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In situ Magnetization Reversal Measurement of Magnetic Tips in a Magnetic Force Microscope

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This work is devoted to the investigation of the magnetization reversal of magnetic tip directly in the magnetic force microscope (MFM) when the external field is created with an electromagnet installed into the microscope. By using special samples containing Co and SmCo ferromagnetic micropatterns it was shown that the magnetization reversal of the tip of the microscope in the high magnetic field led to the essential transformation of the MFM images of planar magnetic microstructures. The computer simulation of the corresponding MFM images and the MFM profiles was used to confirm this conclusion. The analysis of the experimental MFM images of Co micropatterns obtained at the magnetic field in the range from -2000 up to 2000 Oe allowed us to estimate the coercivity of magnetic tips.

1. Introduction

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.

2. Experiments

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. The distance between the magnet poles was 18 mm, the Hall sensor was placed in magnetic gap and used to measure magnetic field.

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 $10\times10\ \mu m^2$ and thickness 200 nm were formed on Si substrate using electron lithography.

Commercial magnetic cantilevers (NT-MDT, Russia) with Co, Cr 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 distant mode in order to minimize the topography contribution to the MFM image. The tip lifts up on the prescribed distance above the sample surface and this distance remains constant. The trajectory of the tip movement can be described by a plane in this case.

3. Results and discussion

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. 1?). 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).

The similar MFM image transformation was observed for SmCo planar square patterns when the external magnetic field is changed. 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.

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. This

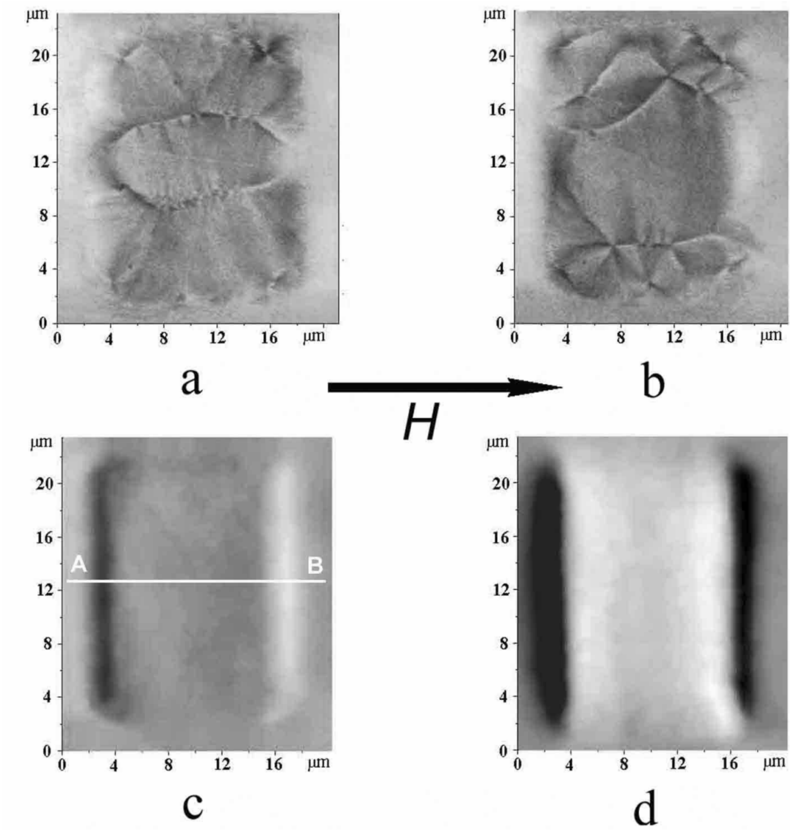

Figure 1. Transformation of the MFM images of the Co pattern with the lateral size of 20 × 15 μm^2 and 80 nm in height in the different external fields: a) – 0, b) – 20, c) – 50, d) – 2000 Oe.

software was successfully tested in theoretical and experimental investigations of different ferromagnetic micro- and nanostructures [2, 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.

It is clear from Fig.2 that is possible to connect the component part of full tip magnetization parallel to sample surface with *?h* parameter. The hysteresis loops reflecting the coercive properties of the different magnetic tips were constructed using *?h* parameters. Fig 3. shows the typical hysteresis loop obtained from the MFM data when the combination the Co tip and Co sample was used. The coercive force for such tip estimated from this curve is about 120 Oe. The first part of this curves marked by the gray triangles corresponds to the first stage of the tip magnetization reversal induced by external magnetic field, when the total tip magnetic moment turns from the perpendicular to parallel direction relative to the sample surface. The analysis of the MFM profile transformation versus the different external fields has shown that only rather magnetic soft samples (as Co for example) are suitable for

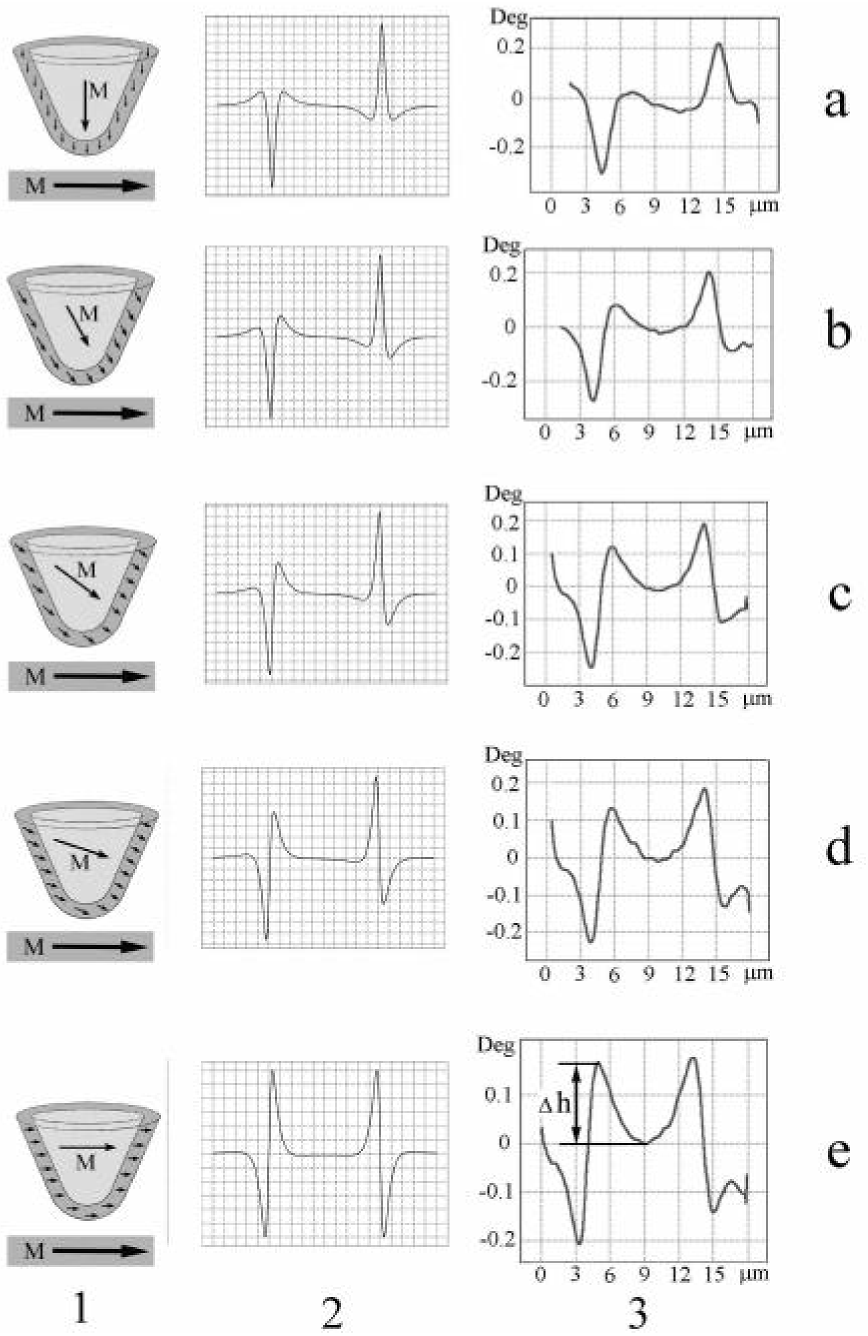

Figure 2. Comparison of the simulated and experimental MFM profiles obtained in the different external fields: a) -100, b) – 350, ?) – 500, d) – 650, e) – 900 Oe. 1) – the scheme of the corresponding tip and sample magnetization, 2) - the simulated MFM profiles, 3) – the experimental MFM profiles measured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

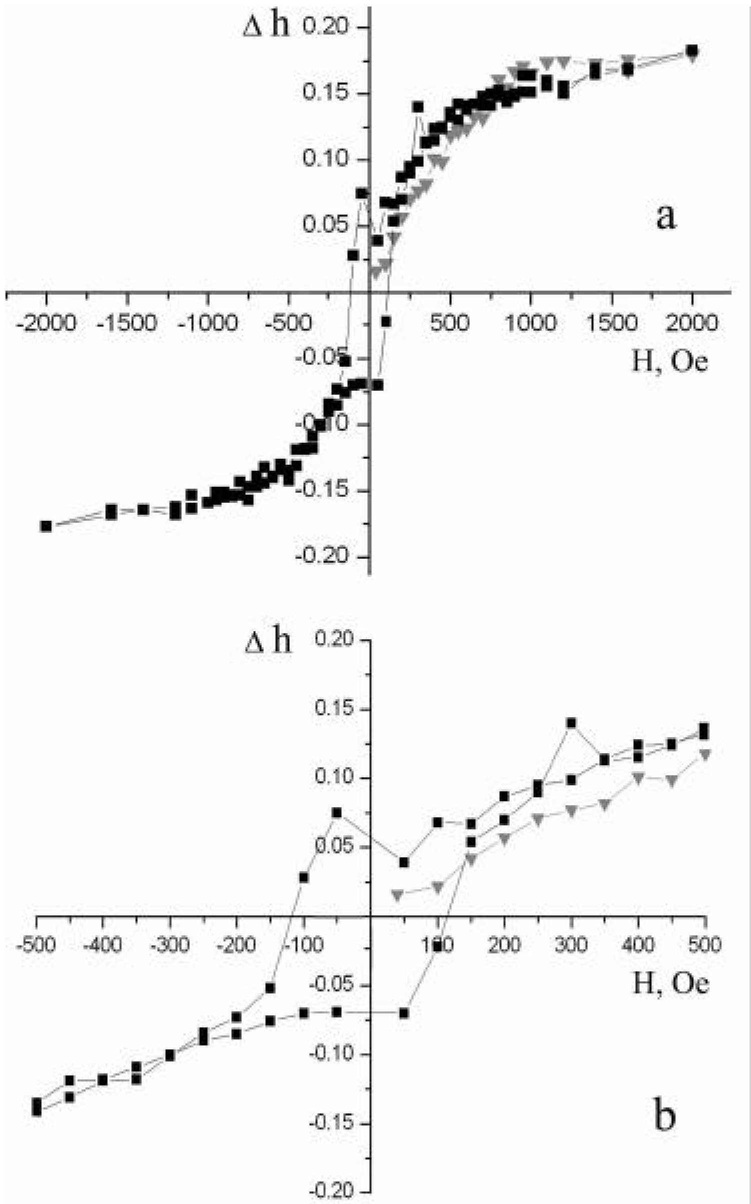

Figure 3. The hysteresis loops obtained for the Co cantilever from the MFM profiles using ?*h* parameter: a) - field scan 2000 Oe, b) - field scan 500 Oe. The gray triangles are the first stage of the tip magnetization reversal induced by external magnetic field.

estimation of the magnetic tip coercive properties. The strong stray field of the magnetic hard testing samples (like SmCo) prevents to make the correct estimation of the magnetic tip coercive force.

4. Conclusion

By using the scanner SMENA combined with the home-made electromagnet it was possible to obtain MFM images in the external magnetic field with the magnitude of up to 2000 Oe. This modernized microscope and the special sample with Co planar patterns placed on its surface allowed us to observe the magnetization reversal of the magnetic tip and to estimate the tip coercivity. The knowledge about the tip magnetic properties and computer simulation gave a possibility to interpret the MFM images of the samples in the strong magnetic field more correctly.

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