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# Development of an integrated NSOM probe

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## Abstract

A new type of NSOM probe has been developed, with a design based on the probes used in Atomic Force Microscopy. The probe consists of a cantilever with at its end a conical tip. This tip has been metal-coated to provide an aperture. With the cantilevered probe, the problem of breaking of the tip due to high normal forces is solved. In operation, the tip is scanned in contact with the sample while regulating the force between the tip and the sample with a beam deflection technique, which allows to simultaneously make an optical and a topographical image of the sample. The probes are made using micromechanical techniques, which allows batch fabrication of the probes. Testing of the probes is done in a transmission NSOM set-up in which the sample is scanned while the tip and the optical path are kept fixed. Using an opaque sample with submicron holes, the new probes have been tested, resulting an optical image with a simultaneously measured topographical image.

## 1. Introduction

In near-field scanning optical microscopy (NSOM) a high resolution optical image of a sample is obtained by scanning a sub-wavelength light source or detector [1,2] close to the sample surface. At present, the tapered and aluminum-coated fiber probe is widely used as sub-wavelength light source.

In operation, the Al-coated fiber has to be kept close to the sample surface and at a constant distance. For controlling the tip–sample distance the shear-force feedback mechanism [3,4] is used in which the fiber is vibrated at its resonance frequency. When approaching the sample the amplitude and phase of the vibrating fiber change caused by a still not completely understood mechanism. Typical tip–sample distances in literature vary between 1 and 20 nm [3–10]. Because the tip–sample distance is small and the fiber is relatively rigid in the direction towards the sample, tip crashes can occur. First measurements on Langmuir–Blodgett film show a possible dependence of the shear-force feedback distance on chemical composition of sample and probe which would lead to intensity fluctuations while scanning a sample. With the cantilevered probe presented here, these disadvantages do not occur due to the small spring constant in the direction towards the sample.

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The design of this new developed probe is based on the standard cantilever-type probes used in atomic force microscopy (AFM). Applying the standard AFM probes in NSOM ensures an easy operable microscope which combines optics with force detection and hereby enabling all AFM contrast mechanisms, e.g. contact, non-contact, lateral force, tapping and adhesion mode in air or liquid, to be combined with NSOM. Earlier investigations [11] have also shown the promising possibilities of these probes. However, the commercially available AFM probes with pyramidal tips are not ideally suited for NSOM usage. The tips on these probes are made of the same material layer as the cantilever, resulting in a hollow $Si_3N_4$ tip. The mechanism with which light, focused from the base side of the tip, is coupled into the hollow tip is less efficient than when a solid tip would be used. These considerations have led to the development of a new cantilever probe with a solid transparent tip.

## 2. Fabrication process

In Fig. 1 a short summary of the fabrication process is shown. The probes are made using micromechanical techniques. The 200 $\mu$m long cantilever is formed from a 1 $\mu$m thick silicon nitride layer, while the tip is shaped from a 5 $\mu$m thick silicon nitride layer. Small silicon disc with a diameter of 10 $\mu$m are patterned onto the 5 $\mu$m thick layer. Using an isotropic etching process in hydrofluoric acid the silicon nitride layer is etched while the silicon disc is not attacked by the etchant, resulting in an underetched tip shape. The etching process is stopped when the silicon disc detaches from the surface. To control the process several different disc sizes are patterned onto the wafer where the smaller discs detach in an earlier stage than the larger ones. Fig. 2 shows the results of the etching process where the different probes were etched for the same period.

The probes are batch fabricated with 448 cantilevers on one 3″ silicon wafer. The resulting spring constant of the cantilever is about 0.3 N/m and its first resonance frequency is about 17 kHz.

As a last step aluminum is evaporated onto the tip under an angle of about 85° relative to the tip axis, while rotating the probe. This results in the Al-layer thickness onto the side walls of the tip to be much larger than on the cantilever and tip end. On the tip used in measuring Fig. 5 aluminum was evaporated so that a 150 nm layer covered the side walls of the tip. After evaporation part of the aluminum was etched away with standard aluminum etchant (Merck 15435, Aluminum Etchant LE) for 10 seconds, until the cantilever was transparent and thereby the tip opened up.

## 3. Results

The SEM image in Fig. 2b shows the tip to have the cone shape which was aimed for with a tip sharpness of about 50 nm.

For testing the probes a set-up was built resembling a confocal microscope, where one objective

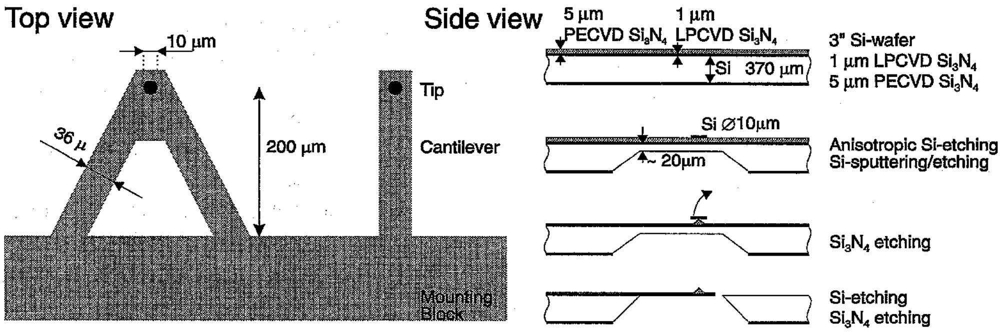

Fig. 1. Overview of the probe fabrication process.

was used to focus light onto the topside of the cantilever and a second objective to collect the light transmitted through the tip and sample, as displayed in Fig. 3. In order to provide space for the AFM

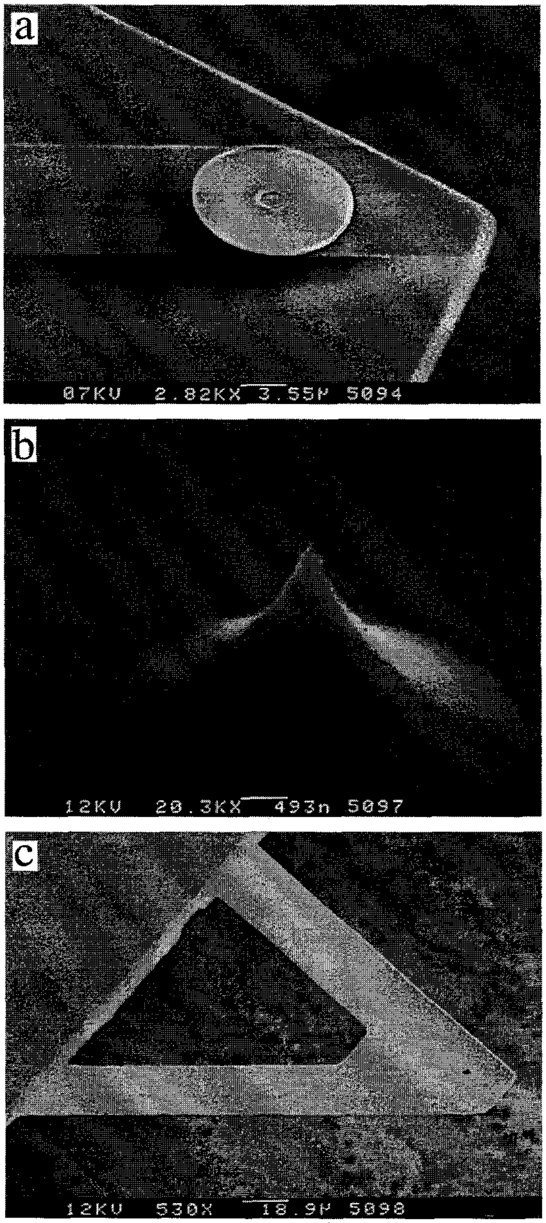

Fig. 2. SEM photographs of the developed probe: (a) a 16 μm silicon disc still attached to the tip and cantilever, (b) the tip resulting from a 10 μm silicon disc, (c) the cantilever with integrated tip.

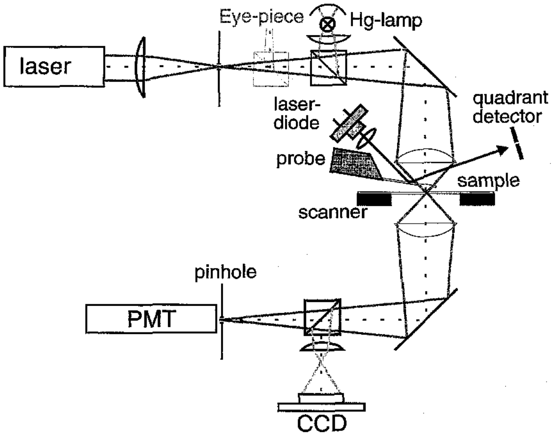

Fig. 3. Set-up used for testing the cantilevered probes.

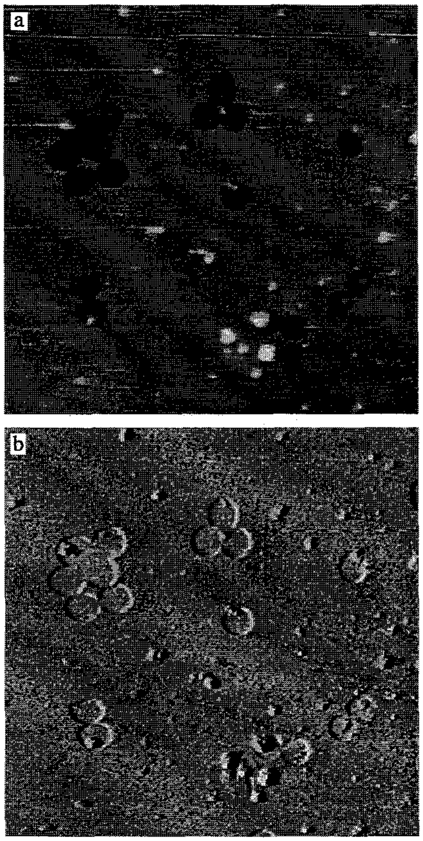

Fig. 4. Images of a silver layer on glass with 481 nm holes scanned with an uncoated tip: (a) height image ($z$-piezo voltage), (b) deflection image.

system extra long working distance objectives with N.A. 0.5 were used (Nikon ELWD). A 8 mW HeNe laser was used which light is focused onto a pinhole. The sample, e.g. microscope object slide, is mounted on a three-axis scanner (Photon Control $X$–$Y$ piezo flexure stage with a scan area of $200 \times 200$ $\mu$m$^2$ combined with a 10 $\mu$m piezo stage for height control). For the beam deflection system, measuring the cantilever bending, a 780 nm laserdiode is focused onto the backside of the cantilever and its reflection is imaged onto a quadrant detector. A feedback system is implemented on the deflection signal.

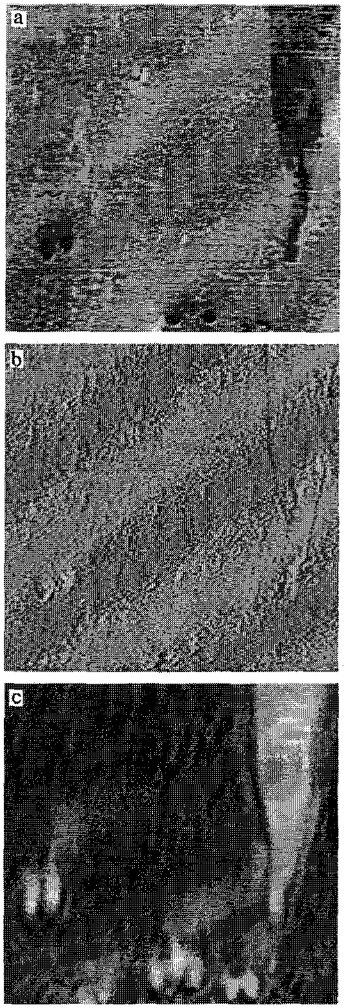

Fig. 5. Images of a silver layer on glass with 481 nm holes scanned with an Al-coated tip: (a) height image ($z$-piezo voltage), (b) deflection image, (c) optical transmission image.

The transmitted light through tip and sample is collected using a similar objective. Background light is further reduced using a pinhole in front of a Hamamatsu R1463 photomultiplier tube.

Fig. 4 shows images of a silver layer with 481 nm holes on glass. The images were made with an uncoated tip, Fig. 4a shows the height image displaying the $z$-piezo voltage and Fig. 4b shows the deflection image displaying the deflection signal driving the feedback loop.

Fig. 5 shows the results of a scan performed with a coated tip on the same sample showing an optical image measured in transmission. The line-scan rate was about 0.3 Hz at 300 points per line. The AFM images are noticeably influenced by the aluminum coating giving rise to tip convolution problems in these images. The optical image shows the individual holes from which an optical resolution of about 300 nm can be estimated. The optical signal measured is tip dependent with typical values of about 100 pW resulting in a transmission efficiency of about $10^{-7}$.

## 4. Conclusions

The AFM images of non-coated tips show good AFM capabilities with resolution proportional to tip sharpness of about 50 nm. SEM images of the probe confirm the cone shaped tip and its sharpness.

From the intensity distribution in Fig. 5 can be estimated that at the moment the optical resolution obtained is about 300 nm. So probably the aperture size exceeds the tip sharpness, which can be explained if the aluminum etching is anisotropic.

When the tips are incorporated in a set-up as shown in Fig. 3 it gives the possibility of combining all known AFM contrast mechanism with near-field optical microscopy, resulting in a user friendly near-field microscope. Especially, combining the microscope with tapping mode atomic force microscopy raises high expectations for future use of this type of probes.

Further advantage of the process is the batch fabrication of the probes with one wafer containing 448 cantilevers. Currently, work is being done to improve coating properties and implement other ways of creating a well defined aperture.

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