Magnetic force microscopy characterization of the magnetization reversal processes in high density arrays of Co bars with strong dipolar interactions

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Magnetic nanostructures have received increasing attention in recent years [1] both because of their potential as high density recording media and for their interesting fundamental properties. Magnetization reversal processes of ordered arrays of magnetic nanoelements depend strongly not only on the individual element characteristics (material, size, shape) but also on interparticle interactions mediated by dipolar magnetic coupling. Many interesting effects have been reported in interacting arrays of particles, such as changes in coercivity and switching width [2], in the dynamic response [3] and collective behavior including a superparamagnetic-ferromagnetic transition as a function of interdot distance [4].

Often, conflicting results are obtained regarding the role of dipolar interactions in dense arrays of nanoelements since dipolar interaction is a long range effect and presents a complex character that changes sign depending on the geometrical configuration of the nanoelements. Thus interactions may induce either a broadening or a sharpening of the reversal process depending on array geometrical characteristics and on the single element reversal process. For this reason, studies in arrays of magnetic nanoelements with a well defined magnetic anisotropy and highly symmetric geometrical arrangements can be optimum for the disentanglement of the different factors that govern interaction phenomena.

In this work, rectangular and rhomboidal arrays of Co bars have been fabricated by e-beam lithography combined with a lift-off process. Typical bar dimensions are 1.5 µm length, 0.3 µm width and 40 nm thickness with interelement distances in the range 0.2-0.5 µm (i.e. comparable to element width). Figure 1 shows a series of magnetic force microscopy images taken in a rectangular array of Co bars under a reversed in-plane magnetic field. The reversed domains that propagate in the array have a very anisotropic character (consisting of only one or two rows of bars) that can be attributed to the dominant ferromagnetic interaction between bars along their dipole axis. Hysteresis loops have been derived from these MFM images assigning a positive/negative dipole moment at each bar depending on the direction of its magnetic contrast (see Fig. 2). The small plateau that appears during the magnetization reversal process is an indication of the “antiferromagnetic” interaction between adjacent rows that helps to stabilize a magnetic configuration with a reduced global magnetic moment.

In order to analyze these results, Co bars could be treated as “magnetic dipoles” in order to compute dipolar interactions across the array. However, for dense arrays of magnetic nanoelements these simple models lead to overestimates of the strength of the interaction field and it is better to consider the interactions between individual magnetic charges to describe the array magnetic behavior [5]. Micromagnetic simulations performed with the OOMMF code [6] for different array geometries will also be presented to compare with the observed experimental results.

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Figures

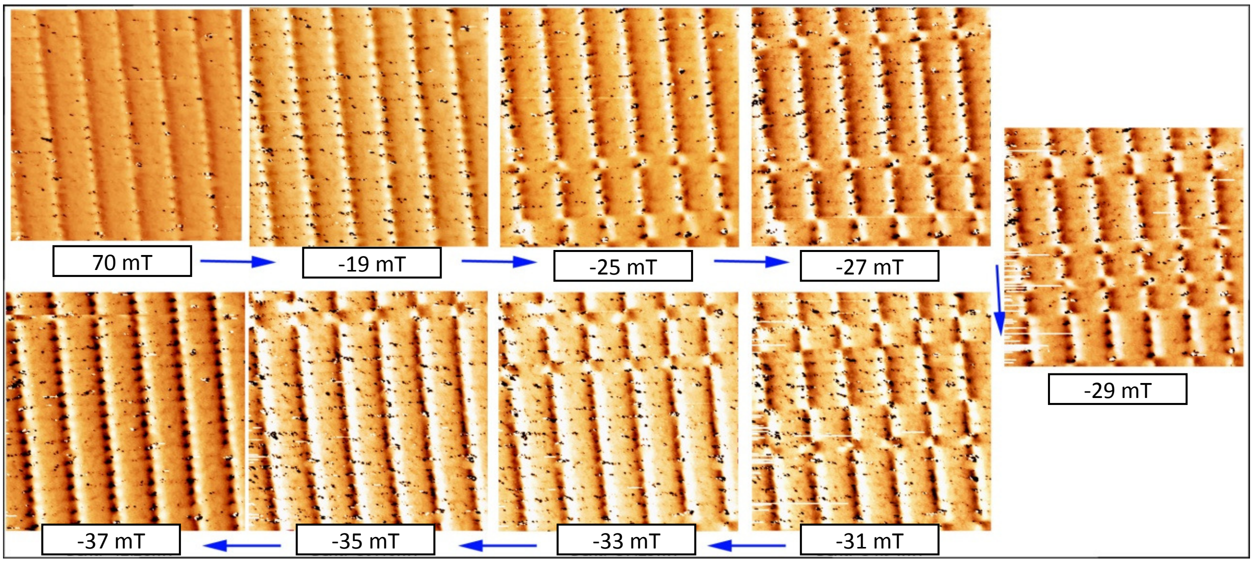

Figure 1: Magnetic Force Microscopy characterization of the reversal process of a dense array of Co bars. Each 10 × 10 μm^2 image was taken under a different constat magnetic fields as indicated by the labels. The field was applied in the sample plane, along the bars (i.e. in the magnetic easy axis of the patterned nanostructure). Blue arrows indicate the temporal sequence of applied fields from positive to negative saturation.

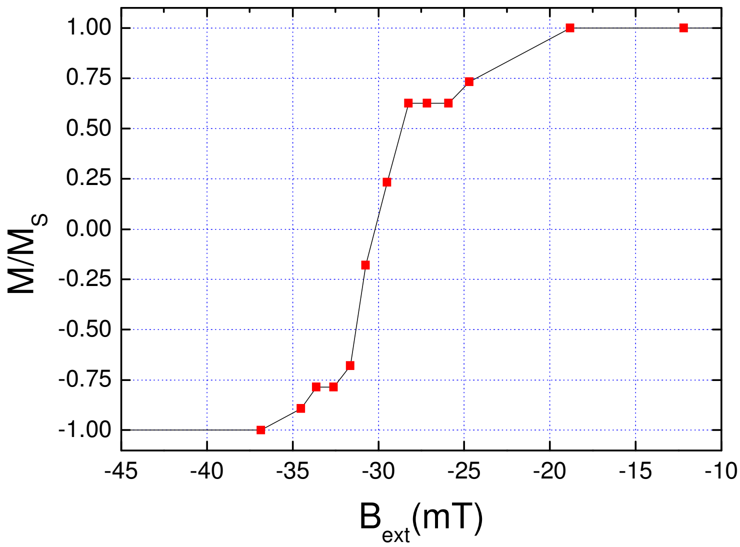

Figure 2: Decreasing field branch of the histeresis loop deduced from the MFM measurments in Fig.1 by assigning a positive/negative dipole moment to each Co bar, depending on the sign of its magnetic contrast.