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Uniaxial anisotropy in epitaxial cobalt films grown on Cu(1 1 13)

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Ultrathin epitaxial Co films grown on a Cu(1 1 13) vicinal surface are shown to exhibit in-plane uniaxial magnetic anisotropy with the easy axis of magnetization parallel to the step edges. Along the easy axis the room temperature coercivity is in the range of a few Oe, depending on the film thickness, whereas along the hard axis no magnetic field effect in the Kerr signal could be observed up to 130 Oe.

Recently it has been demonstrated that the magnetic properties of epitaxially grown ultrathin films are influenced by steps on the template surfaces [1–3]. Vicinal surfaces are characterized by a periodic arrangement of monatomic steps aligned predominantly with one crystallographic direction. This twofold symmetry of the vicinal surface manifests itself in the macroscopic magnetic film properties, i.e. as a uniaxial anisotropy [2,3]. In the case of Fe films grown on a stepped tungsten surface, thickness-dependent changes of hysteresis loops have been observed and the easy axis of magnetization turned out to be perpendicular to the step edges [3]. In the Co/Cu(1 1 13) films the uniaxial magnetic anisotropy has been found by studying the micromagnetic structure in the films. The domain magnetization, i.e. the easy axis, is aligned parallel to the step edges [2]. Thus, remarkable differences between the two systems are to be found for the easy axis of magnetization. To investigate more quantitatively the thickness dependence and the strength of the uniaxial anisotropy in Co/Cu(1 1 13) films we have performed magneto-optical Kerr hysteresis measurements.

All experiments were carried out in situ under UHV conditions (base pressure $< 2 \times 10^{-10}$ Torr). The films have been grown at room temperature with a deposition rate of about 1 monolayer per minute. During growth medium energy electron diffraction (MEED) patterns have been observed as well as MEED reflection intensities measured. In every stage of growth the MEED diffraction pattern was conserved while small intensity variations on a high reflectivity level could be detected. A detailed study, however, has shown that the intensity variations cannot be correlated with the completion of layers. The high reflectivity as well as the missing of MEED intensity oscillations indicate that the surface does not show any considerable increase of roughness in every stage of growth. This is most likely due to predominantely step edge growth and, hence, a layer-by-layer growth. The thickness calibration has been done via Auger peak ratios. The relation between thickness and Auger peak-to-peak amplitudes has been previously calibrated in situ via MEED intensity oscillations obtained with Co/Cu(001). The magnetic hysteresis loops have been measured by the longitudinal magneto-optical Kerr effect.

We have measured hysteresis loops for different film thicknesses as a function of the azimuthal orientation of the crystal with respect to the direction of the applied magnetic field. Fig. 1 shows hysteresis loops for 2, 3 and 10 monolayer films. The rotation angle is measured with respect to the direction perpendicular to the step

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edges, i.e. the hard axis of magnetization. Comparing the hysteresis loops near or in the easy/hard axis, it is obvious that the magnetic behavior is similar for all the films. The uniaxial behavior is very pronounced. Particularly, no changes of the hysteresis loops with varying thickness can be found as it was found with Fe on tungsten in the hard direction [3]. We could not

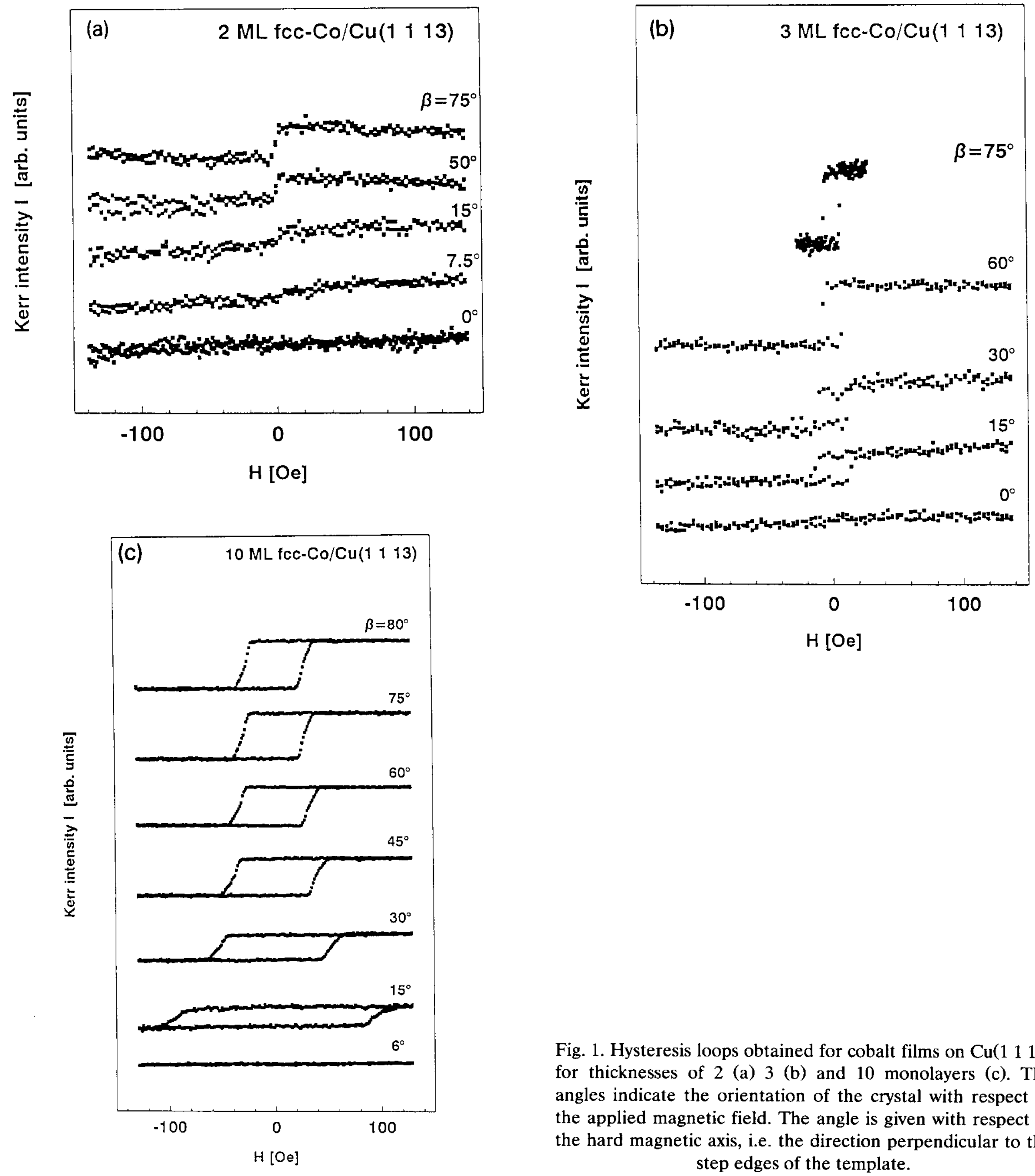

Fig. 1. Hysteresis loops obtained for cobalt films on Cu(1 1 13) for thicknesses of 2 (a) 3 (b) and 10 monolayers (c). The angles indicate the orientation of the crystal with respect to the applied magnetic field. The angle is given with respect to the hard magnetic axis, i.e. the direction perpendicular to the step edges of the template.

obtain any Kerr signal along the hard axis within the available magnetic field of 130 Oe for any film thickness (< 2–10 monolayers). Along the easy axis, however, small coercivity values in the range of a few Oe are found, e.g. for 3 monolayers H_c is about 5 Oe at room temperature. H_c depends on the film thickness. It increases with increasing film thickness as in Co/Cu(001) films [6]. The coercivity value, however, is smaller than obtained with Co/Cu(001) [4–6]. In our investigation of the magnetic microstructures we have obtained the same polarization signals for Co/Cu(1 1 13) and Co/Cu(001) films with equal thickness. As the spin polarization of the secondary electrons roughly scales with the saturation magnetization [7] we might conclude that the saturation magnetization in both film systems is the same.

The angle dependence of the hysteresis loops in fig. 1 can be easily explained by geometric arguments. The reversal of the magnetization occurs if the projection of the magnetic field onto the easy direction exceeds the easy axis coercivity field. The magnetization reversal takes place along the easy axis. We have checked this hypothesis with the 10 monolayer film results (fig. 1c). Fig. 2 shows the coercivity plotted versus the rotation angle. If the above suggestion is true, a 1/sin β behavior should be expected. The dashed curve in fig. 2 represents a 1/sin β fit to the measured coercivity fields. The agreement is quite good which again proves the pure uniaxial behavior found in the rotational hysteresis loops. A similar result can be obtained for the angle dependence of the Kerr signal. The Kerr signal in saturation follows a sin β law which means that the magnetization is aligned with the easy axis [8]. Thus, with increasing easy axis coercivity the onset of observable loops in fig. 1 is shifted to higher angles (related to the hard axis). The early appearence of the loop for the 2 monolayer film (at 7.5°) as well as the large coercivity values for the 10 monolayer film at the lowest angles can be equivalently explained.

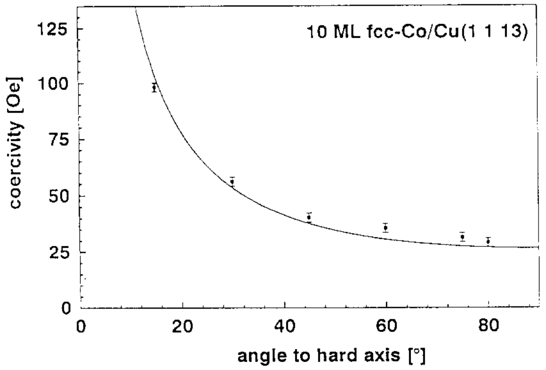

Fig. 2. Plot of the coercivity of the 10 monolayer film versus sample orientation. The measured values from fig. 1c are indicated by circles. The dashed curve is a 1/sin β fit to the measured coercivities.

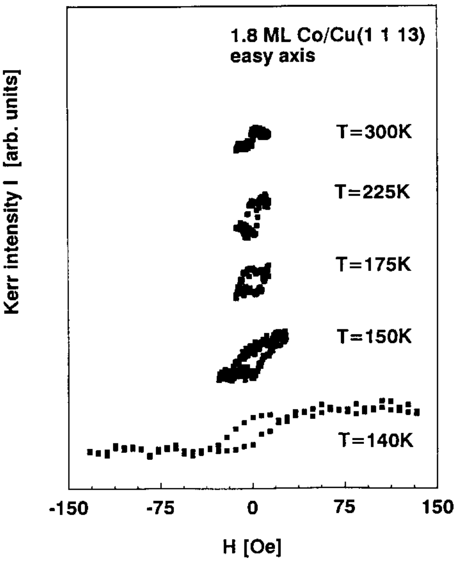

Fig. 3. Temperature dependence of the hysteresis loop of a 1.8 monolayer film.

Further similarities between Co/Cu(001) and Co/Cu(1 1 13) can be found with the thickness dependence of the Curie temperature. Fig. 3 represents the hysteresis loops obtained for a 1.8 monolayer film for various temperatures. The loops shown are taken for the magnetic field along the easy axis. The hard axis experiments did not show any Kerr signal. The easy axis loops exhibit an increase of coercivity and Kerr signal with decreasing temperature equivalent to the findings with Co/Cu(001) [4,5]. At 300 K we obtain a very small Kerr signal and a very narrow loop. Raising the temperature slightly above room temperature causes the easy axis loop to diminish. For thicker films (> 3 monolayer) the Curie temperature is far above 400 K [8]. Thus we may state to have found the same temperature behavior as in the films grown on Cu(001) although some uncertainties in the thickness determination (via Auger in this study) cannot be ruled out. The reversible increase of H_c at lower temperatures has been carefully studied for the room temperature grown films by Mankey et al. [5]. As we find the reversible changes as well, we might conclude with their findings that no intermixing of Co and Cu is present in our films grown on the stepped copper surface.

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