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In-plane magnetic anisotropy symmetry in ultrathin Co films grown on sapphire substrates

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We report on the study of in-plane magnetic anisotropy and magnetization reversal in MBE grown ultrathin epitaxial Mo/Au/Co/Au magnetic films. We used a magneto-optical polar Kerr effect-based magnetometer and real-time data analysis using LabView software. A two-fold in-plane magnetic anisotropy symmetry was deduced from the shape analysis of the magnetization curves measured for various directions of in-plane applied magnetic field. The direction of easy magnetization axis in the sample plane is a result of a small, unintentional miscut of the sapphire substrate found by in-situ STM and X-ray diffraction measurements.

Key words: *magnetic anisotropy; ultrathin film; cobalt*

1. Introduction

In multilayered ultrathin magnetic films, phenomena associated with magnetic ordering, spin-reorientation transition, self-assembling etc., have been intensively studied. In order to understand these phenomena, the knowledge of magnetic anisotropy, strongly depending on the substrate surface morphology, is essential [1, 2]. In this work, we have studied the in-plane magnetic anisotropy and magnetization reversal in ultrathin Au/Co/Au magnetic films.

2. Experimental

The nanostructures deposited on sapphire single crystal (11–20) wafers had the following composition: (i) first buffer layer of 20 nm Mo(110) deposited at 1000 °C

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(ii) second buffer layer of 10 nm Au(111) deposited at room temperature and annealed at 200 °C for 15 min (iii) 3 nm Co layer; (iv) 8 nm thick Au cover layer. The structure of the samples was monitored in-situ by RHEED and Auger spectroscopy. The azimuthal directions and angle of about 0.9° of the substrate miscut were determined by X-ray diffraction.

The study of magnetization reversal was performed at room temperature using the magneto-optical Kerr-effect (MOKE)-based magnetometer with laser light: wavelength of 640 nm and spot diameter of 0.5 mm. Three magnetization components were measured as a function of adjustable magnetic fields. Polar (P) magnetization component was measured using the P-MOKE with the laser light close to normal incidence. The longitudinal (L) and transversal (T) MOKE hysteresis loops measurements were performed in the magnetic field applied in different azimuthal directions in the plane of the samples with the angle of light incidence equal to 49°. The longitudinal and transversal in-plane components were measured using the L-MOKE configuration [3]. The LabView program controlled the measurements of both the P-MOKE hysteresis loops and in-plane hysteresis loops and visualized the loop parameters (saturation, remanence, coercive field) in real-time, as a function of the angle between the field direction and the fixed axis.

3. Results and discussion

P-MOKE hysteresis loop for the perpendicular magnetic field $\theta_H = 0$ is shown in Fig. 1. This curve corresponds to the hard magnetization axis normal to the plane of a sample. A similar effect was observed in Au/Co/Au films with Co thickness > 2 nm [4].

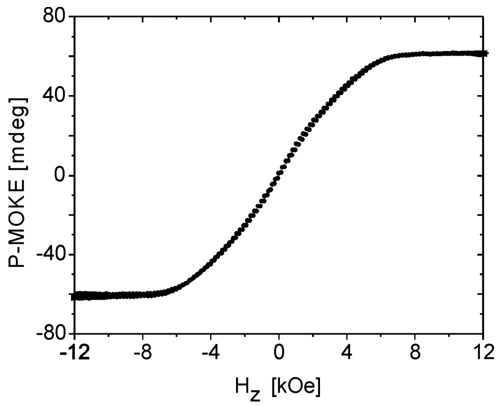

Fig. 1. Hysteresis loops measured as the polar Kerr ellipticity with magnetic field perpendicular to the plane of the sample. The perpendicular magnetic anisotropy constant $K_{u1} = 10.2\times10^6$ erg/cm^3

The L-MOKE and T-MOKE hysteresis loops were measured in the applied magnetic fields oriented at various φ_H angles with respect to the direction perpendicular to the substrate miscut. The curves shown in Fig. 2 illustrate magnetization reversal when magnetic field is applied along hard ($\varphi_H = 90°$) and easy ($\varphi_H = 0°$) directions, respectively.

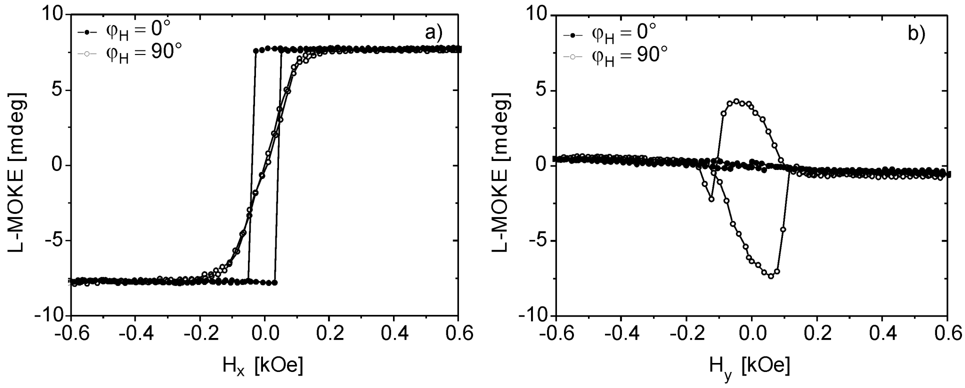

Fig. 2. Hysteresis loops measured as longitudinal (a) and transversal (b) Kerr ellipticity for the in-plane magnetic field applied in $\varphi_H = 0°$ and $\varphi_H = 90°$ directions. The in-plane anisotropy constant $K^{(2)}_{\mathrm{step}} = -0.33\times10^6$ erg/cm^3

Figure 3 shows the angular dependence of the longitudinal and transversal remanence as a proof of the existence of anisotropy. The observed angular dependence is characteristic of magnetic anisotropy in the sample plane with two-fold symmetry. The maxima of azimuthal L-MOKE dependence and minima of T-MOKE correspond to the easy axis magnetization in the plane of the sample.

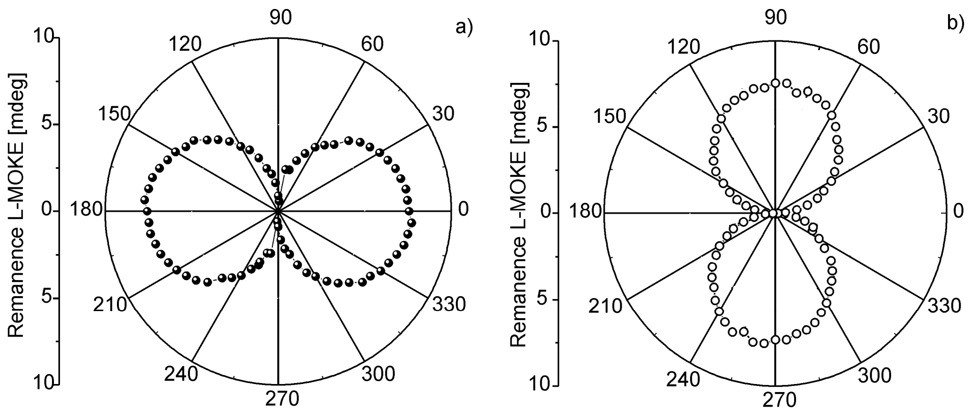

Fig. 3. Azimuthal dependence of the ellipticity remanence for longitudinal (a) and transversal (b) magnetization components. The orientation of easy axis magnetization corresponds to maximum of L-MOKE ellipticity remanence (or minimum from T-MOKE)

The experimental data are discussed taking into account the following energy contributions to the simplified model [5]: (i) perpendicular uniaxial anisotropy; (ii) demagnetization term; (iii) and step-induced uniaxial anisotropy:

$$E_A(\theta,\varphi) = K_{u1}\sin^2\theta - 2\pi M_S^2\sin^2\theta + K^{(2)}_{\mathrm{step}}\sin^2\theta\sin^2\varphi \tag{1}$$

where K_{u1} – the uniaxial perpendicular anisotropy constant, $K_{\text{step}}^{(2)}$ – uniaxial in-plane step-induced anisotropy constants, M_S – the value of saturation magnetization equal to 1420 G, θ is the angle between magnetization direction and the sample plane normal, φ is the angle of in-plane magnetization orientation from perpendicular to miscut direction. Magnetic anisotropy constants $K_{u1} = 10.2\times10^6$ erg/cm^3 and $K_{\text{step}}^{(2)} = -0.33\times10^6$ erg/cm^3 were obtained as fitting parameters of the theoretical curves to the experimental data.

The results could be explained assuming that the easy magnetization axis in the sample plane is induced by a small (<1°) unintentional miscut of the sapphire substrates. Similar results were observed in Au/Co/Au ultrathin films grown on vicinal substrate with miscut equal to 1.2° [5].

Moreover, the in-situ STM measurements carried out earlier in another UHV system on the same type of sapphire substrate covered with Mo buffer show a surface morphology typical of low-angle miscut (Fig. 4). Our previous investigations showed Au grows smoothly on Mo [6] and due to the epitaxy, it reproduces on its surface vicinal character of the substrate covered with Mo buffer. The presence of parallel monatomic steps on Mo buffer surface related with the substrate miscut has an influence on the growth of Co magnetic layer and, in consequence, induces the magnetic anisotropy in the plane of the samples, observed in our experiment.

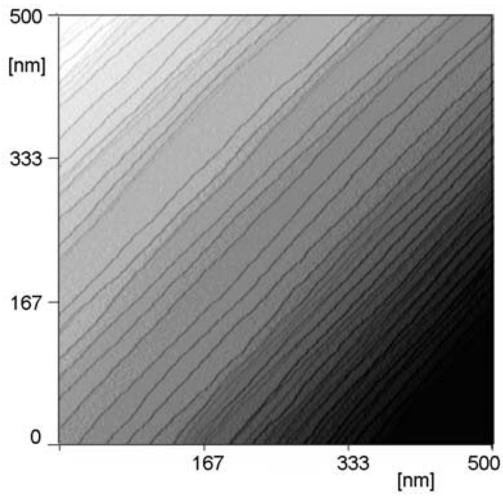

Fig. 4. The in-situ STM image of surface Mo/Al_2O_3 sample

In summary, we have shown that magneto-optical magnetometry is a powerful technique for high sensitivity anisotropy analysis. The two-fold symmetry of the in-plane anisotropy was observed for sample with 3 nm Co layer thickness. The unintentional miscut of the substrate may induce an additional magnetic anisotropy in the plane of the Au/Co/Au ultrathin system.

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