In situ magnetization reversal measurement of magnetic tips in a magnetic force microscope

A. A. Bukharaev, D. A. Biziaev, P. A. Borodin, D. V. Ovchinnikov
Zavoisky Physical Technical Institute of Russian Academy of Sciences
Sibirsky Tract 10/7, Kazan 420029, Russia, bukh@telebit.ru
Tel: (8432) 720668, Fax: (8432) 725075

Using electromagnet installed into the scanning probe microscope allows one to investigate *in situ* the magnetization reversal of micro- and nanostructures. In contrast to our previous investigations [1], in this work we have used a scanner SMENA made by NT-MDT company in order to obtain magnetic force images. The scanner SMENA was combined with a homebuilt electromagnet. It allowed us to create a magnetic field along the sample plane with the magnitude of up to 2000 Oe.

During such experiments the knowledge about the coercive properties of magnetic force microscopy tips is very important for correct interpretation of the magnetization reversal of micro- and nanostructures observed by the magnetic force microscope (MFM). Before the MFM measurements the magnetic tip was usually magnetized along the axis perpendicular to the sample surface in order to obtain the highest magnetic contrast of MFM images. Obviously, it is possible to realize the magnetization reversal of the tip by the high external field and to make it parallel to the sample surface. In this case the apparent changes in the MFM images may be connected with the magnetization reversal of the soft magnetic tip instead of the real magnetization reversal of the sample.

This work is devoted to the investigation of the magnetization reversal of the magnetic tip of the cantilever directly in the MFM when the external field on the sample and the tip is created simultaneously with the electromagnet installed into the microscope.

The special samples with Co and SmCo planar patterned microstructures were used. The cobalt separate rectangular micropatterns were formed on the HOPG surface using a system of intersected masks and evaporation of the cobalt powder in a vacuum chamber. The details of obtaining the Co samples were described in [1]. The SmCo planar square patterns with the lateral size of 10×10 μm^2 and thickness 200 nm were formed on Si substrate using electron lithography. In addition, the samples containing the stripes with buried αFe nanoparticles prepared by Fe^+ bombardment into SiO_2 were investigated [2].

Commercial magnetic cantilevers (NT-MDT, Russia) with Co and SmCo coating were used in the experiments. The MFM tip was preliminary magnetized along its symmetry axis in a strong magnetic field of higher than 2000 Oe. The MFM measurements were performed with the constant height mode in order to minimize the topography contribution to the MFM image.

The obtained MFM images demonstrate the multidomain magnetic structure when the external magnetic field is close to zero, as those of the Co pattern show (Fig.1 a, b). The multidomain structure transforms to the uniform magnetization with two typical magnetic poles on the MFM image when the external magnetic field is increased up to 50 Oe (Fig. 1c). In our experiments further transformation of the MFM images continued at higher external magnetic fields, although the uniform magnetization of the sample remained (Fig. 1d). Obviously, this MFM image transformation is connected with the magnetization reversal of the magnetic tip. The total tip magnetization turns from being perpendicular to the sample surface to being parallel. This conclusion was confirmed by the comparison of the corresponding simulated and experimental MFM profiles presented in Fig2.

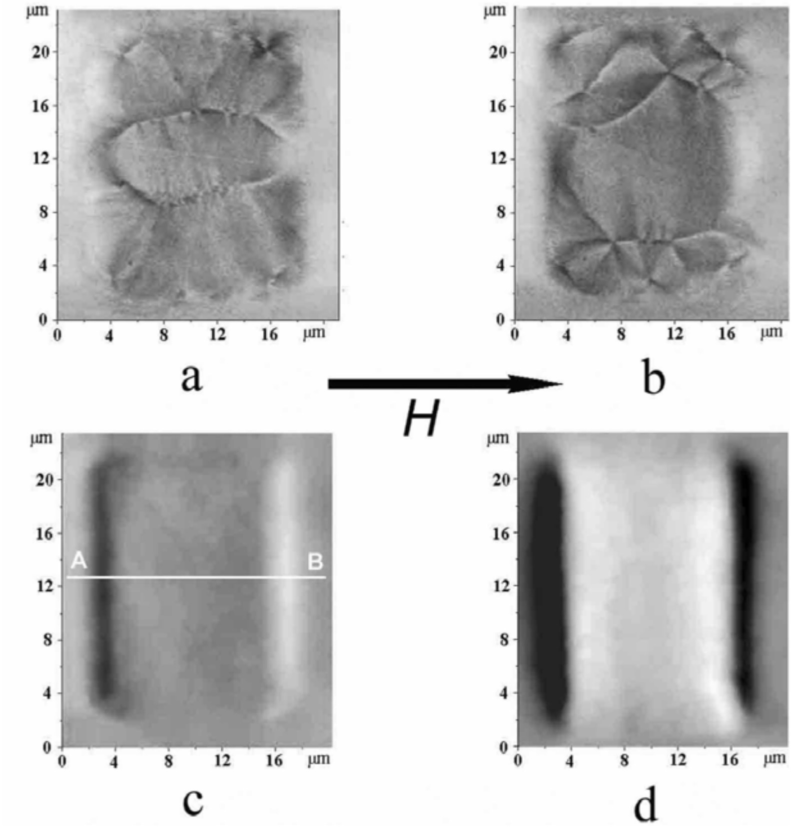

Fig.1. Transformation of the MFM images of the Co pattern with the lateral size of 20 × 15 μm^2 and 80 nm in height in the different external fields: a - 0, b – 20, c -50, d – 2000 Oe.

The simulated MFM profiles were obtained with a homebuilt computer program package "virtual MFM" which allows one to simulate three-dimensional MFM images basing on the bulk parameters of the tip and sample which were taken very close to the real ones [3]. In our case the tip was approximated by a nonmagnetic truncated cone with the convergence angle of 30º. The apex of the cone was made round with the rounding radius of 20 nm. This nonmagnetic part of the tip was covered evenly by thin ferromagnetic coating with the thickness of 50 nm.

The analysis of the MFM profile transformation versus the different external fields has shown that these data allow one to estimate the coercive properties of the magnetic tips.

The work was supported by Ministry of Science of the Russian Federation (Grant N 37.039.11.0047) and the Russian Foundation of Basic Research (Grants N 02-02-16686).

We thank to Dr. G. M. Mikhailov for providing the SmCo samples.

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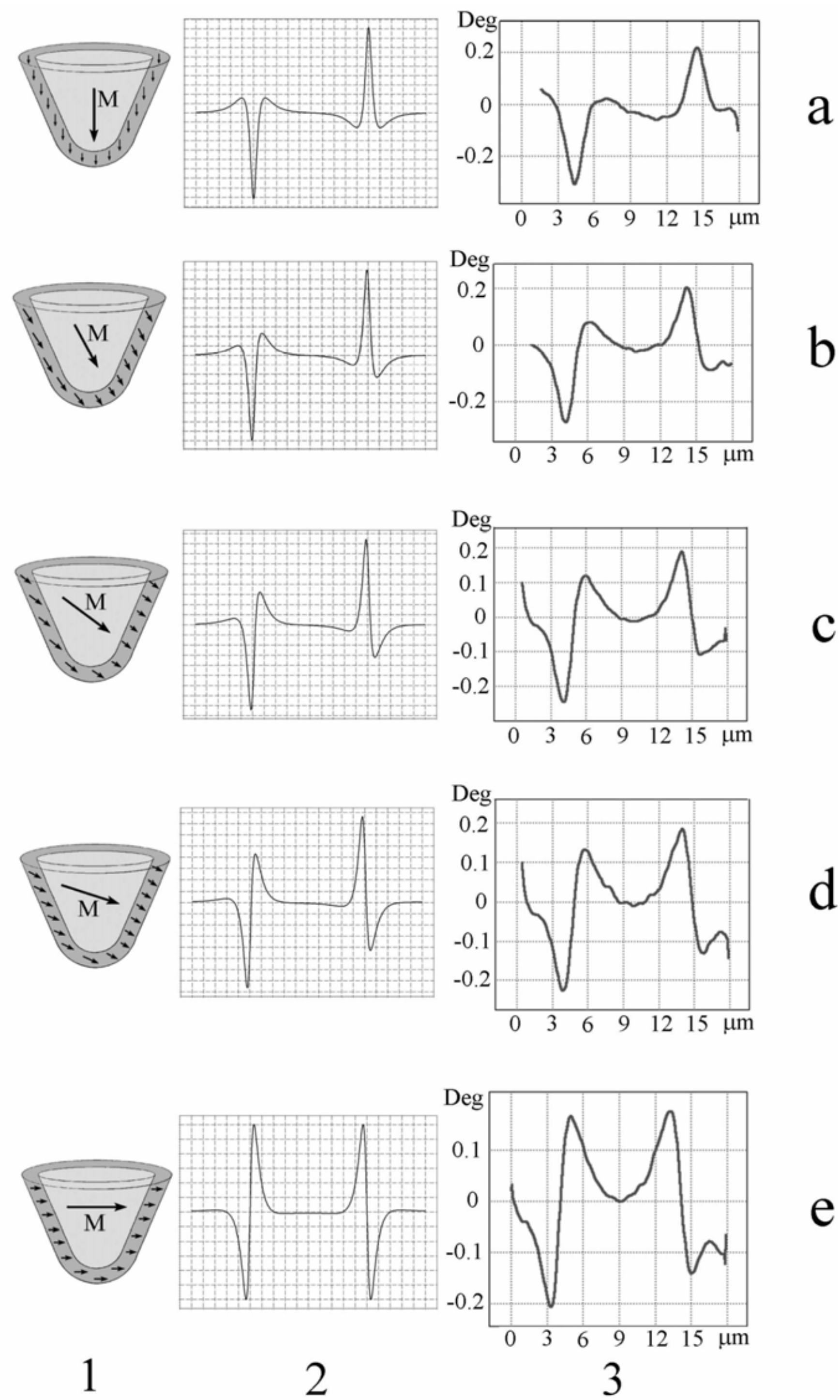

Fig. 2. Comparison of the simulated and experimental MFM profiles obtained in the different external fields: a -100, b – 350, c – 500, d – 650, e – 900 Oe. 1 – the scheme of the corresponding tip magnetization, 2 - the simulated MFM profiles, 3 - experimental MFM profiles measured along the line A-B marked in Fig. 4c.