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THE INFLUENCE OF ANNEALING ON MAGNETIC PROPERTIES OF ULTRATHIN COBALT FILM

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Abstract: The influence of annealing on the magnetic properties of MBE grown Au/Co/Au(111) structures with ultrathin wedge-shaped Co layers has been studied by magnetooptical techniques. The magnetization reversal process (upon a magnetic field applied in a perpendicular direction to the sample plane as a function of Co layer thickness) was probed locally at room temperature by classical magneto-optical magnetometer and optical microscope, both based on the polar Kerr effect for the "as-deposited" sample and those annealed at 150° and 250°C. Magnetic anisotropy constants were evaluated from a set of magnetization curves measured in the magnetic field with components perpendicular and parallel to the sample plane. A drastic decrease of the coercivity field, remnant magnetization and anisotropy constants was observed for the sample annealed at 250°C. Enhanced diffusion at interfaces, induced by thermal treatment, seems to be responsible for the observed effects.

Metallic magnetic multilayers composed of ferromagnetic and non-magnetic films have been a subject of great interest in recent years. Detailed knowledge of the thermal stability of such systems is crucial particularly for practical applications. Speckmann *et al*. [1] have investigated *in-situ* magnetic domain structures and the magnetic surface morphology of Co films upon annealing. The studies of reorientation transition in wedged Co/Au(111) films [2] provide quantitative evidence for the increase of surface anisotropy after annealing. Annealing induced increase of surface anisotropy has been observed for Co/Au multilayers [3, 4]. In the past our group studied in detail [5-7] the magnetic properties of MBE grown ultrathin cobalt films in a gold envelope. Co deposited on Au was *in-situ* annealed. These samples after gold coverage were studied *ex-situ*. A decrease of effective magnetic anisotropy, related to volume contribution, was observed [6]. In the present work we are focused on the influence of annealing, measured *ex-situ*, on the magnetic properties of Co layer embedded between gold slabs.

The Au/Co/Au sandwiches were grown in a molecular beam epitaxy system in the low range of 10^{10} Torr. Al_2O_3 (11-20) wafers 10 mm × 10 mm in size buffered with a 20 nm Mo layer were used as substrates. Co and Mo were evaporated by electron guns and Au by effusion cells at rates lower than 0.05 nm/s. All deposition processes were performed at room temperature (RT). The bottom 20 nm Au layer deposited directly on the Mo buffer was annealed at 200°C to minimize its surface roughness. Then a cobalt wedge was grown with a thickness gradient of 1.2×10^7. Finally, the whole structure was covered with a 10 nm thick gold layer. The growth process of the samples was monitored by RHEED. Details of sample preparation and characterization are provided elsewhere [5]. The samples were split into identical parts after the deposition process and annealed at three temperatures of 150°, 250° and 300°C in an ultra-high vacuum for 20 minutes. The results here presented have been obtained for three samples: (i) a reference one which was not treated thermally after the deposition; (ii) one annealed at T_a = 150°C and (iii) one annealed at T_a = 250°C.

The measurements of magnetization reversal were carried out at room temperature by means of a magnetooptical magnetometer with the polar Kerr effect. The Kerr rotation angle φ ($H_\perp$, $H_{||}$ = const) of a laser beam of 0.2 mm in diameter was determined locally, as a function of magnetic field components $H_\perp$, $H_{||}$ perpendicular and parallel to the sample plane, respectively.

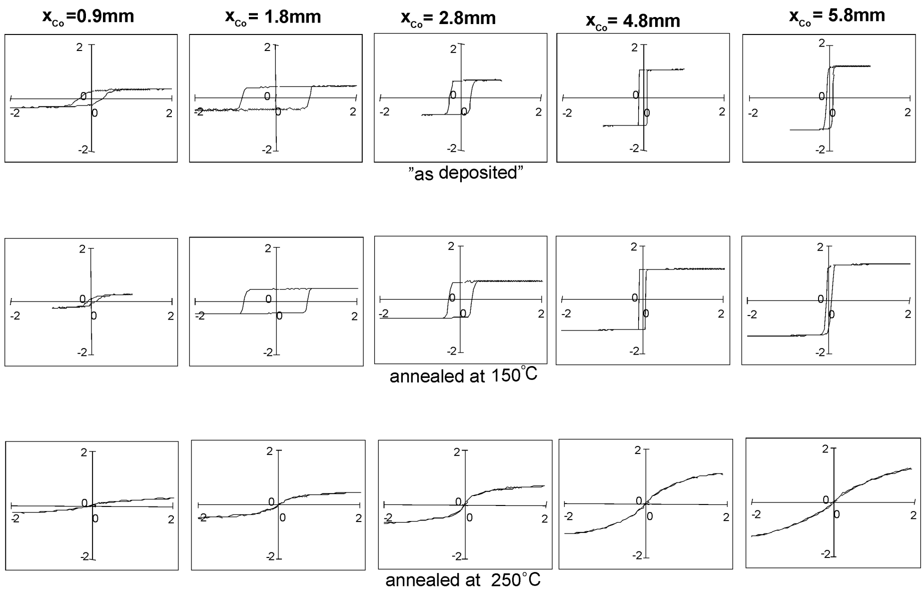

Fig. 1. Examples of hysteresis loops measured for "as deposited" and annealed samples

Figure 1 shows a set of hysteresis loops measured in the magnetic field perpendicular to the sample plane. The dependencies of: $H_C(d)$ – the coercivity field – and Φ_{max} – the maximal value of Kerr rotation – on Co layer thickness are shown in Fig. 2. $\Phi_{max}(d)$ dependence is similar for all studied samples. A drastic decrease of the coercivity field can be observed after annealing at 250°C.

Magnetic anisotropy K_{1eff} and K_2 constants were determined by fitting theoretical curves to experimental data $\varphi(H_\perp, H_{||} = \text{const})$, under the assumption that magnetic film total energy E_{TOT} (θ) is expressed by the following standard formula:

$$E_{TOT}(\theta) = -H_\perp M_S \cos(\theta) - H_{||} M_S \sin(\theta) + K_{1eff} \sin^2(\theta) + K_2 \sin^4(\theta)$$

where θ angle is measured from the sample normal direction: $\cos(\theta) = \varphi(H_\perp, H_{||})/\Phi_{max}$.

The influence of annealing on magnetic anisotropy constants is shown in Fig. 3. The dotted line shows $K_{1\mathrm{eff}}(d)$ curve fitted to experimental points measured for as-deposited sample assuming $K_{1\mathrm{eff}}(d) = -2\pi M_s^2 + K_{1v} + (K_{1sb} + K_{1so})/d$ [4] where the demagnetization term as well as the volume and both buffer (K_{1sb}) and overlayer (K_{1so}) surface anisotropy contributions are taken into account.

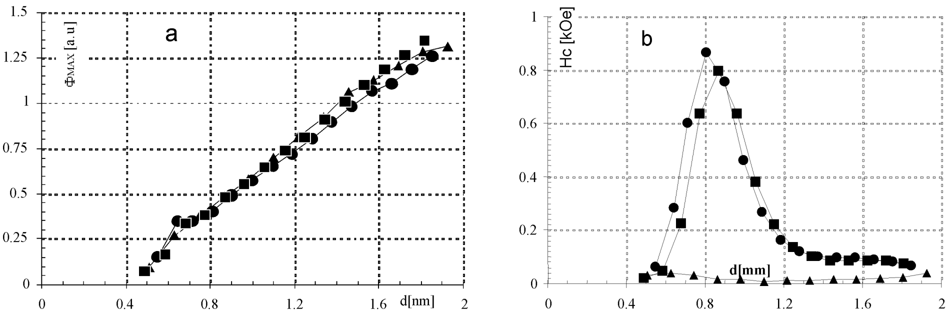

Fig. 2. Cobalt thickness dependencies of : a) maximal Kerr rotation; b) coercivity field. “As deposited” – circles, annealed at 150°C – squares, annealed at 250°C – triangles

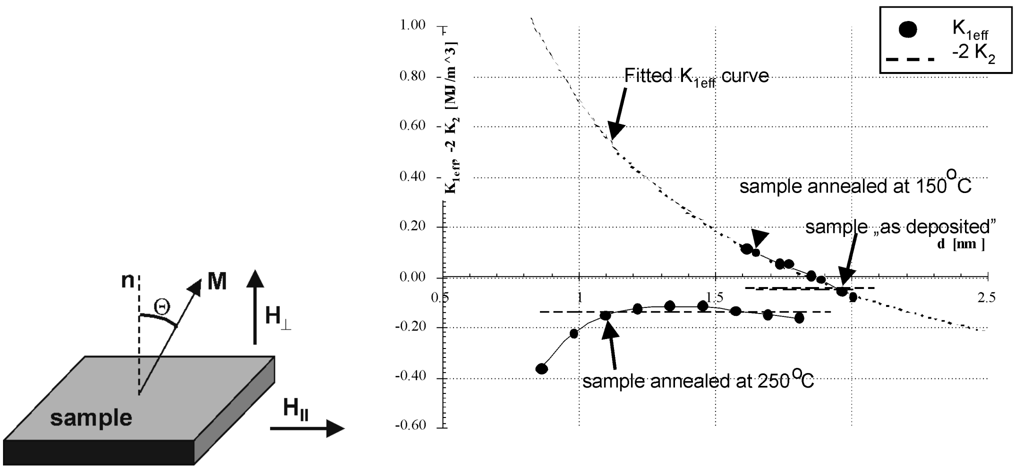

Fig. 3. Thickness dependencies of anisotropy contants in the as deposited and annealed samples

Annealing at T_a =150°C practically does not affect the magnetic parameters in comparison with the reference as-grown sample. A drastic decrease of magnetic anisotropy is found upon annealing at 250°C.

Enhanced diffusion at the interfaces, as a consequence of annealing, seems to be responsible for the observed changes.

Acknowledgements

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