High-aspect ratio probes with selected geometry for advanced MFM measurements

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In present-day recording technologies, magnetic force microscopy (MFM) is of particular interest, since it can be used to perform high-precision magnetic mapping and diagnostics of nanoelectronic elements [1], in particular, reading and writing of magnetic information with single domains accuracy [2,3]. It should be noted the importance of probes features in MFM technique, since geometric parameters and composition of the probe could influence on the sensitivity, resolution and contrast of the resulting MFM images.

The main aim of the work was to identify the optimal parameters of high-aspect ratio magnetic probes based on nanowhisker structures to improve the quality of the MFM measurements.

We considered two types of probes: standard pyramidal probe and high-aspect ratio nanowhisker (NW) probe covered by magnetic film. The simulation of the high-aspect probes was carried out in COMSOL Multiphysics by the finite element method. The Gauss law was used to the magnetic field to determine the distribution of the magnetic field. The equation (1) was used for the magnetized areas:

$$\mathbf{B} = \mu_0 \left(\mathbf{H} + \mathbf{M} \right), \quad (1)$$

where μ_0 – magnetic constant, H – vector of the magnetic field, M – vector of the material magnetization. The magnetic domain size was simulated as 30 nm, magnetic coating thickness of the probes 20-50 nm, NW width 25-75 nm, NW height 250-750 nm, radius of tip curvature 10 nm.

Simulation showed that NW probe has about twice larger force gradient values compared to the standard probe with the same thicknesses of magnetic material. Standard probe parameters were coincided with NSG01 tips (NT-MDT, Russia); NW tip parameters were: height – 500 nm, diameter without magnetic coating – 50 nm, magnetic material – Co, material of NW – Pt/C, magnetic coating for tips varied 20-50 nm.

The experimental results coincide with simulations. A hard drive disk with magnetic pits was measured by standard probes and NW probes, fabricated by focused electron beam technique at the top of standard probes with presence of gas-precursor.

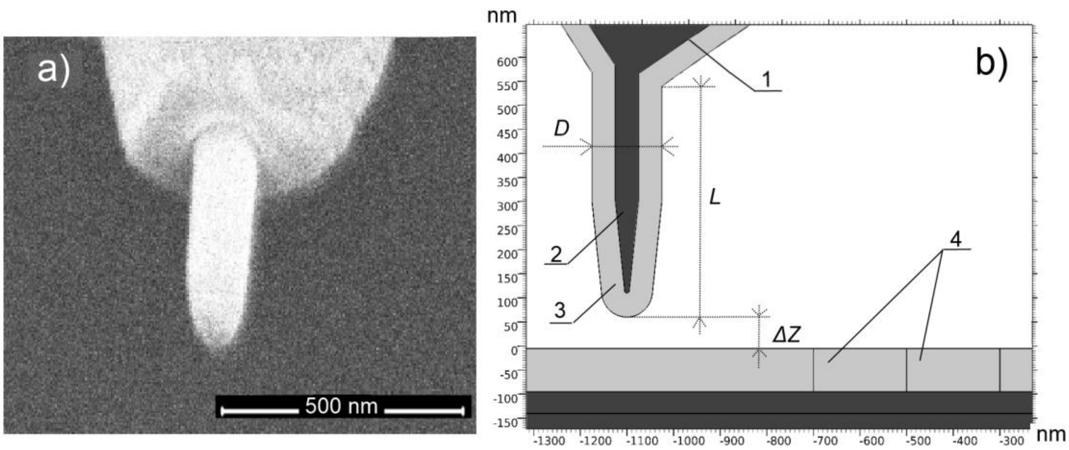

Figure 1. SEM image of the NW probe (a) and its model (b): 1 – the top of the Si pyramid, 2 – NW, 3 – the magnetic coating, 4 – magnetic domains, D – NW diameter (150 ± 30 nm), L – NW height (500 ± 50 nm), ΔZ – distance from the probe to the substrate (10 ± 0.1 nm).

In addition, simulation of the alteration of magnetic coating thickness, magnetic material and geometry of the NW probe was carried out. It was found that NW thickness (magnetic coating –

constant) increase and NW length decrease leads to force gradient reduction. As expected, increasing the thickness of the magnetic coating leads to force gradient increase. The lowest gradient values were obtained using Ni coating (5.8 μN/m for NW), the best results were found for Co (31.4 μN/m) and especially for CoFe coating (239 μN/m). A gradual gradient increase was observed by increasing the angle of inclination of the NW relative to the surface normal.

Thus, the optimal parameters of high-aspect magnetic probes were found to improve the quality of the MFM measurements. It was found that NW probe has a larger magnetic force gradient compared to the standard probe with the same thicknesses of magnetic material, which should lead to an improvement of the MFM image quality in the phase contrast mode.

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