Magnetization reversal of uniaxial Co films with tunable crystallographic order

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It is well established that crystallographic order has a very pronounced relevance for the magnetic properties of materials due to the quantum mechanical spin-orbit coupling, which is responsible for magneto-crystalline anisotropy [1]. The control of magnetic properties and in particular the tuning of magneto-crystalline anisotropy is also essential for technological applications, such as hard disk drive media [2] or magnetic random access memories (MRAMs) [3]. However, most magnetic materials characterization studies have been focused either on nearly perfect crystallographic samples or highly disordered samples in the past, and there are only very few studies, in which the region in between perfect crystalline samples and disordered materials has been explored.

Here, we have studied the influence of crystallographic order onto the magnetization reversal process in granular Co films. In order to allow for a well-defined variation of the crystallographic order a reproducible processing sequence was developed that enables the continuous modification of epitaxial growth for (10$\underline{1}$0) Co films by partially interrupting the epitaxial growth sequence. Specifically, we used the epitaxial growth sequence Ag(110)/Cr(211)/Co(10$\underline{1}$0) onto HF-etched Si (110) substrates, which enables the fabrication of high-quality epitaxial Co-films with an in-plane easy axis of magnetization by means of ultra high vacuum (UHV) sputter deposition [4]. In order to disturb or interrupt the epitaxy in a well defined manner we have deposited an ultrathin SiO_2 film of the order of one monolayer thickness on top of the Si substrate prior to the Ag layer deposition. By using different deposition times for this Si-oxide layer (t_{ox}), we managed to fabricate Co (10$\underline{1}$0) samples with different crystallographic order level.

Figure 1 shows an X-ray θ-2θ measurement for a fully epitaxial grown sample and a sample with t_{ox}=12s, corresponding to partial epitaxy interruption. While we only observe the Si (220), Ag (220), Cr (211), Co (10$\underline{1}$0) and Co (20$\underline{2}$0) peaks for the fully epitaxial sample, we find multiple Ag peaks that correspond to different crystallographic orientations for the sample with partial epitaxy interruption. Nonetheless, this sample still has a high degree of Ag (220) and Co (10$\underline{1}$0) texture, if one does a quantitative analysis of the X-ray data. The degree of Co (10$\underline{1}$0) texture decreases further in a systematic fashion as t_{ox} is increased.

We have studied the magnetization reversal process in these samples by means of macroscopically and microscopically magneto-optical Kerr effect measurements. Figure 2 shows single domain (SD) vs. multi domain (MD) magnetization state maps, determined from quantitative Kerr microscopy [5], for three samples with different degrees of disorder (fig. 2a t_{ox}=0 s, fig. 2b t_{ox}=12 s and fig. 2c t_{ox}=15 s) as a function of the applied field angle β with respect to the easy axis (EA) and the applied field strength. Here, the blue color indicates a single domain state while other colors reveal the existence of multi-domain structures. We find that while in crystallographically well ordered films no static domain states exist in the entire field size and orientation range, magnetization reversal by means of non-uniform intermediate stable or meta-stable states exists for partially epitaxial samples with sufficient inter-granular misalignment. We also observe that these non-uniform states are more common for intermediate field orientations in between the macroscopic EA and hard axis (HA) directions.

Furthermore, we also observed an anomaly in samples with partial crystallographic alignment, for which conventional HA behavior disappears. When the magnetic field is applied along the nominal HA in such samples, a frustrated magnetic state occurs, which arises from the competition between ferromagnetic exchange and the uniaxial anisotropies of misaligned adjacent grains. The existence of such a frustrated state is related to a non-uniform magnetization reversal in the nominal HA and

produces considerably high values of remanent magnetization and coercive field (figs. 3 (b)), while only 2° away from the nominal HA, the magnetization reversal is dominated by coherent rotation, as it is expected for highly uniaxial samples along or near the HA (figs. 3 (a) and (c)). The anomaly has been theoretically explained by means of a two-grain coupled Stoner Wohlfarth model and has been corroborated experimentally by microscopic imaging.

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References

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Figures

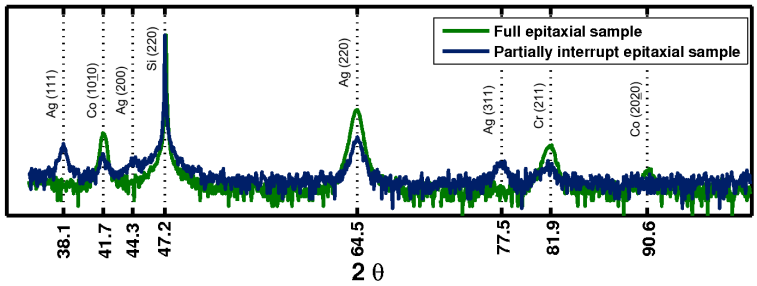

Figure 1: X-ray diffraction spectra in θ-2θ configuration for a fully epitaxial sample t_{ox}=0s (green) and for a partially epitaxial sample with t_{ox}=12s (blue).

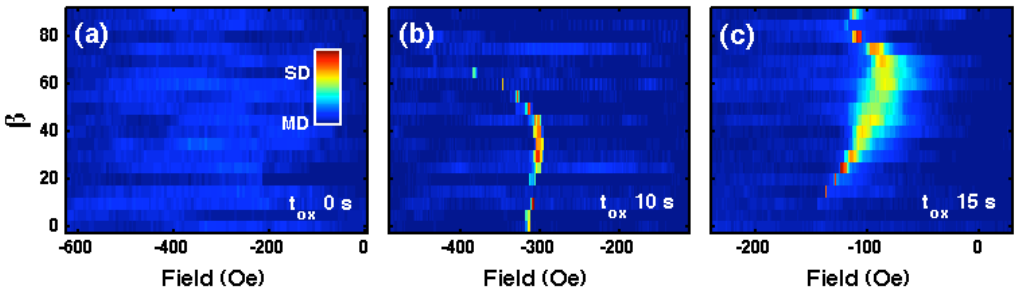

Figure 2: Single-domain/multi-domain existence map for samples with different degrees of crystallographic order as a function of applied field angle and strength: (a) fully epitaxial (10$\underline{1}$0) Co sample, and partially epitaxial samples, generated by SiO_2 underlayer deposition of (b) 12s and (c) 15s duration.

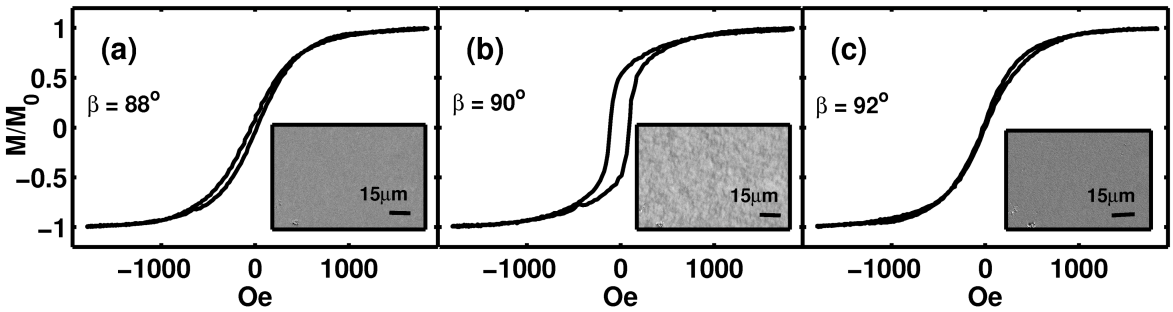

Figure 3: Hysteresis loop for a partially epitaxial sample, grown with t_{ox}=12 s, for magnetic field orientations ±2° away from the HA (a) and (c) respectively, and along the nominal HA (b). The inset figures show the remanent magnetization states taken by Kerr microscopy after applying a magnetic field along the corresponding field angle.