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Magnetic force microscopy of magnetization reversal of microstructures *in situ* in the external field of up to 2000Oe

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ABSTRACT

This work is devoted to the investigation of the magnetization reversal of microstructures directly in the magnetic force microscope (MFM) when the external field on the sample is created with an electromagnet installed into the microscope. By using special samples containing Co 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 confirmed 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. 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.

Keywords: Magnetic force microscopy, magnetization reversal, magnetic cantilever, coercivity, computer simulation.

1. INTRODUCTION

Magnetic micro- and nanostructures have unique properties which make them good candidates as the basis of the novel materials for high-density magnetic storage media[1]. Moreover, the study of such objects may help to solve some problems of the theory of micromagnetism and essentially contribute to the physics of magnetic phenomena. Thus the magnetic microstructures are of great interest to the different researchers and investigators.

Magnetic force microscopy is widely used for studying the structure of magnetization of planar magnetic nanoobjects[2-5]. Particular attention is paid to this problem with respect to the usage of these structures for ultrahigh-density recording of information in modern computers. The most urgent problems among the up-to-date ones in this field of research are the following: 1) to create new magnetic recording structures on the basis of monodomain nanoparticles[6]; 2) to study the domain structure in mono- and multidomain lateral structures[7]; 3) to restore the structure of magnetization of objects from their magnetic force image[8,9]; 4) to study the magnetization reversal directly in a magnetic force microscope (MFM) when the external field on the sample is created with an electromagnet installed in the microscope[9,10].

This paper is concerned with the fourth problem above. New experimental possibilities of our MFM were used to study the magnetization reversal of various magnetic microstructures *in situ* in the external field with the magnitude of up to 2000 Oe. Particular attention was paid to studying demagnetization of computer hard disks with recorded information in order to estimate their noise immunity from the influence of external electromagnetic fields.

To investigate the changes in the MFM image caused by the magnetization reversal of the magnetic tip was the second task of this work. Usually the magnetic tip was magnetized along the axis perpendicular to the sample surface in

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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 MFM images may be connected with the magnetization reversal of the soft magnetic tip instead of the magnetization reversal of the sample.

2. SAMPLE PREPARATION AND EXPERIMENTAL TECHNIQUES

In contrast to our previous investigations[10], in this paper we use the scanning head SMENA made by the firm NT-MDT (Russia) in order to get magnetic force images. The magnetic tip (cantilever) is attached to the piezotube in this type of the scanning head and the sample is placed separately on the special stage (Fig. 1a). In this case due to positional relationship between the piezotube, the magnetic cantilever and the sample it is possible to use the large electromagnet. Fig.1.b presents the photo of the scanning head SMENA combined with a home-made electromagnet. This set-up enables us to create the field in the sample plane of about 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 usage of this magnet enables studying magnetization reversal in magnetic-rigid media, which was impossible previously. The "lifting" mode[10] was used to obtain both the topography and the magnetic images from the same area of a sample.

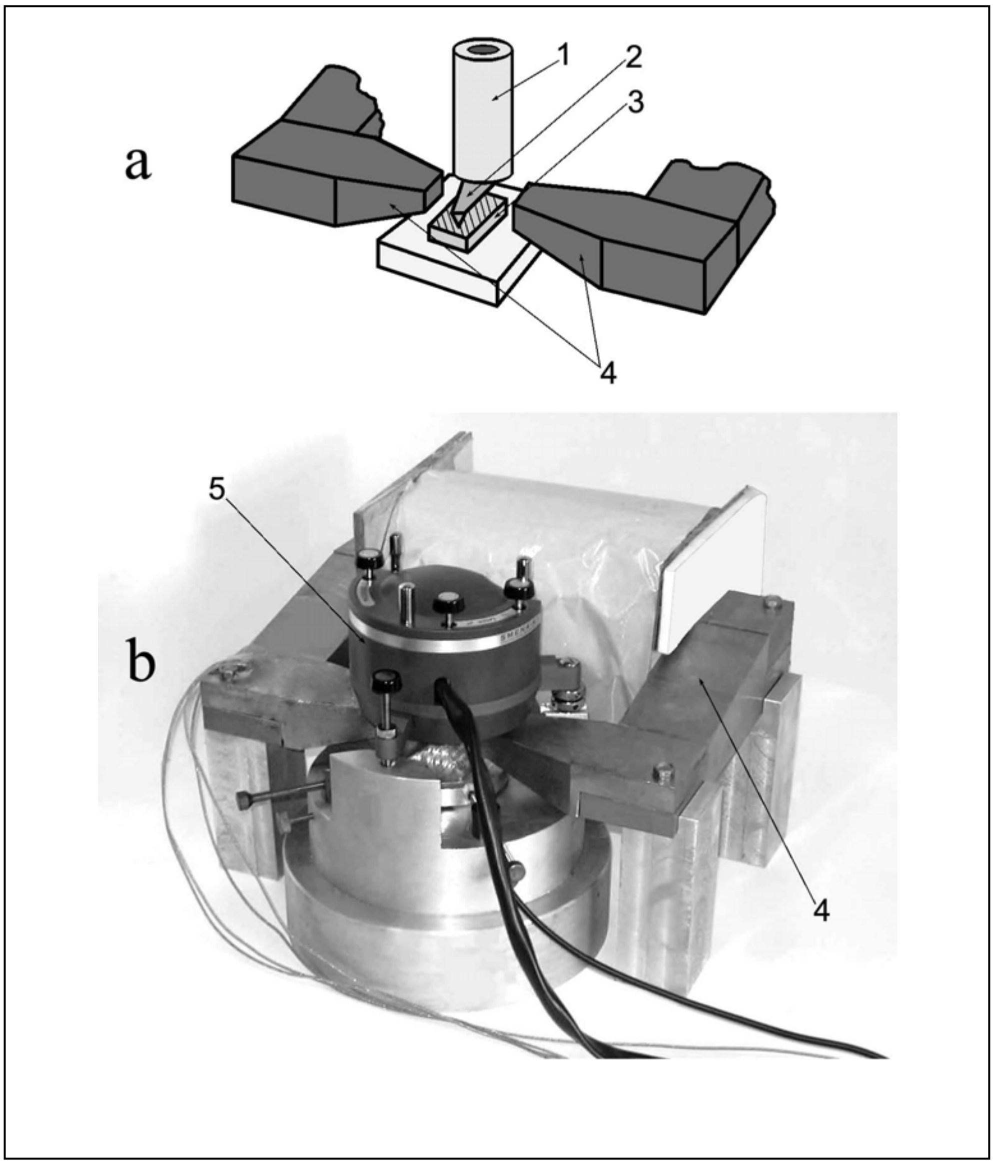

Figure 1. *a* – the scheme of positional relationship the piezotube of the scanning head (1), the magnetic cantilever (2), the sample (3) and the poles of the electromagnet (4) for the magnetic force microscopy measurements in the external magnetic field; *b* - the photo of the scanning head SMENA (5) combined with a home-made electromagnet (4) according to the presented scheme.

The special samples with Co planar patterned microstructures were obtained by vacuum evaporation. The cobalt films were formed on the HOPG surface in a vacuum chamber by heating and vaporizing of the cobalt powder. This film was patterned by the masks with the mask hole element size of $25 \times 25\ \mu m^2$ placed over the HOPG surface during evaporation. The samples with different pattern heights from 40 to 200 nm were obtained due to variation of the mass of the evaporated cobalt powder. The atomic force microscope (AFM) was used to control the size and height of the Co patterns. Fig. 2a presents the topography of one of such samples obtained with the AFM. Previously[10] we have detected that such planar cobalt patterns show a uniform magnetization state and have a total magnetic moment along the sample surface in the external field of higher more than 50 Oe.

Commercial magnetic cantilevers (NT-MDT, Russia) with Co and Cr 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.

3. RESULTS AND DISCUSSION

The topography and corresponding MFM images of the Co patterns were obtained at different values of the increasing external magnetic field step by step using the lifting mode of our microscope. A typical value of a step was 50 Oe. Fig. 2b shows the MFM image of the rectangular Co patterns presented in Fig. 2a in the external magnetic field of 100 Oe. The corresponding profile of the MFM image obtained across the white line in the Fig. 2a is presented in Fig. 3a. It is clear, that in this case the Co patterns have a uniform magnetization state with typical magnetic poles at the edges of the rectangular patterns. The multidomain magnetic structure was observed only at the external magnetic field of less than 50 Oe. The evident transformation of the MFM image takes place at magnetic field of 200 Oe (Fig. 2c). The corresponding magnetic profile shows the new additional holes and protrusions (Fig. 3b). This structure of magnetic images and corresponding profiles remains the same as the external magnetic field increases from 200 Oe up to 2000 Oe. Fig. 2d and Fig. 3e show the magnetic image and corresponding profile obtained at external magnetic field (H_{ext}) of 2000 Oe.

We explain the transformation of the MFM image of the Co patterns at 200 Oe by the magnetization reversal of a rather soft magnetic tip used in our experiments. In this case the total magnetic moment of the tip changes its direction from perpendicular to parallel relative to the sample surface due to the external magnetic field.

The computer experiment was carried out to prove that the 90-degree turn of the total magnetic moment of the tip causes the observed MFM image transformation. The home-made software was recently developed by us to simulate MFM images of different ferromagnetic structures with known geometrical parameters and magnetization structure. This software allows one to take into account the real shape of the tip and the sample structures, and also to use the magnetization structures of both objects calculated with the micromagnetic theory. This software was successfully tested in theoretical and experimental investigations of different ferromagnetic micro- and nanostructures[8-10].

A separate ferromagnetic rectangular pattern in a uniformly magnetized state formed on a nonmagnetic substrate was taken as an object of the MFM computer simulation. The shape and size of the patterns was taken close to those of the real Co patterns. 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 a thin ferromagnetic coating with the thickness of 50 nm and the specific magnetization of 1700 Oe/cm^3. It was supposed that the tip was uniformly magnetized along (or across) its axis of symmetry.

The computer simulation was carried out for two configurations. First, when the direction of the total magnetic moment of the uniformly magnetized sample (M_s) is parallel to the sample surface and the total magnetic moment of the tip (M_t) is perpendicular to it (the left-hand side of Fig. 3). The corresponding simulated MFM profile is presented in Fig. 3c. Second, when the direction of the total magnetic moment of the uniformly magnetized sample remains parallel to the sample surface, but the total magnetic moment of the tip is parallel to the sample surface due to its magnetization reversal (the right-hand side of Fig. 3). Fig. 3d shows the simulated MFM profile for the second case.

A comparison of the experimental and simulated the MFM profiles demonstrates that MFM image transformation observed at 200 Oe is actually due to the 90-degree turn of the tip total magnetic moment caused by the external magnetic field.

On the basis of the knowledge about coercive properties of the magnetic tip it is possible to more correctly investigate the storage of recorded information on the hard disks of computers and their demagnetization in the external magnetic field.

Our investigations with the MFM including an electromagnet showed that for some hard discs with the recorded information the first transformation of the MFM images was observed at 200 Oe. At the same time the MFM measurements demonstrate that the same hard disc was degaussed at 800 Oe due to demagnetization of magnetic domains. According to the new information about coercive properties of the used magnetic tip it is obvious that this transformation of MFM images of the hard disc at 200 Oe is due to the magnetization reversal of the tip, when the total magnetic moment of the tip changes its direction from perpendicular to parallel with respect to the sample surface.

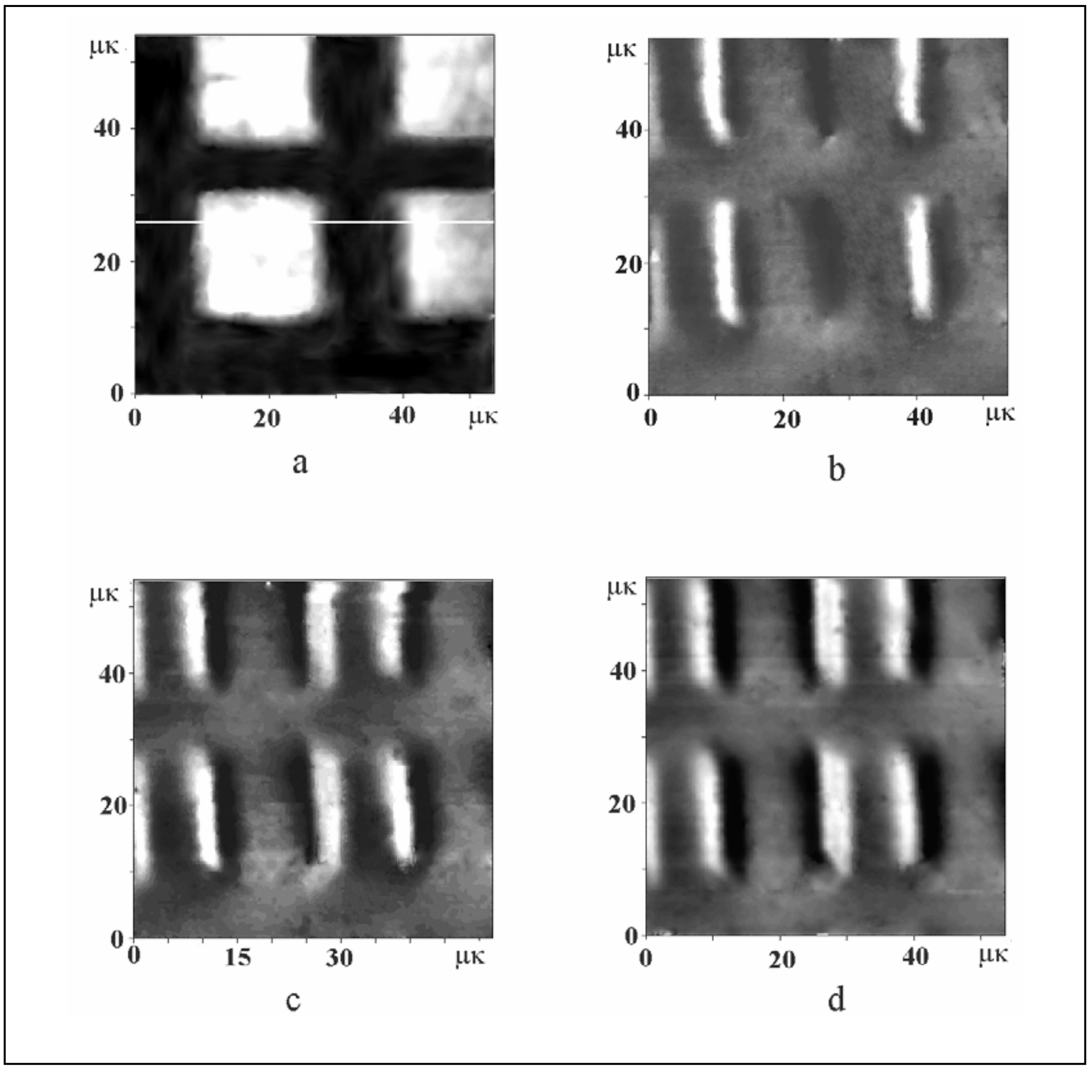

Figure 2. Results of MFM experiment for studying of the Co planar patterns in the external magnetic field with different magnitudes. *a* – the topography of the surface area of the sample with Co patterns; *b* – the MFM image of the same sample area in the presence of

the external magnetic field of 100 Oe; *c* – the MFM image of the same sample area in the presence of the external magnetic field of 200 Oe; *d* – the MFM images of the same sample area in the presence of the external magnetic field of 2000 Oe.

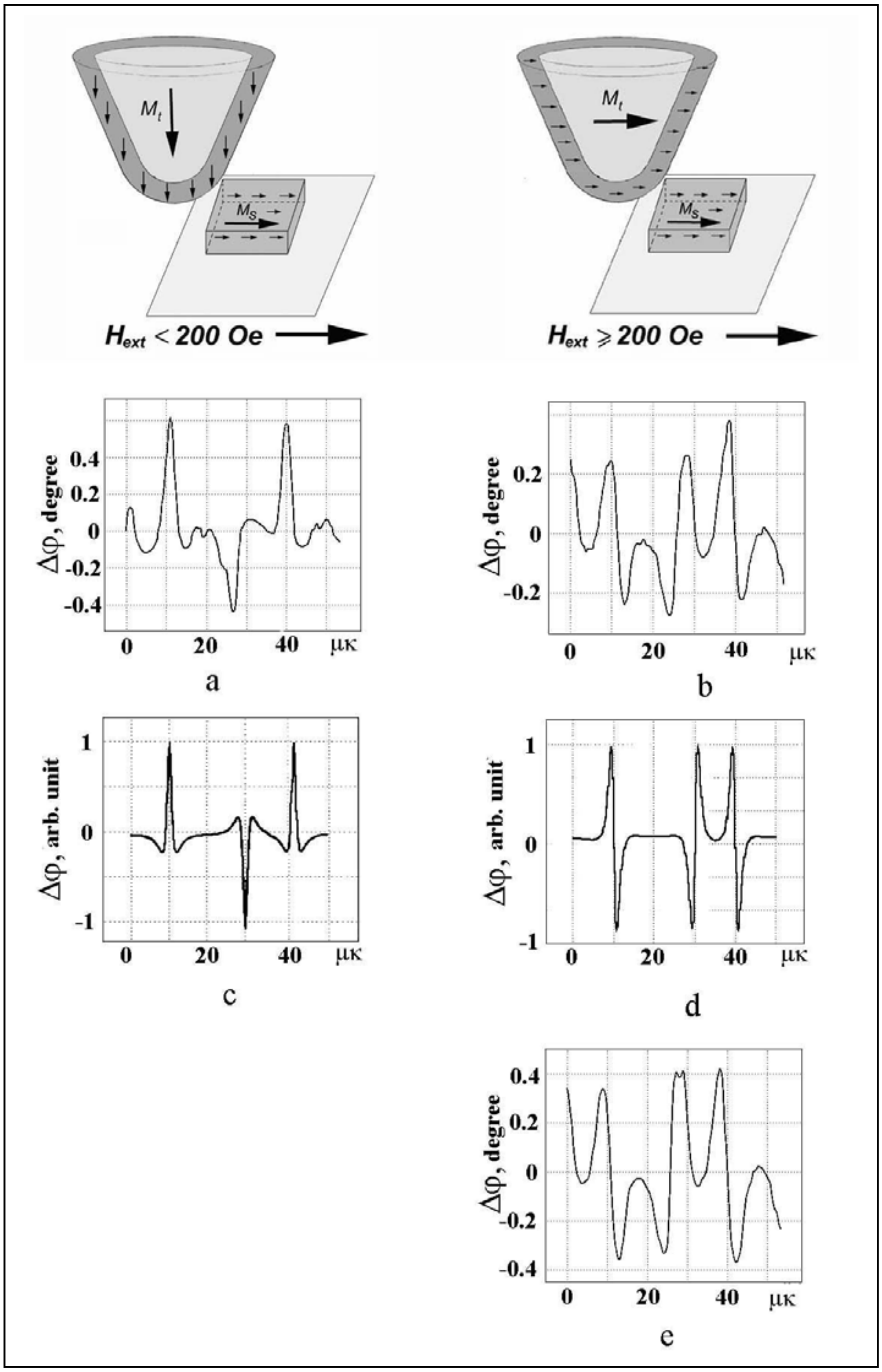

Figure 3. *a* – the experimental profile of the MFM image across the white line (Fig. 2a) for the Co patterns in the external magnetic field 100 Oe; *b* - the experimental profile of the MFM image across the same line for 200 Oe; *c* – the simulated profile of the MFM image across the line for the Co patterns in the external magnetic field 100 Oe; *d* – the simulated profile of the MFM image across the same line for 200 Oe; *e* – the experimental profile of the MFM-image across the same line for 2000 Oe. The left-hand side of Fig. 3 corresponds to the case when the total magnetic moment of the tip is perpendicular to the sample surface. The right-hand side of Fig. 3 corresponds to the case when the total magnetic moment of the tip is parallel to the sample surface.

4. CONCLUSIONS

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.

ACKNOWLEDGMENTS

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REFERENCES

1. J. I. Martin, J. Nogues, K. Liu, J. L.Vicent, and I.Schuller, "Ordered magnetic nanostructures: fabrication and properties," *J. Magn. Magn. Mat.*, **256**, pp. 449-501, 2003.
2. M. R. Koblischka, B. Hewener, U. Hartmann, A. Wienss, B. Christoffer, and G. Persch-Schuy, "Magnetic force microscopy applied in magnetic data storage technology" *Appl. Phys. A.*, **76**, pp. 879 – 884, 2003.
3. E. D. Dahlberg and R. Proksch, "Magnetic microscopies: the new additions," *J. Magn. Magn. Mat.*, **200**, pp. 720-728, 1999.
4. M. R. Freeman, and B.C.Choi, "Advances in magnetic microscopy," *Science*, **294**, pp. 1484-1488, 2001.
5. S. Porthun, L. Abelmann and C. Lodder, "Magneric force microscopy of thin film media for high density magnetic recording," *J. Magn. Magn. Mat.*, **182**, pp. 238-273, 1998.
6. S. Chou, "Ultrahigh-density recording: storing data in nanostructures," *Data Storage*, **9/10**, pp. 35-40, 1995.
7. T. Shrefl, J. Fidler, K. Kirk, and J. Chapman, "Simulation of magnetization reversal in polycrysyalline patterned Co elements, " *J. Appl. Phys.*, **85**, pp. 6169-6171, 1999.
8. D. V. Ovchinnikov, and A. A. Bukharaev, "Computer simulation of magnetic force microscopy images with a static model of magnetization distribution," *Technical Physics*, **46**, pp. 1014–1019, 2001.
9. D. V. Ovchinnikov, A. A. Bukharaev, and P.A. Borodin, "Determination of micromagnetic structure of ferromagnetic patterns on the basis of experimental MFM-images and computer simulation," *Phys. Low-Dim. Struct*., **5/6**, pp.1-6, 2002.
10. D. V. Ovchinnikov, A. A. Bukharaev, P. A. Borodin, and D. A. Biziaev, "*In situ* MFM investigation of magnetization reversal in Co patterned microstructures," *Phys. Low-Dim. Struct*., **3/4** , pp. 103-108, 2001.