Magnetisation reversal in magnetic patterned structures by means of field-dependent MFM

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Introduction

Nanostructured thin films, consisting of periodically patterned ferromagnetic materials, have been extensively investigated in the last decade due to the development of magnetoelectronic devices for high-density information storage, MRAM and magnetologic [1,2]. In order to reach a complete understanding of their properties, the magnetic characterisation techniques must follow the ongoing miniaturisation of devices to sizes of the order of 100 nm. The study of magnetic domain patterns is a powerful tool to analyse the local magnetic behaviour of magnetic thin films for magneto-recording and spintronics [3]. Magnetic force microscopy is a valuable technique to investigate the reversal mechanisms of the magnetisation in micrometric and sub-micrometric patterned thin films that cannot be studied with magneto-optical methods because of their limited resolution [4,5]. However, acquiring tens or hundreds of images consecutively at different applied magnetic fields is often impossible or impractical. Therefore, in this work a field-dependent MFM-derived technique is discussed and applied to sub-micrometric magnetic dots.

Materials and Methods

Square dots of $Ni_{80}Fe_{20}$ (size 800 nm and 2 µm, thickness 30 nm) have been prepared by sputtering on Si-oxide substrates and subsequently patterned by means of electron beam lithography. Experimental local hysteresis loops are obtained by repeatedly scanning the same profile of the studied patterned structure with an MFM. Each scan is performed under the application of an in-plane magnetic field having a different intensity, whose variations are synchronised with the end-of-line TTL signal of the microscope. By properly analysing the phase signal of the magnetic force microscope and plotting it as a function of the applied magnetic field, local hysteresis loops can be measured on micrometric and sub-micrometric structures [6].

Results and Conclusions

An example of magnetic domain configuration in a square dot having a size of 2 µm is shown in Figure 1 for different applied field values. The arrows schematically indicate the alignment of the magnetisation within each domain. Although in this way it is possible to follow the complete magnetisation reversal processes of the studied structure, the acquisition of tens or hundreds of images is time-consuming and often impossible because of the wearing out of the MFM tip. Therefore, a different approach is envisaged. An example of a local hysteresis loop measured on a 800 nm large $Ni_{80}Fe_{20}$ square dot is shown in Figure 2: panel (a) shows the repeated scan of a cross section of the dot, making visible the dot edges and its width. Panel (b) shows the corresponding phase signal, sensitive to the magnetic interaction between the dot and the tip, that changes as a function of the applied magnetic field, reported in panel (c). Panel (d) is a vertical cross section of panel (c), showing the correspondence between the scan line number and the applied field.

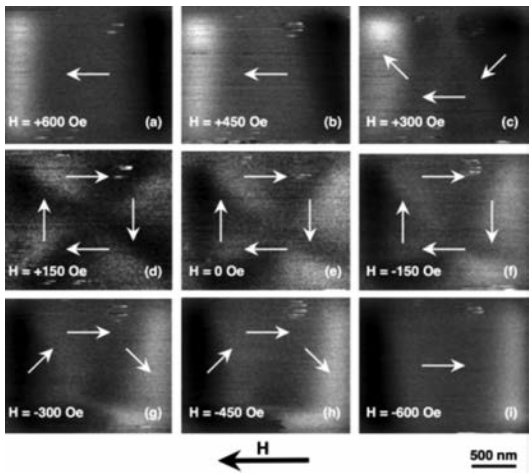

Figure 1. MFM signal (phase channel) of a $Ni_{80}Fe_{20}$ square dot with a size of 2 µm acquired at different applied field values.

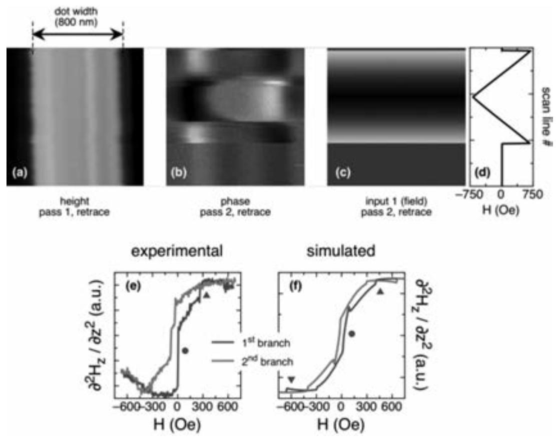

Figure 2. $Ni_{80}Fe_{20}$ dot with a size of 800 nm. (a) Height channel of the chosen profile, repeated over time. (b) Phase channel (magnetic signal). (c) Applied magnetic field value, (d) as a function of the scan line number. (e) MFM local hysteresis loop (experimental) and (f) corresponding simulated loop. Up triangles: formation of C-state; circles: nucleation of the vortex; down triangles: vortex expulsion.

By properly analysing the phase signal, for example by determining the phase contrast close to the dot left and right edges, local “hysteresis loops” can be extracted from the MFM measurements, as shown in panel (e). These loops plot the field dependence of the second derivative along z of the magnetic field generated by the distribution of the magnetisation of the sample, in the volume where the MFM tip is located, and represent the evolution of the magnetic domain configuration as the field is swept. Characteristic features of the magnetisation process, such as vortex nucleation and expulsion, or transition from saturation to C-state are identified. The experimental data are compared with micromagnetic simulations performed on a model system having the same composition and geometry as the studied sample. The equilibrium configuration of the magnetisation is calculated for each applied field value. Then, the map of the second derivative of the field generated by the magnetisation is computed, wich can be directly compared with experimental MFM images. Finally the same analysis procedure is applied on the calculated field maps, and the simulated “hysteresis loop”, having the same meaning as the experimental one reported in Figure 2 (e), is obtained from the simulated data (Figure 2 (f)). The agreement between experimental and simulated MFM maps, at different applied fields, and “hysteresis loops” provides the necessary validation for the technique. By means of this technique, the deep investigation of the magnetisation reversal process in patterned structures can reveal insightful details concerning the magnetisation equilibrium states, thanks to the MFM high spatial resolution and the accurate control of the applied magnetic field.

References

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