Magnetization reversal and the intermediate state stability in thin Co-films

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The process of magnetization reversal is a fundamental aspect of magnetism and of crucial relevance in many industrial applications, which explains why it is a very active area of research. In this work we have conducted a Kerr effect microscopy study for the purpose of analysing the microscopic effects that occur during magnetization reversal at different applied field directions in order to understand the underlying physics.

Co-films with uniaxial in-plane anisotropy have been grown by means of UHV sputter deposition. This specific magneto-crystalline anisotropy of the samples has been achieved by means of epitaxial growth onto single crystal Si(110) wafer substrates and the use of a suitable template layer sequence [1].

The magnetization reversal and the intermediate domain stability have been analysed by means of an EVICO@ Kerr effect microscope for various angles of the externally applied field. Images taken in the positive saturation state, during reversal and at the negative saturation state are shown in Figure 1 for different applied field angles. Specifically, we have studied the reversal for the applied field oriented along the easy axis, 30º away from the easy axis and 60º away from the easy axis. Initially the sample is always saturated positively and the magnetization is uniform in all three cases. However, as we remove the positive field and start applying the field in the opposite direction, i.e. applying a negative field, we can observe different reversal behaviors for different applied field orientations just before and during the magnetization switch. In the first case (Figure 1 (a2)) (external field applied along the easy axis) the magnetization is still uniform without any domain state before the switch, however for the other two cases (Figure 1 (b2, c2)) intermediate multi-domain states are visible due to partial switching of the local magnetization structure.

To represent the entire magnetization reversal sequence in a compact and quantitative way, we developed a new representation method. In this method, all data that are contained in an entire image sequence (movie) are condensed into a single picture. If we quantify the numbers of pixels per gray scale in a Kerr microscope image, a histogram of the magnetization distribution can be obtained. A color coded scheme is then utilized to display different probabilities of each histogram point in order to obtain a single line representation for each applied field value (each Kerr microscope image). Combining all such lines for different applied field strengths produces a local magnetization probability vs. field picture of the magnetization reversal as shown in Figure 2. This new magnetization reversal representation contains substantially more information than a single magnetic hysteresis loop. With this representation method we can examine and quantify different effects that can take place during magnetization reversal such as, domain creation, uniform rotation of the magnetization and sample size avalanches.

Using this new method we have analyzed the magnetization reversal along different external applied fields directions: along the easy axis, 30 ° and 60 ° away from the easy axis (Figure 2). We have observed that the stability range of intermediate non-uniform magnetization states, that are absent for the easy axis reversal, is increasing as we go further away from the easy axis. When the external field is applied along the easy axis, the magnetization reversal is fully correlated without any intermediate stable domain creation, consistent with describing the reversal as a macro-spin process. (Figure 2 (a)). However, if we go away from the easy axis the magnetization reversal is no longer a sample size avalanche and intermediate stable states start appearing. For the external field applied 30º away from the easy axis, we already have (meta-)stable multi-domain states (Figure 2 (b)). Moreover. the field range in which such domain states occur, increases as one increases the angle away from the easy axis. For a field 30º away from the easy axis, the field range of these intermediate domains is between -2.2 mT and -2.7 mT, while for fields 60º away from the easy axis (Figure 2 (c)) the field range increased to -1.74 mT to -2.77 mT.

In addition to these non-uniform reversal states, we can also observe a uniform magnetization rotation for these last two cases as we increase the strength of the applied field opposite to the magnetization direction. Here, the magnetization distribution peak does not remain at the full positive saturation value, but starts bending towards the negative saturation state prior to the domain state reversal.

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References:

[1] Yang W., Lambeth D.N. and Laughling D.E. Journal of Applied Physics. **Vol 85, 8** (1999)

Figures:

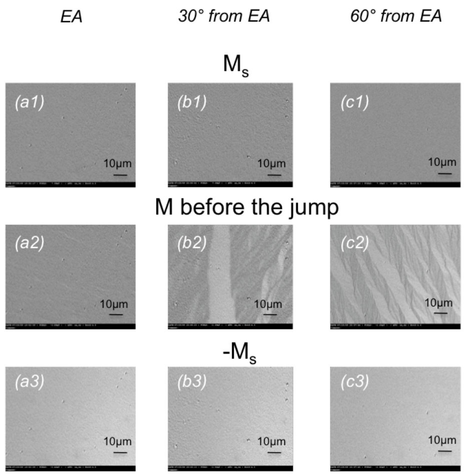

Figure 1 Kerr microscope images (physical dimensions 55 μm x 42 μm) of magnetization states in a uniaxial Co sample: at positive saturation, near or during reversal (external applied field a2: -3.09 mT b2: -2.59 mT c2: -2.29 mT) and for negative saturated states. The external field is applied along a) the easy axis b) 30 ° away from the easy axis and c) 60 ° away from the easy axis.

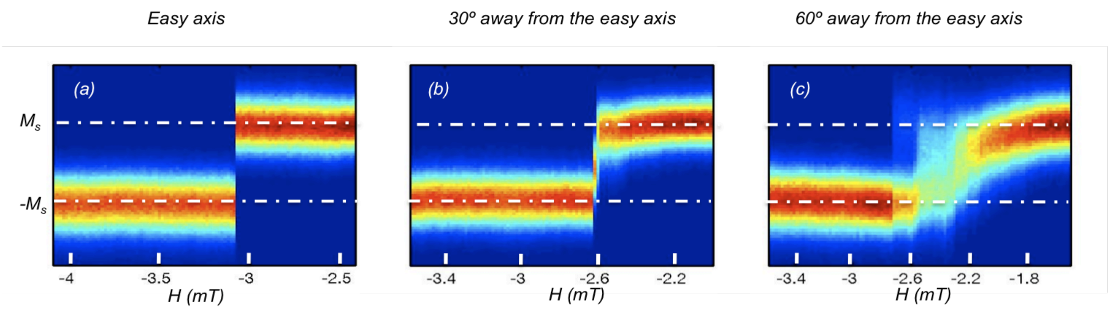

Figure 2 Magnetization reversal in a uniaxial Co sample using a histogram representation method: External field applied along a) the easy axis b) 30 ° away from the easy axis and c) 60 ° away from the easy axis.