Fabrication of probes for scanning near-field optical microscopy using focused ion beam

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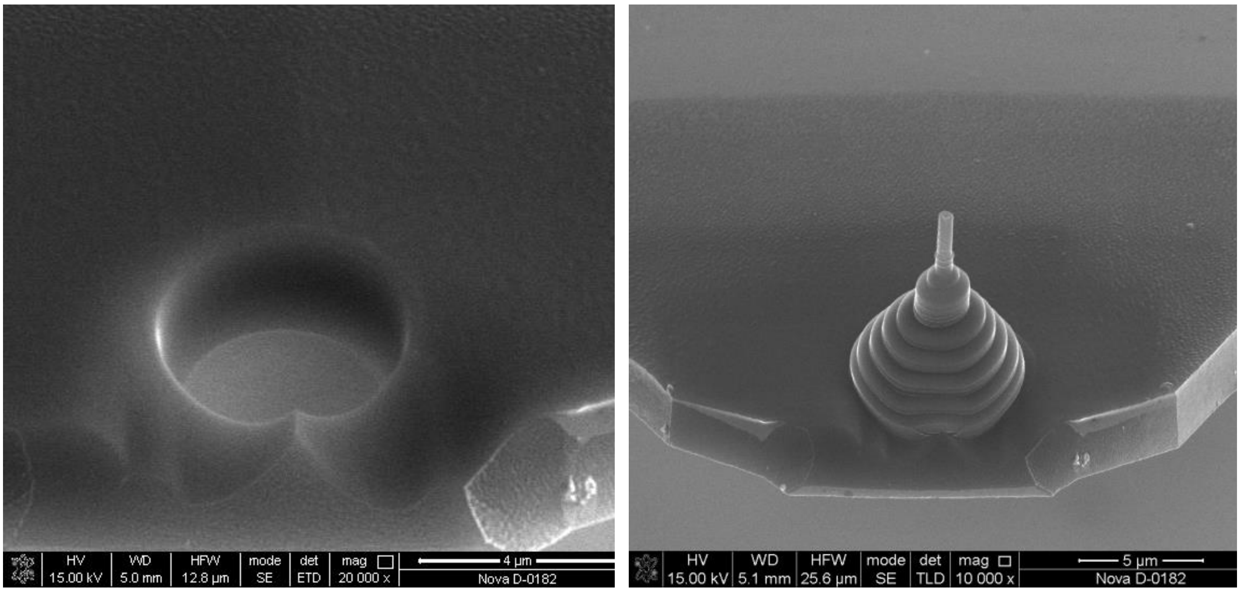
At the present stage of nanotechnology development one of the most promising methods of surface diagnostics is scanning probe microscopy (SPM). The use of SPM methods makes it possible to study the local geometric, electrical and mechanical properties of the substrate surface, as well as to form nanoscale structures on the surface of solids [1]. The perspective direction of SPM is scanning near-field optical microscopy (SNOM), which significantly allows to increase the optical microscopy resulution and provide reliable control of the distance between the tip and the sample. SNOM is a microscopy technique for nanostructure investigation that breaks the far field resolution limit by exploiting the properties of evanescent waves. In SNOM, the excitation laser light is focused through an aperture with a diameter smaller than the excitation wavelength, resulting in an evanescent field (or near-field) on the far side of the aperture [2]. When the sample is scanned at a small distance below the aperture, the optical resolution of transmitted or reflected light is limited only by the diameter of the aperture. One of the main problems in SNOM technology is the creation of probes with a controlled aperture size. The use of traditional technological processes does not allow to vary the aperture diameter and create probes for SNOM of the required shape. The application of new methods of local nanostructuring makes it possible to form probes of various geometric shapes for specialized methods of SPM and SNOM. One of the most promising methods for the formation of nanoscale structures with high accuracy and resolving power is the method of focused ion beams (FIB) [3,4]. The FIB method allows to perform technological operations of local ion beam etching and ion-induced deposition of materials from the gas phase without the needs of resists, masks and chemical etchants. A wide range of materials deposited by this method allows the use of FIB in the formation of nanoscale structures probes for nanodiagnostics. The aim of this work is to create probes for scanning near-field optical microscopy using the FIB method and their experimental study [5].

Traditionally, FIB technology is used to etch the tip of the probe through and thus forming an aperture probe. However, this approach has several disadvantages: the small diameter of the aperture inlet, the complexity of aligning the aperture with the axis of the probe tip, the negative effect of the redeposited material. To eliminate these drawbacks, it is proposed to use the ion-induced deposition method to form a hollow tip of a probe with a controlled aperture diameter.

Experimental studies were carried out using a Dual beam (FIB-SEM) system Nova NanoLab 600 (FEI Company) and the Ntegra Vita scanning probe microscope (NT-MDT, Russia). The standard AFM cantilevers NSG-10 (NT-MDT, Russia) with broken probes due to operation were used as a substrate. At the initial stage of the formation of a new probe tip by ion-beam etching removed part of the beam containing silicon tip. The ion-beam etching current was 20 nA.

At the next stage of the research, a through hole was formed in the cantilever beam using focused ion beam milling on Nova NanoLab 600 system. The resulting hole of 5 μm in diameter is the input for optical radiation in the SNOM method (Fig 1a).

After forming the hole through the beam, gas C6H14 was supplied to the area of the formed hole through the gas injector, which, when interacting with the gallium ion beam with an energy of 30 keV, decomposed into volatile components (which were immediately removed by the vacuum system of the microscope) and solid carbon, which was deposited on the surface. The trajectory of the ion beam was determined by digital patterns so that the deposition of carbon occurred in an orderly manner from the base of the cone (about 5.5 μm in diameter) to its tip. The result was a conical tip formed by the edge height of about 5-6 microns (Fig 1b).



(a) (b)

Figure 1. (a) SEM images of the 5 μm hole in the cantilever and conical aperture probe, (b) fabricated by FIB-induced deposition.

After that, at the end of the cone by ion-beam etching at low ion beam currents, an outlet for optical radiation with a diameter of 50-200 nm was formed. The main advantage of the proposed technology is the ability to form probe tips of different shapes and sizes. The probe shown in Figure 1b has a tip radius of about 200 nm, which also allows it to be used to obtain AFM images.

The fabricated probes have been tested, and it has been found that the probes created by this method have a longer service life as an AFM measurement tool. In addition, the ability to vary the diameter of the aperture makes it possible to form optimized probes for the desired wavelengths. The ability to form aperture SNOM probes based on broken cantilevers makes it possible to significantly improve the economic efficiency of the proposed technology.

The results obtained in the study can be used in the development of technological processes for the fabrication and modification of special aperture probes for scanning near-field optical microscopy, and in the development of procedures for the express monitoring of parameters of the technological process for manufacturing elements for micro- and nanoelectronics and micro- and nanosystems engineering.

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