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Domain structures and magnetization processes in thin Co films with in-plane anisotropy

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Magnetization reversal and domain structures in thin Co films in the thickness range $2 < d < 100$ nm with in-plane magnetic anisotropy were studied. Both magneto-optical (MO) vector magnetometry and MO microscopy were used. A crossover of in-plane anisotropy symmetry from two-fold to six-fold was observed with increasing thickness of the Co layer from 2 nm to 100 nm. The evolution of the domain structure during magnetization reversal was studied for various orientations of the magnetic field relative to the anisotropy easy axis using a longitudinal Kerr MO microscope.

Key words: magnetization reversal; domain structure; Kerr effect; magneto-optic vector magnetometry

1. Introduction

Studies of magnetic domain structures and magnetisation processes occurring in nanostructures are attractive for both scientific and technological interests. Magneto-optical MO vector magnetometry combined with MO microscopy are powerful techniques for flexible anisotropy analysis with high sensitivity. Such a magnetooptical study of ultrathin Co films with in-plane anisotropy was the purpose of this work.

2. Experimental details

Sample preparation. The Au/Co(d)/Au sandwiches were grown in a molecular beam epitaxy system Riber EVA 32 in the low range of 10^{-10} Torr vacuum. Al_2O_3

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(11–20) substrates buffered with a 20 nm thick Mo layer were used. Co and Mo were evaporated from electron guns and Au from an effusion cell at the rates lower than 0.05 nm/s. The bottom 20 nm Au layer, deposited directly on the Mo buffer, was annealed at 200 °C to minimize its surface roughness. A cobalt layer with a selected thickness d from the range 2–100 nm was then grown at 300 K. Finally, the whole structure was covered with an 8 nm thick gold layer. The growth process of the samples was monitored in-situ by RHEED. A more detailed description of sample preparation and structural characterization is provided elsewhere [1].

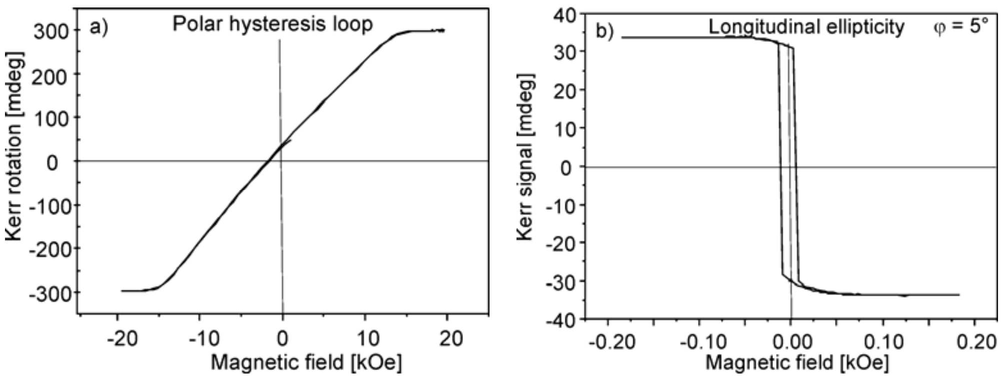
MO vector magnetometry. Measurements based on the MO Kerr effect were performed at room temperature with the laser light wavelength of 640 nm and spot diameter of 0.5 mm. Three components of the magnetization vector were separated using an adjustable in-plane magnetic field produced by a computer-controlled electromagnet and using a precise sample rotation system. The polar (perpendicular to the film) magnetization component was measured using the polar MO Kerr effect. The longitudinal and transversal in-plane components (parallel and perpendicular to the applied magnetic field) were measured using the longitudinal MO Kerr effect.

3. Results and discussion

The transition from the out-of-plane easy magnetization axis state to the in-plane state occurs at a Co film thickness of about 1.8 nm [2]. MO vector magnetometry shows the existence of easy magnetization axes oriented in the plane of the film for the Co layer thickness $d > 2$ nm. A two-fold symmetry of the magnetization reversal process was observed for the values of d smaller than 10 nm. This is probably related to a small, unintentional (less than 0.5 deg) miscut of the Al_2O_3 substrate. A similar behaviour was reported in other papers (see Refs. [4, 5]). Six-fold symmetry was found for thicker (d >10 nm) Co films. The analysis presented below is based on the results obtained for the sample with a 31 nm thick Co film.

The hard magnetization axis normal to the film plane can be deduced from the hysteresis loops shown in Figs. 1a–c. The lack of remanent magnetization (Fig. 1a) is evidence for magnetization alignment in the plane of the sample. Two different shape loops recorded for various orientations of the in-plane applied field are shown in Figs 1b, c. They suggest the occurrence of in-plane anisotropy depending on the azimuthal orientation. The six-fold symmetry is visible in the angular dependence of the longitudinal remanence of ellipticity (Fig. 2a), with a weak transverse component (compared to the longitudinal effect). Six-fold symmetry is also present in the angular dependence of the transversal remanence (Fig. 2b).

The magnetization reversal processes, with the resulting multi-domain structure, can be deduced from the shape analysis of the low field longitudinal loops shown in Figs. 1b, c. Observations of domain structures (DS) were performed with a longitudinal Kerr effect micro-magnetometer equipped with a home-made polarizing optical microscope. Both high-sensitivity and high-resolution micro-magnetometer configurations [3] were applied. The former setup was used to obtain an overview of the domain pattern on a large scale. The advantage is the lack of optical elements other than the sample between the polarizer and analyzer, making contrast conditions optimal. Images with a light inclination angle of 50° are presented in Figs 3a-c. The evolution



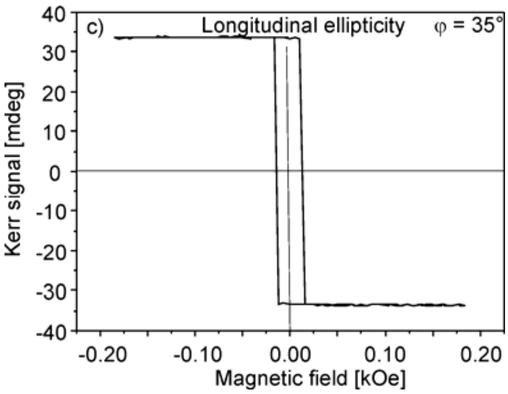


Fig 1. Hysteresis loops in a sample with 31 nm thick Co layer: a) polar configuration, b) longitudinal configuration, magnetic field is in hard axis direction, c) longitudinal configuration, magnetic field applied in easy axis direction, φ – the angle between applied magnetic field and a specified edge of the sample

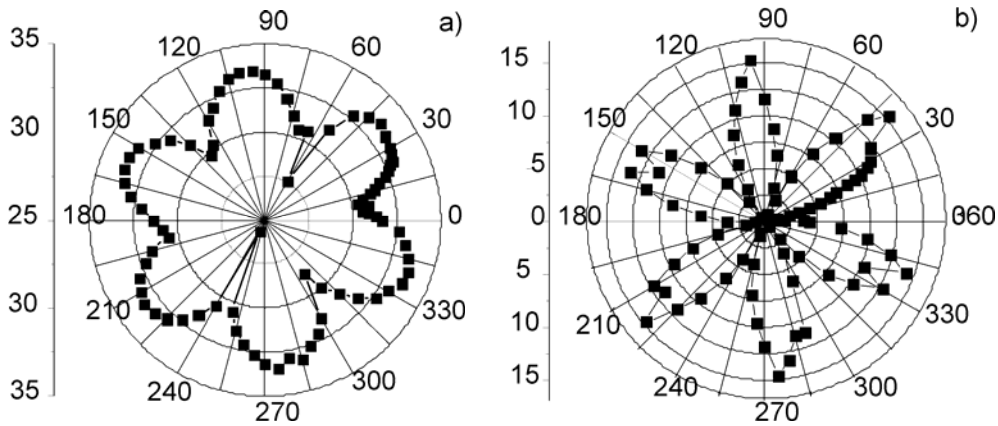


Fig. 2. Polar plot of ellipticity remanence: a) longitudinal, b) transversal. Measurements were performed for the sample with 31 nm thick Co layer

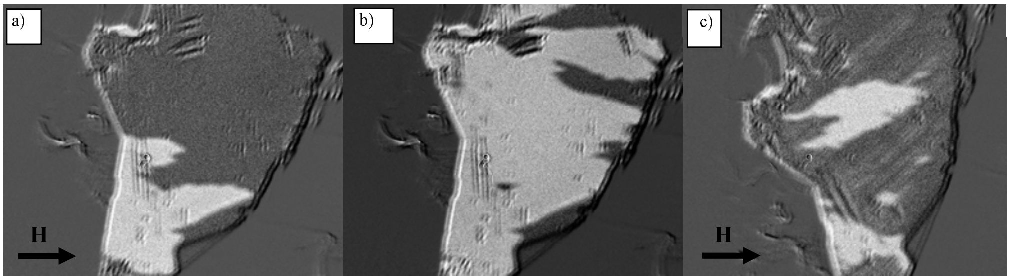


Fig. 3. Domain structures in the sample with 31 nm thick Co layer: a, b) magnetic field applied in the easy axis direction $\varphi = 35°$, c) magnetic field applied in the hard axis direction, $\varphi = 5°$. Size of the pictures – 8 mm×10 mm. Remanence images DS obtained by magnetic field impulses; amplitude 20 Oe, time 600 ms

of domain structure during magnetization reversal was studied for various orientations of the applied magnetic field. The magnetisation reversal for the magnetic field applied along the easy axis is shown in Figs. 3a, b. The domain wall propagation mechanism is dominant here. A higher density of nucleation centres was observed when the magnetic field was applied in the direction of the hard axis (Fig. 3c).

4. Conclusions

MO magnetometry studies carried out for samples with Co layer thickness of $d > 2$ nm reveal the thickness dependence of in-plane magnetic anisotropy. The two-fold symmetry of in-plane anisotropy changes to six-fold symmetry with increasing Co layer thickness above $d = 10$ nm. Most probably, the two-fold symmetry is due to the small unintentional substrate being miscut, and the six-fold one is caused by the magnetocrystalline anisotropy of the dominating cobalt hcp phase in thick layers [6].

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