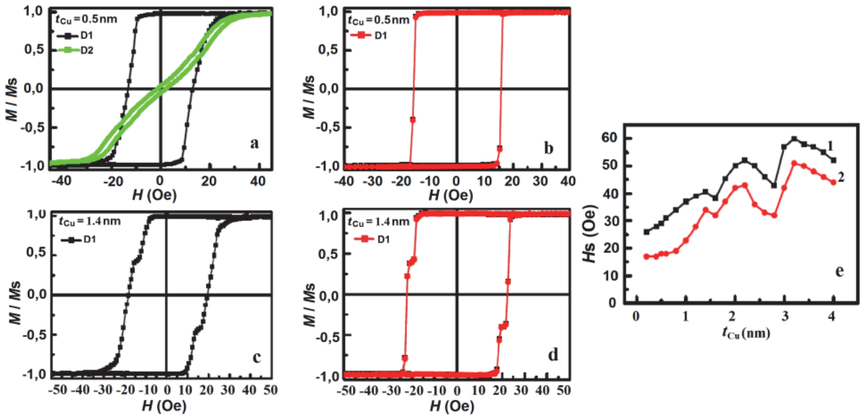

Figure 2. Hysteresis loops of Co/Cu/Co samples measured employing magneto-optical (a, c) and vibration sample (b, d) magnetometers; (e) dependences of $H_S(t_{Cu})$ obtained by using the data of magneto-optical (curve 1) and vibration sample magnetometers (curve 2).

According to the commonly accepted notions [9], the main mechanism of the induced magnetic anisotropy is pair ordering of atoms.

The shape of hysteresis loops observed for the Co/Cu/Co samples measured in the magnetic field applied along the D1 direction depends on t_{Cu}. In particular, it was found that some of the samples are characterized by almost rectangular hysteresis loops (Fig. 2a,2b) while others are characterized by more complex double-stage loops (Fig. 2c,2d). According to the calculations performed in [10], and the experimental results [6–8] the double-stage and almost rectangular hysteresis loops are observed at antiparallel and parallel orientations of magnetization components in Co layers. Thus, the obtained data can be explained by an exchange interaction between the FM layers through the Cu layer and its oscillating behavior with changing t_{Cu} (transition from FM to the antiferromagnetic (AFM) interaction). In the samples with the AFM-exchange interaction between the magnetic layers, the magnetization components in Co layers, parallel to the EMA, have the opposite directions, *i.e.*, these thin-film structures are similar to an uniaxial antiferromagnetic. The saturation field, H_S, of the samples with the AFM-exchange interaction between the magnetic layers is higher than H_S of the samples with the FM exchange. It is caused by an additional energy, which is necessary for overcoming the AF exchange between the magnetic layers.

One can see in Fig. 2e that the period of the oscillations of H_S, Λ, is of the order of 1 nm. At the same time according to the mechanism of the exchange interaction between the FM layers through the NFM interlayer via the RKKY interaction, the magnitude of Λ must be of the order of π/κ_F [11–13], where κ_F is the Fermi wave vector. For most metals π/κ_F is of the order of 0.3–0.4 nm. The found longer period of the oscillations of H_S can be explained by an influence of quantum size effects manifested in the change of the electronic structure of ultra-thin magnetic layer (the appearance of the so-called quantum well states) as compared with bulk samples [14,15].

4. Conclusion

The study of magnetic properties of the Co/Cu/Co thin film samples has shown that the dependence of the saturation magnetic field reveals an oscillating behavior as a function of t_{Cu}. The found period of the oscillations is consistent with the calculated value of Λ, obtained by taking into account quantum size effects, which manifests in the change of electronic structure of ultra-thin films as compared to the bulk sample.

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