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# Micromagnetic studies of Fe/Co ellipses with competing anisotropy contributions

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## Abstract

The effects of competing magneto-crystalline and shape anisotropies on magnetization reversal were studied in arrays of sub-micron Fe/Co ellipses of compositions Fe<sub>2</sub>/Co<sub>6</sub> and Fe<sub>8</sub>/Co<sub>3</sub> with magnetic force microscopy, MFM. A simple model assigning magnetization values to the different types of domain structures observed in the MFM images was used to estimate the field dependence of the total magnetization of a sample. The agreement with macroscopic magnetization measurements is discussed.

*Key words:* Fe/Co multilayers, competing anisotropies, MFM, domain structure

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The process of magnetization reversal in arrays of sub-micron size ellipses made of bcc Fe/Co(001) multilayers was studied with MFM in applied magnetic fields up to 150 mT. Two different types of multilayer structures were used: a Fe<sub>2</sub>/Co<sub>6</sub> film with high magneto-crystalline anisotropy and a Fe<sub>8</sub>/Co<sub>3</sub> film with low magneto-crystalline anisotropy, where the figures stand for numbers of monolayers. For details of the samples see [1]. In both types of multilayers, the competition between magneto-crystalline and shape

anisotropies was investigated in ellipses (nominal size  $150 \times 450 \times 20 \text{ nm}^3$ ) with their axes either along the easy or the hard magneto-crystalline directions, making a total of four different samples. Similar studies have been performed by others on e.g. Co [2] and permalloy [3].

First a saturating magnetic field,  $B_{sat}$ , was applied parallel to the long axis of the ellipses and then removed. The domain structures of the ellipses were subsequently imaged in the MFM as a function of the field applied  $180^\circ$  to  $B_{sat}$ .

Four different magnetic domain structures of the ellipses were identified during the switching process, as illustrated in Figs. 1 and 2. The structures are referred to as saturated, nearly saturated, equilibrium and distorted two domain structures.

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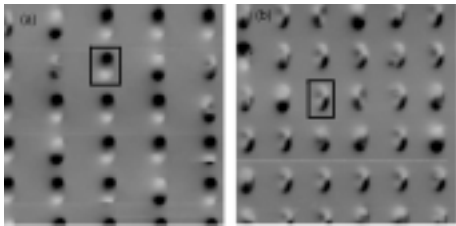


Fig. 1. MFM-images of the Fe2/Co6 ellipses in an applied field of 60 mT. The scan size is 5  $\mu\text{m}$ . The long axes of the ellipses are parallel to the magneto-crystalline (a) easy and (b) hard axis. The marked elements are in (a) saturated and in (b) a distorted two domain structure, see also Fig. 2(b).

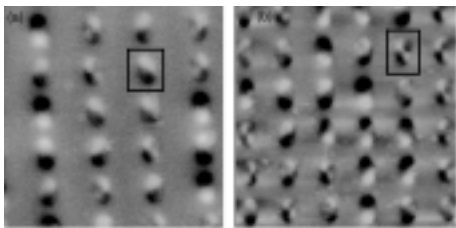


Fig. 2. MFM-images of the Fe8/Co3 ellipses in an applied field of 45 mT. The scan size is 5  $\mu\text{m}$ . The long axes of the ellipses are parallel to the magneto-crystalline (a) easy and (b) hard axis. The marked elements are in (a) a nearly saturated structure, and in (b) an equilibrium two domain structure, which consists of two domains of equal size but opposite magnetization direction.

For all the samples, at a low applied field,  $B \leq 20$  mT, practically all the elements were in a saturated, or nearly saturated, state anti-parallel to the field. When a high enough field,  $B \geq 100$  mT, was applied all the elements exhibited saturated, or nearly saturated, states parallel to the field. In intermediate fields, however, the relative occurrence of the magnetic structures was found to vary depending on the orientation of the ellipses and the strength of the magneto-crystalline anisotropy. In the case of co-operating shape and magneto-crystalline anisotropies, the magnetization of the elements was observed to switch almost directly from one saturated state to the other. However, for the ellipses with two different anisotropy axes multi-domain states were frequent prior to switching and the field interval where switching occurs was broader, see Figs. 1 and 2. For a detailed discussion of the differences between samples see [1].

Demagnetization curves were extracted from the MFM measurements by assigning magnetization

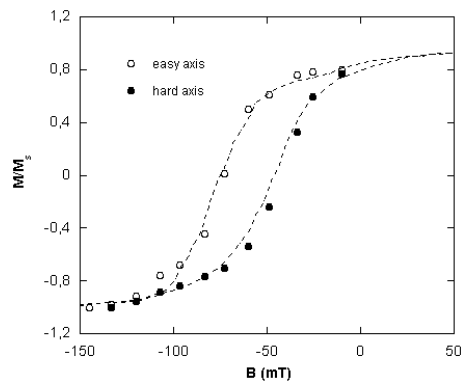


Fig. 3. The Fe2/Co6 demagnetization curves extracted from the MFM measurements. Hard and easy axes refer to the samples with the long axis of the ellipses parallel to the hard and easy magneto-crystalline axis respectively. The dashed line is the macroscopic magnetization curve from [1]. The nearly saturated elements were assigned a constant magnetization value for each sample, determined by results from [1] and the two-domain-structures were assumed to exhibit a linear increase in magnetization, from zero for the field at which the structure first appears to  $M/M_s = 1$  for the field at which the structure becomes saturated. The completely saturated elements were assigned the magnetization value 1.

values to the different types of domain structures observed in the MFM images. A comparison with the results from alternating gradient magnetometer measurements [1] gives a quantitative agreement between the MFM results and the magnetization curves. For the samples with high magneto-crystalline anisotropy, Fe2/Co6, the agreement is particularly striking, see Fig. 3. However, for the Fe8/Co3 elements the results of the MFM and macroscopic magnetization measurements are less compatible due to difficulty to distinguish between completely and nearly saturated states, possibly caused by the low magneto-crystalline anisotropy of the sample.

## References

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