TRUE VARIABLE FIELD MAGNETIC FORCE MICROSCOPY FOR NANOSTRUCTURES CHARACTERIZATION

Miriam Jaafar[1], *Julio Gómez*[2], *Manuel Vázquez*[1], *Agustina Asenjo*[1]
[1]Instituto de Ciencia de Materiales de Madrid, CSIC, 28049 Madrid
[2]Dpto. Física de la Materia Condensada, UAM, 28049 Madrid

m_jaafar@icmm.csic.es

Spin structures of nanoscale magnetic elements are the subject of increasing scientific effort. As the confinement of spins, imposed by geometrical restrictions, makes these structures comparable in size to some intrinsic characteristic length of the magnet new properties emerge. Part of this effort is devoted to the development of new techniques with suitable resolution and sensitivity to characterize nano-objets. Particularly interesting and hard to achieve is a direct study of their magnetization reversal process [1, 2]. In this respect, Magnetic Force Microscopy (MFM) is an advanced technique for domain observation, which can become a powerful "local" technique to study the switching process at the nanometer scale when an in situ magnetic field is applied. Moreover, since atomic force microscopy based techniques enables the simultaneous observation of magnetic domains and surface topography of the same area, the quantitative analysis of these reversal processes reveals the interplay between both structure and magnetic properties.
A new variable external field magnetic force microscope (VF-MFM) is here introduced [3]. The most outstanding feature of the system is its capability to perform stable images under a variable external magnetic field that can be applied both in-plane (up to 0.15 T) and out-of-plane directions (up to 0.2 T). The main advantage of the so-called Variable Field Magnetic Force Microscope (VFMFM) is its mechanical stability under variable external magnetic field applied both in-plane and out-of plane directions. This microscope has been used to characterize different magnetic nanostructures.
The application of a magnetic field during the MFM operation can be used to modify the magnetic state of the tip as well as the magnetic state of the sample. While the effect of the magnetic field depends on the relationship between the maximum applied field and the coercivity of the sample, the magnetization of the tip and /or the magnetization of the sample can be switched by choosing a suitable magnetic field.
Furthermore, the evolution of the MFM signal versus the external magnetic field [4, 5, 6] allows us to achieve the hysteresis loop of nanoelements. The results obtained for an array of Ni nanowires embedded in AAM (Anodic Alumina Membrane) are shown in figure 1. In addition to the standard MFM images, we have performed the so-called "3Dmodes" [7] measurements. This new imaging mode is achievable thanks to the above mentioned mechanical stability that allows the observation of spin dynamic at the nanoscale. This new method has been used to obtain the hysteresis loop of the MFM probes [8] (see figure 2).

References:

[1] Choe S B, Acremann Y, Scholl A , Bauer A , Doran A, Stohr J and Padmore H A Science **304** (2004) 420-422.
[2] Yamada K, Kasai S, Nakatani Y, Kobayashi K, Kohno H, Thiaville A and Ono T Nature Materials **6** (2007) 270 - 273
[3] M Jaafar, J Gómez-Herrero, A Gil, P Ares, M Vázquez and A Asenjo, submitted to Nanotechnology
[4] Endo Y , Fujimoto H, Kawamura Y, Nakatani R and Yamamoto M J. Magn. Magn. Mat. **310** (2007)2436
[5] Asenjo A, Jaafar M, Navas D and Vázquez M J. Appl. Phys. **100** (2006) 023909
[6] Escrig J, Altbir D, Jaafar M, Navas D, Asenjo A and Vázquez M Phys. Rev. B **75** (2007), 184429
[7] Gómez-Navarro C, Gil A, Álvarez M, De Pablo P J, Moreno-Herrero F, Horcas I, Fernández R, Colchero J, Gómez-Herrero J and Baró A. M Nanotechnology **13** (2002) 314

[8] Jaafar M, Asenjo A and Vázquez M 2008 IEEE Nano in press

Figures:

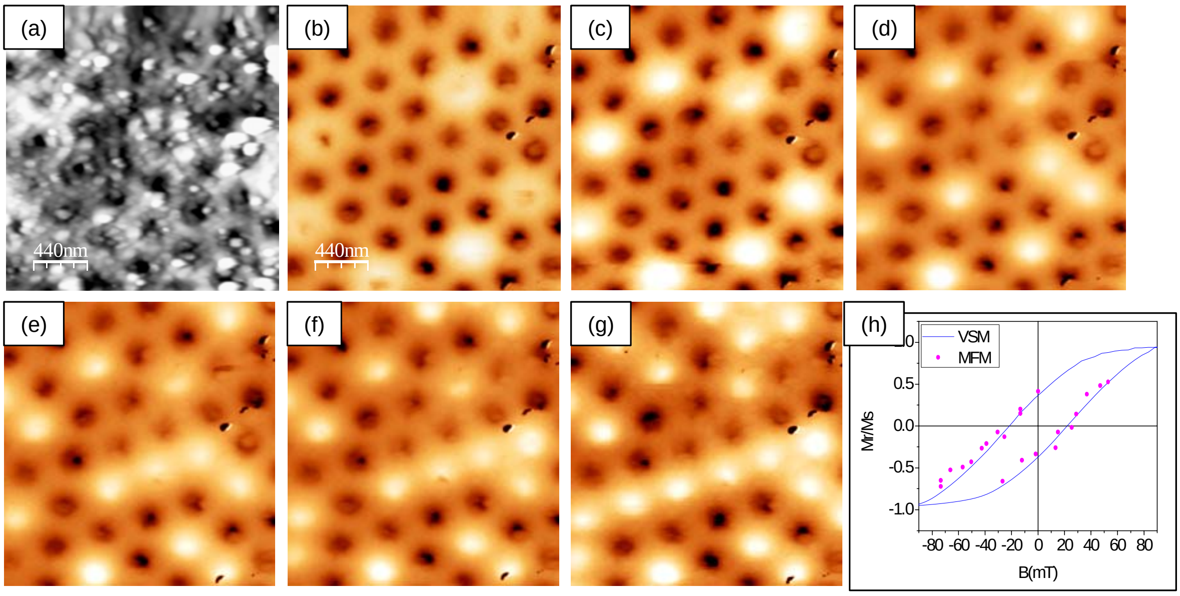

Figure 1 (a) AFM images at 60 mT of an array of Ni nanowires embedded in alumina membrane.(b) MFM images for 6 different magnetic fields 60 mT, (c) 40 mT, (d) 15 mT, (e) 0 mT, (f) -15 mT, (g)-25.5 mT. The MFM contrast (frequency shift) of the images is around 40Hz.(h) Hysteresis loop of the array measured by VSM and VF-MFM

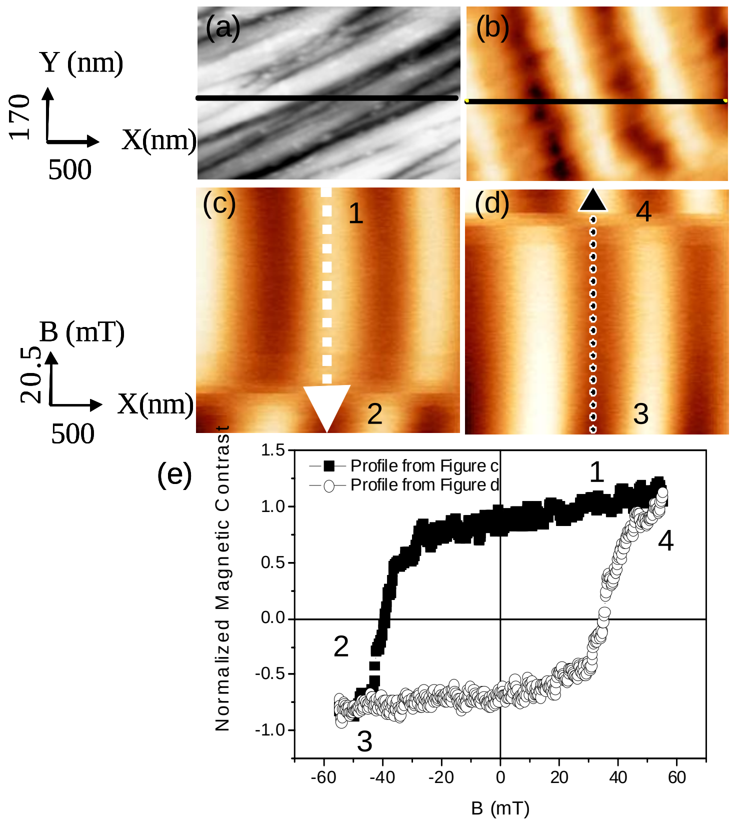

Figure 2 (a) AFM topography of a commercial hard disk (b) MFM image obtained in the same area (c) (d)"3dmode" images where the horizontal x direction (in nm) is the frequency shift (magnetic signal) for different out-of-plane magnetic fields (vertical direction in mT), the field is increased along the arrows directions (e) Hysteresis loop of the MFM probe obtained from the marked lines in (c) and (d)