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Specialized probes with nanowhisker structures for scanning probe microscopy

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Abstract. Probes with single nanowhiskers (SNWs) and nanoscalpels (NSs) for scanning force microscopy were created and studied. SNWs consisting of an amorphous Pt/C material and amorphous carbon SNWs were grown up at top of standard Si cantilevers with help of focused electron beam technique. By means of test samples it was shown that a SNW probe give more contrast and accurate images of deep channels and steps on a sample surface in comparison with a standard Si cantilever having the same radius of top as SNW. It was revealed that unlike the standard Si probe, the SNW probe allows to visualize fine nanostructure an erythrocyte membrane. The specialized NS probes achieve better results than standard probes when they work in force lithography mode. Moreover, the possibility of applying NS probes for precision movement of nanoparticles and cell nanosurgery are demonstrated.

1. Introduction

The main element that determines quality of the scanning probe microscopy (SPM) images is a probe. Nowadays works at a modification and improvement of a technology of probes fabrication are performed including nanowhisker structures growth on the probe tips. One of the widely used methods of nanowhiskers growth remains the method of molecular beam epitaxy [1] that allows fabricating arrays of nanowhiskers on the tops of probes. However, this method has difficulties with single nanowhiskers growth with strict control of their parameters such as length, thickness, orientation to initial growth surface. These parameters are required to achieve a stable scanning of objects with complex topology of their surface.

Solution of this problem is applying a new method for nanostructures growth under an influence of electron beam in vacuum chamber. This method allows producing structures in form of single nanowhiskers (SNWs) [2] and nanoscalpels (NSs) [3] on the tips of the probes. The SNWs probes are designed for high-precision imaging of nanotopography, as well as the NSs probes are fabricated for stable force lithography and manipulation of nanoparticles.

It should be mentioned that a significant challenge of SPM application is the study of native biological objects immobilized in a liquid [4, 5]. In this case SPM experiments carried out with SNW structures in various environments may become the first step to precision SPM study of native biological objects with complex topology structures.

The aim of this work was to fabricate and study the influence of SNW probes on SPM visualization of objects with different nature in different SPM modes and environments, as well as to determine the influence of the NS probes on structures created during the SPM lithography.

2. Experimental setup

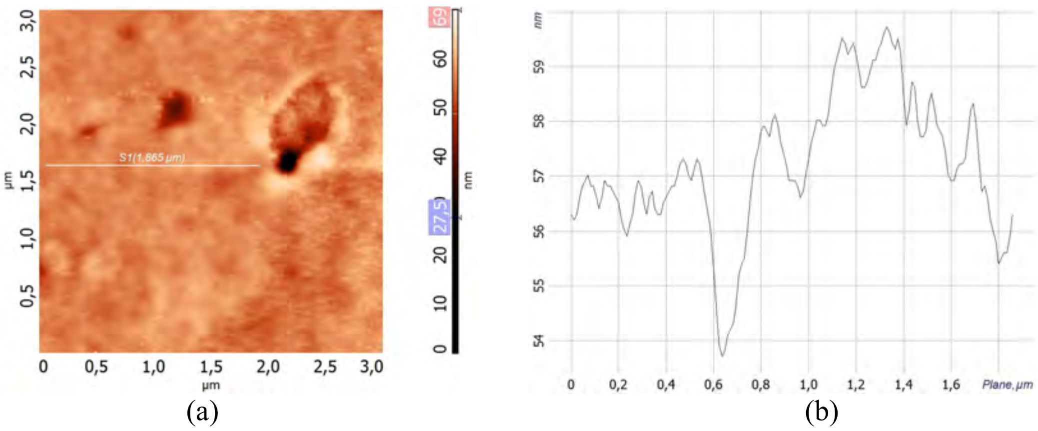
Creation of the nanowhisker structures on the tops of probes and control of their parameters were performed by means of FEI Inspect (USA) and Carl Zeiss CrossBeam Neon 40 (Germany) scanning electron microscopes. Studies of the features of nanowhisker probes were carried out on NT-MDT Ntegra Aura (Russia) scanning probe microscope.

Samples with different nature such as biological (dried erythrocyte cells) and inorganic (calibration grid, silicon structures, polycarbonate and gold substrates, etc.) objects were investigated. Distilled water, phosphate buffered saline (PBS), borate buffer, 0.1 M NaOH and 0.5 M NaOH were selected as test liquids. The SPM measurements were performed both specialized nanowhisker and standard probes.

3. Results and Discussions

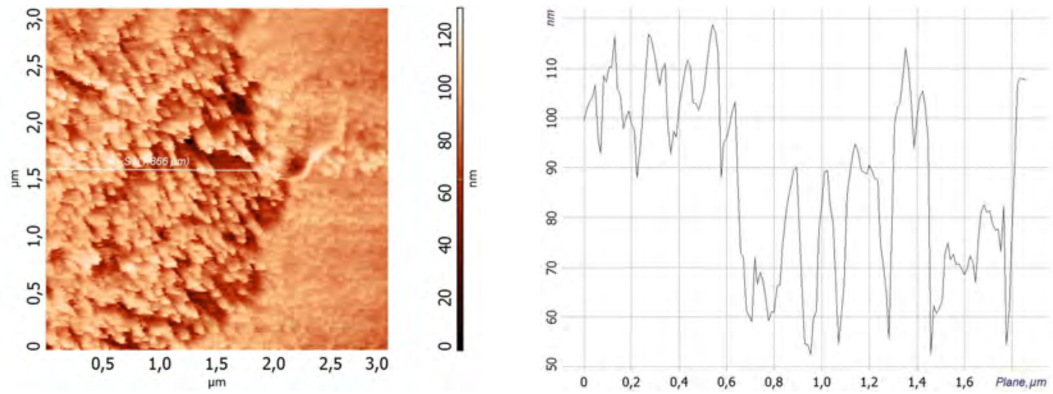
SNWs consisting of an amorphous Pt/C material were characterized with following geometrical parameters: 700-800 nm length, 40-60 nm diameter, and 7-12 nm curvature of tip radius. NSs were fabricated as asymmetrical C nanostructures with 60-80 nm width, 300-400 nm depth, and a length not exceeding 400 nm.

SNW probes demonstrated better quality of SPM images in comparison with standard Si probes in the study of biological objects, as well as samples with inorganic nature. It was shown that SNW probes clearly visualize samples surfaces with sharp features compare to standard probes with the same tip radius due to the increased aspect ratio of probe length to diameter. Moreover, SNW probes have better penetrating ability in microchannels and nanopores, as well as provide more contrast and accurate images in case of surfaces with topology in the range of 2-50 nm. Thus, the results of erythrocytes study showed that SNW probes significantly improve image quality and resolution of the scanning probe microscope (Fig. 1, 2). The visualization of PMMA (Polymethyl methacrylate) microchannel obtained with standard and SNW probes is shown in Fig. 3. It is seen that the SNW probe has substantially better penetration ability (up to 100 nm) than the standard probe (up to 40 nm).



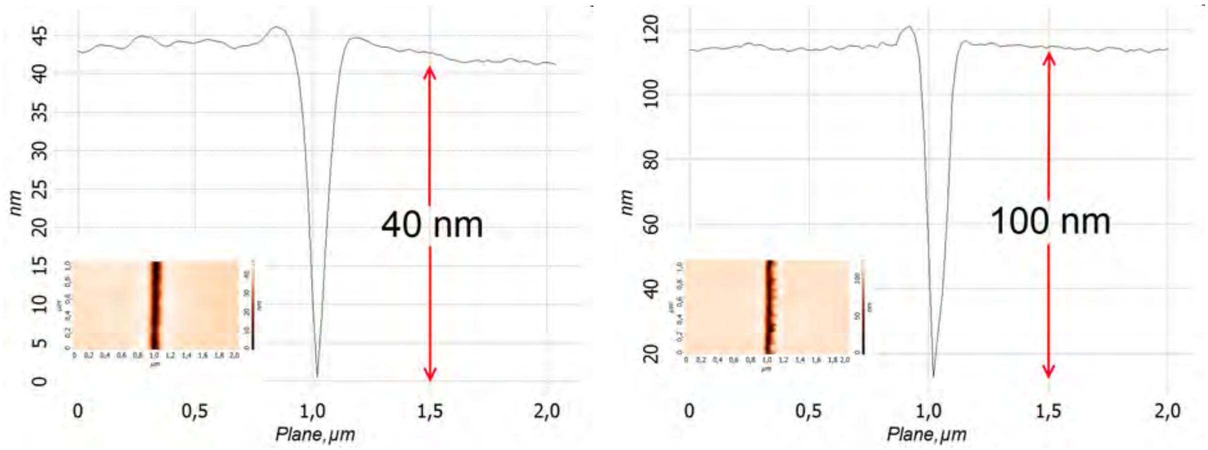
(a) (b)

Fig. 1. SPM image (a) and the cross section (b) of the erythrocyte membrane surface obtained with standard probe.



(a) (b)

Fig. 2. SPM image (a) and the cross section (b) of the erythrocyte membrane surface obtained with SNW probe.

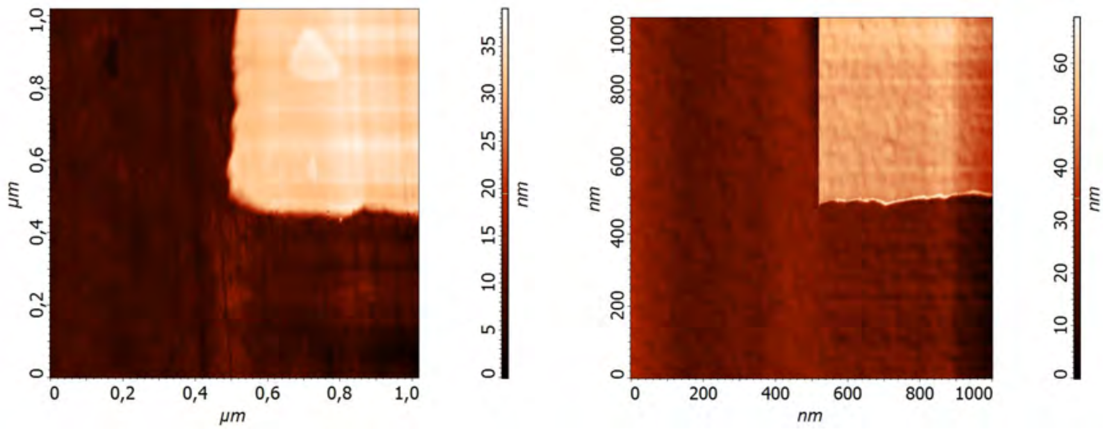


(a) (b)

Fig. 3. SPM images and cross section areas of PMMA microchannels obtained with standard probe (a) and SNW probe (b).

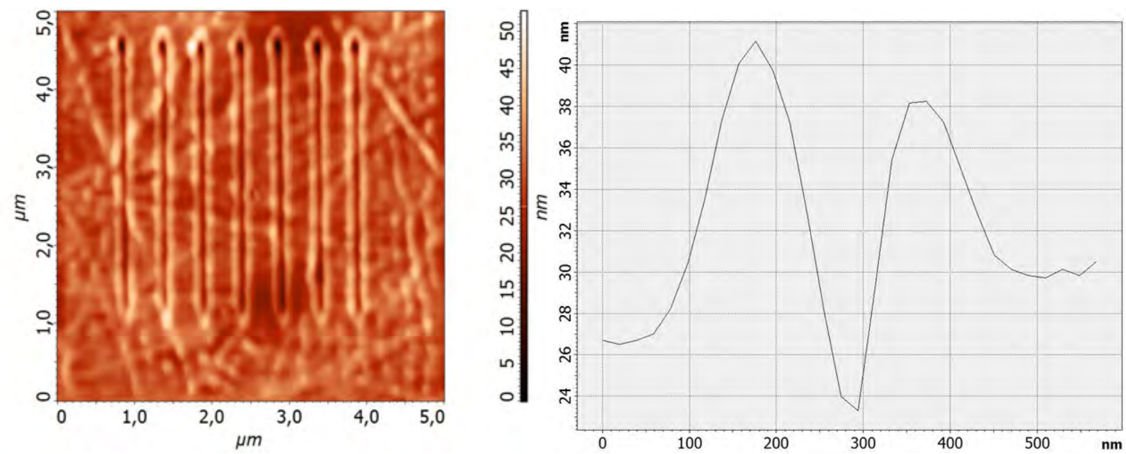
To identify the best modes of SPM operating in the liquid the calibration grid NT-MDT TGQ01 (Russia) was investigated. The calibration grid is a set of periodically arranged square-shaped cells with constant height. Study of the calibration grid with help of SNW probes in the liquids showed that PBS is the best liquid according to image quality. The highest resolution was achieved in contact mode while the best accordance with parameters of test structures was observed in tapping mode.

SNW probes are shown significantly improved image quality and resolution of the SPM in liquids in comparison with standard probes (Fig. 4). Thus, in PBS tilt width of grid in X direction has values of about 4 nm for SNW probes and about 20 nm for standard probes, in Y direction has values about 12 nm and 38 nm, correspondingly.



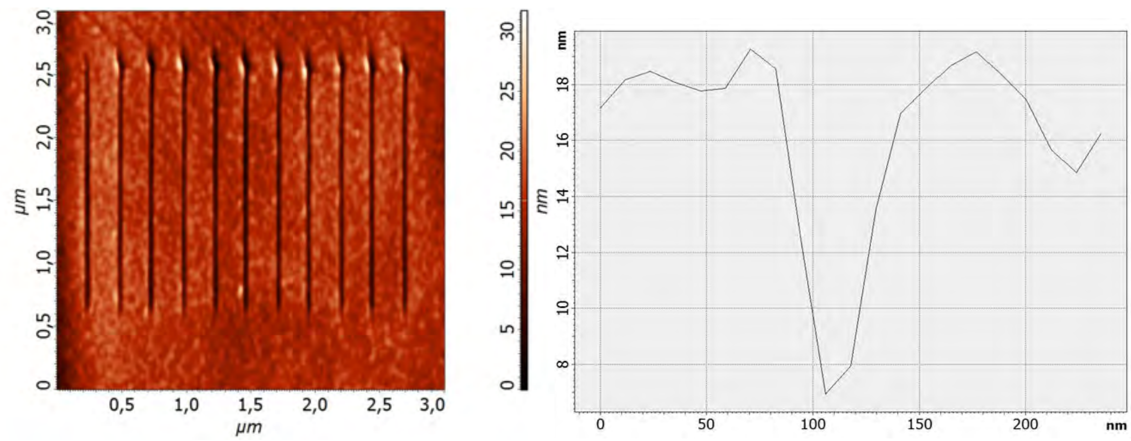
(a) (b)

Fig. 4. SPM images of one cell of TGQ01 grid obtained in PBS with standard probe (a) and SNW probe (b).



(a) (b)

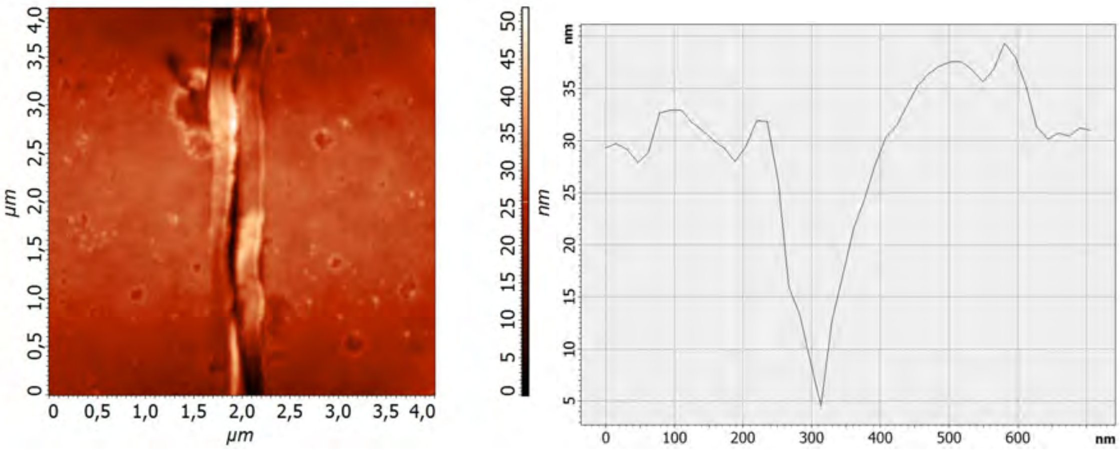
Fig. 5. SPM image (a) and the cross section (b) of the diffraction grating on the gold layer (10 nm) obtained with standard probe force lithography.



(a) (b)

Fig. 6. SPM image (a) and the cross section (b) of the diffraction grating on the gold layer (10 nm) obtained with NS probe force lithography.

NS probes were characterized with enhanced mechanical stability in force lithography mode and showed better results of produced structures on polycarbonate substrates with a gold coating (10 nm) compare to standard probes (Fig. 5, 6). During SPM lithography with NS probes was found out that the most suitable parameters of diffraction gratings producing (with period from 50 nm to 500 nm) on the gold layers are values of forces in the range of 1-2 μN. The most suitable velocity of the probe movement during lithography process is 2 μm/sec.



(a) (b)

Fig. 7. SPM image (a) and the cross section area (b) of erythrocyte membrane incision with NS probe (6.5 μN force).

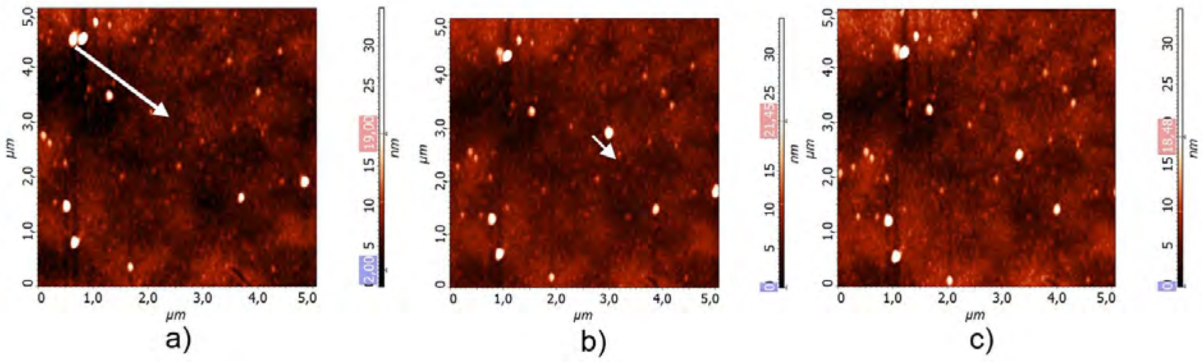


Fig. 8. Manipulation of nanospheres with NS probes: a) the initial position of the particle; b) the initial displacement of the particle, strong impact (about 500 nN); c) repeated displacement of the particle, low impact (about 250 nN).

NS probes also were used for precision cell nanosurgery of dried erythrocyte membranes (Fig. 7). Dissection was carried out by moving the probe relative to the surface of the erythrocyte membrane with a predetermined impact force (0.5 - 7.5 μN) and velocity of about 0.5 μm/sec. In addition the possibility of precise manipulation of nanoparticles (250-300 nm in diameter) was demonstrated by using broad part of NS (Fig. 8).

4. Conclusions

The results showed that the specialized SNW probes gives more reliable and detailed images of surface topology in comparison with standard probes, particularly in the surface features size in range of 2-50 nm. It was revealed that specialized NS probes give better results than standard probes during atomic force lithography. Moreover, the possibility of NS probes applying for precision nanoparticles movements and cell nanosurgery are shown.

These studies have demonstrated the benefit of specialized probes with nanowhisker structures compare to standard probes. Thus, the foundation for the further applications of such structures in the field of nanotechnology and biology was created.

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