Kerr microscopy studies of magnetization reversal uniformity in thin Co-films

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We have studied the magnetization reversal of thin Co-films as a function of film thickness by means of magneto-optical Kerr effect microscopy. While all films exhibit uniaxial in-plane anisotropy and very sharp magnetization reversal at their respective coercive fields H_c, we also observe distinct differences in the overall reversal process for films of different thickness. Specifically, we find thinner films with a thickness of 15 nm or less to produce non-uniform magnetization states on the 1 - 10 micron lateral length scale, while thicker films of 30 nm thickness and more are characterized by domain wall motion and uniformly magnetized domains.

Thin Co-films were grown by means of e-beam evaporation onto naturally oxidized silicon (110) wafers. Our Oerlikon UNIVEX 350 deposition system is equipped with a 6 pocket rotary system for e-beam evaporation and 2 pockets for thermal evaporation. It also allows for substrate rotation during deposition to achieve excellent film uniformity and it enables substrate temperatures of up to 850°C. During the cobalt deposition, the vacuum pressure was better than 10^{-5} mbar. The deposition rate was continuously monitored and controlled by a quartz crystal sensor and held constant at 0.5 ± 0.1 Å/sec for all films. The accuracy of the deposition rate and total film thickness was furthermore corroborated by means of ellipsometry measurements. Magnetic measurements were performed using an advanced wide-field EVICO® Kerr-microscope for magnetic domain imaging and magnetic hysteresis measurements. Our system is equipped with a custom-build rotatable electromagnet for in-plane fields of up to 150 Oe (12 kA/m) and allows for the simultaneous measurement of local M(H)-curves and recording of underlying domain processes, with a lateral resolution down to the limit of optical microscopy (approximately 500 nm). The magnetic field can be varied in steps of down to 0.1 Oe.

Figure 1 shows measurements obtained for a 15 nm thick Co-film with the external field applied along the easy magnetization axis. The Kerr microscope image illustrates the non-uniform magnetization state that occurs upon relaxing the magnetic field from positive saturation. The local M(H)-curves show that the large area hysteresis loop corresponds to the average of two main types of local hysteresis loops, which can be observed on the micron scale. Some parts of the sample show very rectangular hysteresis loops with nearly full remanence, while other parts exhibit a rather substantial reduction of the remanent magnetization, even though the large magnetization jump at H_c is synchronized for both areas. The easy axis magnetic behaviour of a 30 nm thick Co-film is substantially different, as shown in Figure 2. In this case the magnetization relaxes into a uniform state as the external field is reduced to zero from positive saturation. In contrast to the thinner Co-films, for which the magnetization switching occurred in a single avalanche given our field resolution, thicker films show a more gradual magnetization reversal, as illustrated by the sequence of Kerr-microscope images shown in Fig. 2. Here, the reversal is dominated by the motion of domain walls in between macroscopically large and uniform domains.

The difference in behavior can be understood by the different role the exchange energy has. Due to substrate roughness and the polycrystalline nature of the films, inter-granular exchange coupling is weak in the initial onset layer during growth. Thus, on average thinner films exhibit a lower level of inter-granular exchange coupling, enabling them to exhibit non-uniform magnetization states at low fields, in which the local magnetization follows the easy axis distribution of the grains. For thicker films, this non-uniformity is more strongly suppressed due to the more prominent role of the inter-granular exchange coupling, which forces the magnetization to align throughout the sample. This physical picture is supported by model calculations.

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Figures:

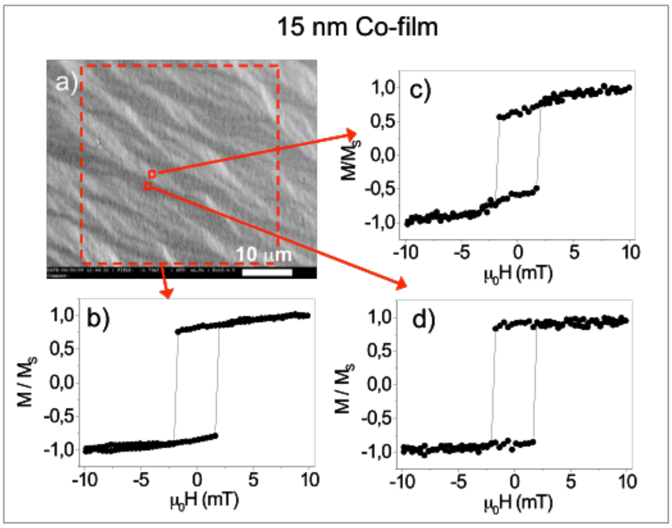

Figure 1 Panel a): Kerr microscope image (55 mm x 42 mm) of a 15 nm thick Co-film taken at remanence upon field reduction from saturation along the magnetic easy axis. Panel b): Easy axis MOKE hysteresis loop measured within the area of 40 µm x 40 µm marked in Panel a). Panels c) and d): MOKE hysteresis loops measured within the two regions of 1 µm x 1 µm marked in Panel a).

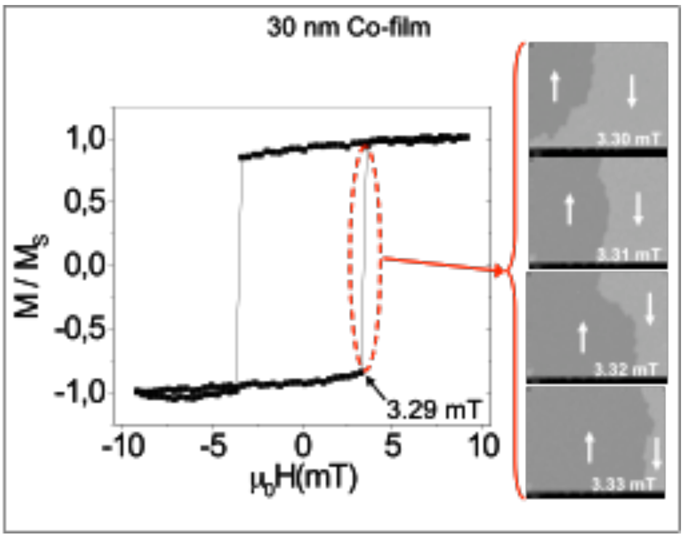

Figure 2 MOKE hysteresis loop recorded with the external field applied along the magnetic easy axis for a 30 nm thick Co sample. The insets display a sequence of Kerr microscope images (435 µm x 330 µm) illustrating the domain reversal pattern in the sample.