Scanning probe microscopy cantilevers improvement for advanced research and manipulation at nano scale.

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Abstract. Scanning probe microscopy (SPM) is a widely used method for the different kind of objects investigation. It allows to obtain information about the surface topography including its mechanical and electromagnetic characteristics at nano scale. SPM also could be used for manipulation of nanoobjects. The most popular and widely used SPM methods are atomic force (AFM) and magnetic force microscopy (MFM). Both of them based on measuring interaction between sample and cantilever (probe). Type of cantilever its curvature radius, coating, resonant frequency, hardness and other parameters significantly influence on the SPM images. Scientist constantly improving process of probes producing to fit the current demands. It is important to keep in mind that collected AFM data could contain not only direct information about the sample but also it might be a convolution of the sample and cantilever in case then the tip size comparable with the studied object. Convolution effect limits the AFM resolution [1]. Thus one of the most important task for researchers is to minimize this effect by reducing tip size both for AFM and MFM methods.

1. Introduction

Classic microelectronic batch process allows to create hundreds AFM cantilevers simultaneously with tip curvature radius from 10 nm and more. Individual process methods (for example focused ion beam) allows to reduce tip radius but for one cantilever per time only. Authors developed technology to reduce probes curvature radius by using defocused ion beam [2]. The method could be used for both individual and batch processes.

In case of MFM method researchers should use cantilever with magnetic coating to have possibility to “feel” magnetic structure of the sample. In addition to required magnetic characteristics the coating should also has a minimum thickness, good adhesion to the surface of the silicone tip, increased mechanical strength and corrosion resistance. The most common used magnetic coating for MFM is CoCr and FeNi thin films with thickness of 50nm – 100nm [3]. Thus tip curvature radius is typically 100nm and more. Thick coating leads to better sensitivity. However, there is some limitation of magnetic
coating thickness. Increasing the thickness of the coating material leads to resolution decreasing during the surface topography and magnetic structure scanning. Resolution of the magnetic image is also suffering due to parasitic influence of magnetic field to the image from distant magnetic objects located on the measured surface. In other hand thin coating leads to week sensitivity of the tip and might be easily damaged by surface mechanical impact. Authors studied pulsed plasma deposition (PPD) method for magnetic thin film coating creation.

2. **AFM probes sharpening by defocused ion beam.**

The authors studied tip sharpening process using a defocused ion beam of a group of cantilevers placed on silicon substrate. Ion beam etching tool with Kaufman Ar+ ion source was designed to have possibility to etch the whole wafer with size up to 200 mm. The design of substrate holder allows to orient substrates at an angle to the ion beam with possibility of rotation.

Defocused ion beam etching was performed with Ar+ ion incidence angle from 0° to 90° with step of 5°. Calibration grating of silicon pyramid matrix with high from 0,5 to 0,6 um and period 3 um, diagonal period 2,12 um was used for tip curvature radius estimation [4]. All measured tips show reducing curvature radius after etching process. Best result was achieved in case of ion incidence angle of 75° compare to axis of tip symmetry. The tip curvature radius reducing of 2.5 times was achieved. Figure 1 and figure 2 show AFM images of calibration grating with the period of 3um obtained by common silicon cantilever and etched cantilever (of ion incidence angle of 75° compare to axis of tip symmetry) respectively.

![Figure 1](image1.png)  
**Figure 1.** AFM image of calibration grating with the period of 3um obtained by common silicon cantilever.  

![Figure 2](image2.png)  
**Figure 2.** AFM image of calibration grating with the period of 3um obtained by etched cantilever.

3. **Method of pulsed plasma deposition for cantilever’s magnetic coating**

Authors proposed pulsed plasma deposition (PPD) [5] as a method for creation cantilever’s magnetic coating. Authors proposed to deposit magnetic coating only to the front face of the tip (figure 3). Fe thin film deposited on a Si tip with thickness of 50nm. The covering of only front face of the tip allows reducing curvature radius of the tip for nano scale magnetic objects investigation. Cantilevers with Fe thin film annealed in vacuum with the temperature of 450° C during 20min. Then cantilevers were covered by carbon thin layer with thickness of 2nm only. Carbon layer protects the tips from corrosion and increase thier mechanical reliability.
Figure 3. SEM image of typical silicon cantilever with direction of Fe deposition.

Figure 4 shows SEM front face tip images of clear Si cantilever and figure 5 shows cantilever with Fe magnetic coating covered by carbon.

3.1. Magnetic cantilever verification
Test object with Fe nano practical was created. Ferromagnetic material with thickness of 10nm was deposited to silicon oxide substrate. Then sample was annealed at 600°C during 30min. After annealing thin film dispersed to randomly placed nanoparticles with the size from 10nm.

Figure 6. AFM image Fe nanoparticle.  
Figure 7. MFM image Fe nanoparticle.

Figures 6 shows topography image of a separate Fe nanoparticle with scan size of 200x200nm and particle diameter of 60nm. Figure 7 shows MFM image of magnetic contrast of same particle. White and black areas show attractive and repulsive forces of single-domain structure.
4. Conclusion
Ways of SPM cantilevers improvement for advanced research and manipulation at nano scale were demonstrated. The paper shows that defocused ion beam etching could reduce silicon cantilever curvature radius of 2.5 times with possibility of batch processing. Pulsed plasma deposition could be used for creation high sensitive magnetic cantilever.

References
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