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Contents

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Development of a Micro-SPM (Scanning Probe Microscope) by Post-assembly of a MEMS-stage and an Independent Cantilever

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Abstract: The development of miniature scanning probe microscopes (SPM) on the basis of the MEMS technique has gained more and more interest. Here a novel approach is presented to realize a micro-SPM, in which by means of post-assembly a conventional cantilever is mounted onto a MEMS positioning stage and used to detect the topography variation of the surface under test. Compared with other integrated micro-SPMs, the proposed micro-SPM can maintain the lateral resolution by simply renewing its cantilever in use, and therefore features low cost, practicability and longer lifetime. Preliminary experimental results are reported, which demonstrate that the proposed microSPM can be realized. *Copyright © 2007 IFSA.*

Keywords: Scanning probe microscope, MEMS stage, Cantilever, Optical deflection detecting

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1. Introduction

Nowadays scanning probe microscopes (SPM) are widely used in various scientific disciplines and industrial fields, and became an indispensable tool, particularly for nanotechnology. In spite of their achieved successes regarding measurement resolution and accuracy, traditional SPMs, comprising conventional components, still embody such unsurmountable disadvantages, like high cost, huge volume (which implies that it is impossible to apply them for on-site or in-situ measurement tasks), relative low image speed (which implies that it is difficult to apply them for imaging dynamic bodies, e.g. biological matter).

Noticing that MEMS technique and devices feature small size, low power consumption, high precision in manufacture, the potential for low cost through batch fabrication, the ability for on-site applications, etc., efforts to integrate SPM with MEMS technique have long been undertaken. For instance, in [1] an

AFM tip was integrated with a two-dimensional micro-stage, which successfully took the image of a tungsten carbide needle. To some extent, self-actuated and/or self-deflection-sensing cantilever and cantilever arrays [2, 3] can also be regarded as results of the above efforts. Recently we have noticed that a so-called "single-chip AFM" [4] was proposed, in which the cantilever actuation, the deflection sensing and the digital signal processing (DSP) unit were realized within one chip.

However, as we know, the outstanding lateral resolution of an SPM thoroughly depends on the actual radius of the SPM tip, which in general dramatically increases after certain rounds of scanning, due to the wear with the surface under test. Comparing the complexity for fabrication and calibration of the integrated micro-system with its relatively short life-time, it seems that to integrate the SPM tip with a cantilever or a micro-stage by "all-in-one" fabrication is not a perfect solution for a micro-SPM.

Here the concept of post assembly is presented to economically realize a micro-SPM, in which a typical conventional cantilever is proposed to be mechanically mounted onto a micro-stage or dismantled from the micro-stage after its tip is worn out. In this way, the well-designed and calibrated micro-stage could then be repeatedly and efficiently utilized.

2. One-Dimensional (Line-Scan) Micro-SPM by Post-Assembly of MEMS Positioner and Cantilever

As shown in Fig. 1, in this paper a conventional AFM cantilever (L = 450 µm, W = 38 µm, T = 2 µm) was mounted onto the outgoing end of the main shaft of a one-dimensional micro-positioning stage (detailed in [5]) by means of an optical adhesive. The 1D micro-positioner is a typical electrostatic comb-drive actuator, and was fabricated by the SCREAM technique, where the resonance frequency of the micro positioner amounts to f_{rs_mp} = 4 kHz (movable part on the y-axis in Fig. 1). In the case of quasi-static driving, the in-plane displacement of the main shaft of the micro-positioner can be clearly determined by the drive voltage U^2, i.e.

$$y = \frac{1}{k_y} \cdot \eta \cdot U^2, \tag{1}$$

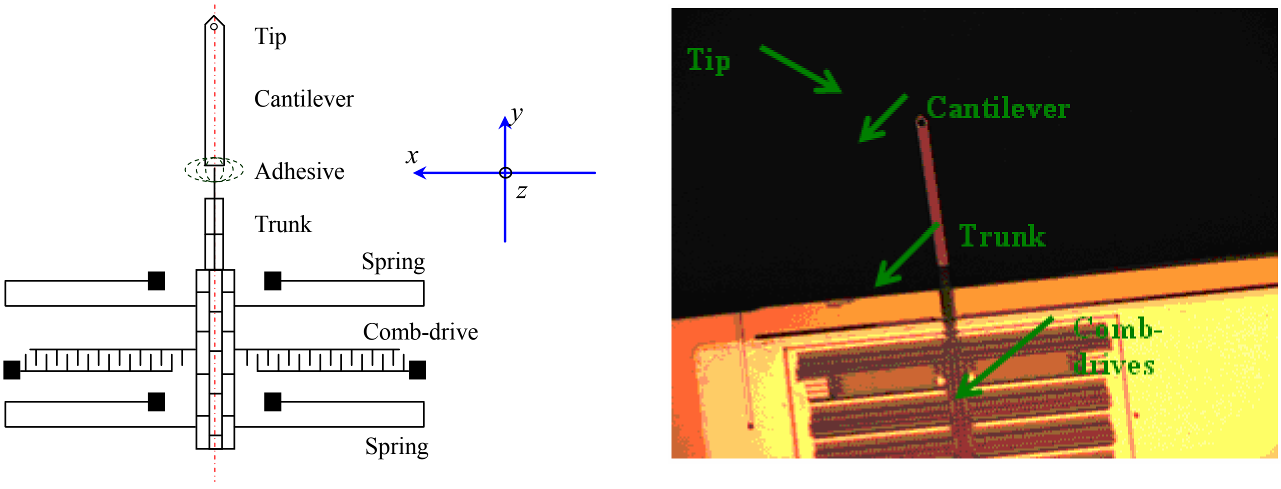
where k_y is the spring constant of the micro-positioner along the y-axis, η is the coefficient of the actuator within the micro-positioner determined by the number of the comb pairs, the aspect ratio of the substructures, etc. [6].

The thickness of the suspending structure is about 16 µm, therefore the stiffness of the micro-positioner along the z-axis should be much higher than that of the cantilever ($k_{z\ ct}$ = 0.43 N/m), which ensures that the whole movable structure of the micro-positioner has no vertical vibration during the surface scan with the cantilever.

As one of the important specifications, the resonance frequency of the micro-SPM can be calculated as follows:

$$f_{rs} = \frac{1}{2\pi}\sqrt{\frac{k_y}{m_{mp} + m_{ct}}}, \tag{2}$$

where m_{mp} is the equivalent mass of the micro-positioner's suspending structure and m_{ct} is the mass of the cantilever. Obviously, since the cantilever is much lighter (0.08 µg) than the movable part of the micro-positioner (about 5 µg), its influence on the micro-SPM can be actually neglected, i.e. $f_{rs} \approx f_{rs\_mp}$.



(a) Scheme (b) Photograph

Fig. 1. A novel realization of a micro-SPM with a 1D micro-stage and a separate cantilever.

Compared with similar work in [7], in which multi-cantilevers were connected together by means of optical adhesive to obtain a novel form of the deflection sensor, it is worthwhile to point out that the residual glue region is now effectively reduced mainly due to the siphonage effect contributed by the etch trench of the main shaft, and therefore the residual (effective) cantilever length is now increased. This can be one of the effective rules for further design of the micro-SPM based on a micro-stage.

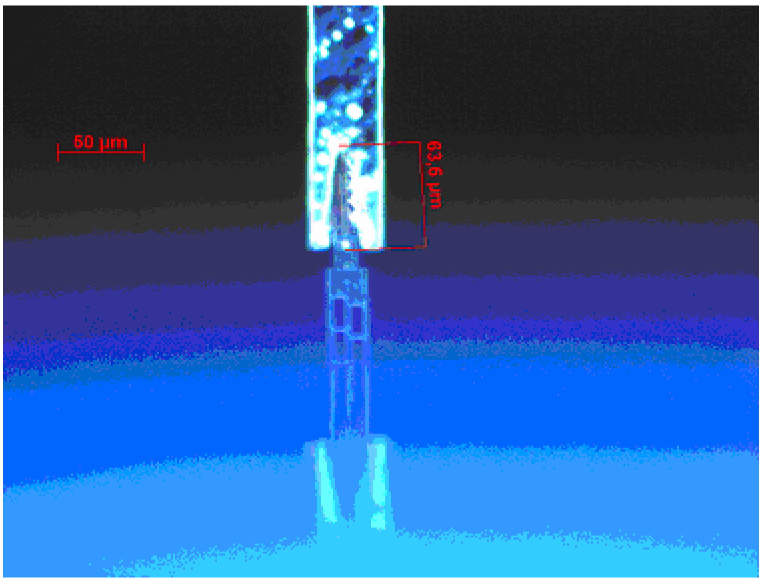
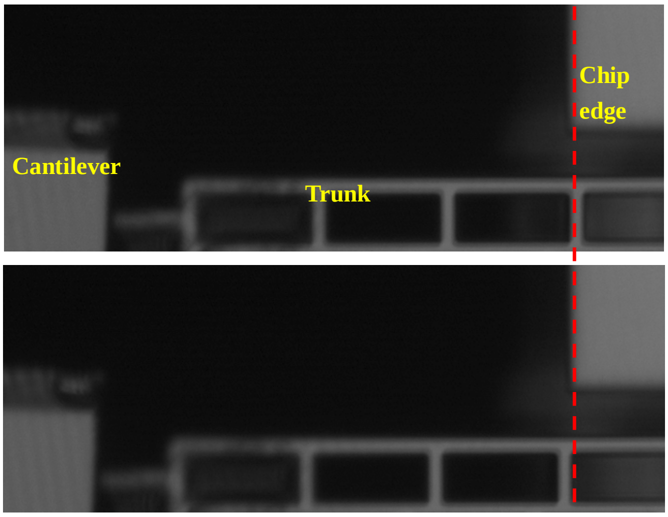


Fig. 2. Photograph of the glue region of the micro-SPM in Fig. 1.

Fig. 3 illustrates the in-plane displacement of the micro-SPM, which coincides quite well with the experimental data of the micro-positioner detailed in [8].



(a)

(b)

Fig. 3. Photograph of the in-plane scan of the micro-SPM (upper part) in Fig. 1.
(a) Drive voltage U = 0 V, (b) Drive voltage U = 60 V.

3. Preliminary Experimental Results

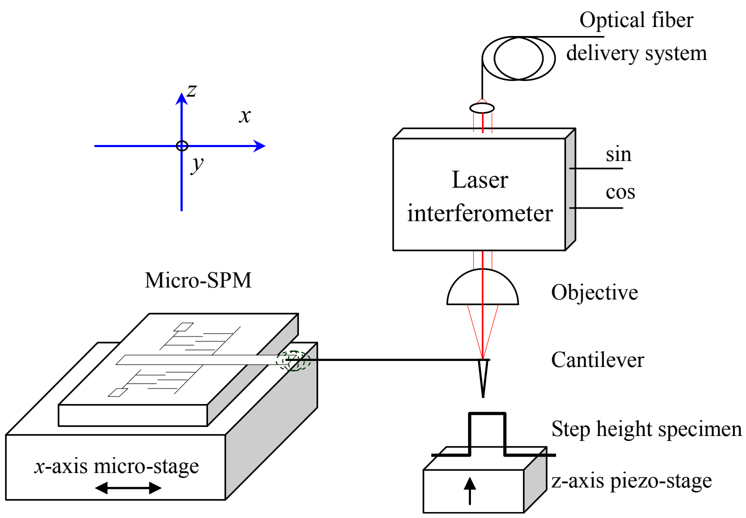
The performance of the micro-SPM has been investigated experimentally by means of scanning a step height specimen. As shown in Fig. 4, a single-frequency laser interferometer was employed to detect the deflection of the cantilever. The measurement beam of the laser interferometer was focused onto the back side of the cantilever by means of a microscope objective (Olympus 5X, 0.13NA), creating a detecting laser spot with about 6 µm in diameter. A piezoelectric micro-stage was used to coarsely position the micro-SPM chip horizontally. The specimen with a step height of about 200 nm was mounted on a nano-stage (P714, Physik Instrumente, closed-loop with 1 nm resolution), which would drive the specimen to engage the SPM tip.

Fig. 5 details the cantilever response, when the specimen is driven to contact its tip, in which the specimen was oscillated by the nano-stage with a frequency of 1 Hz and amplitude of 175 nm. It can be seen that due to the overengagement (30 nm) the cantilever has a backlash of up to 140 nm. This phenomenon has to be taken into account in order to design the proper control strategy for the micro-SPM.

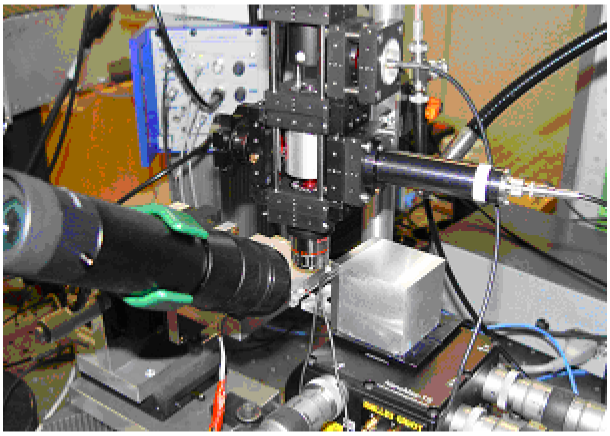
Finally, with the help of the micro-stage, the step height specimen was scanned and the measured topography is shown in Fig. 6. The measurement result shown in this figure corresponds well with the nominal value (h = 200 nm) of the step height specimen. The ripple within the measured profile of the step height was mainly introduced by relative vibrations between the laser interferometer, the specimen and the micro-SPM chip, since the three components were mounted on a separate post and two different coarse 3D stages, respectively.

4. Conclusion

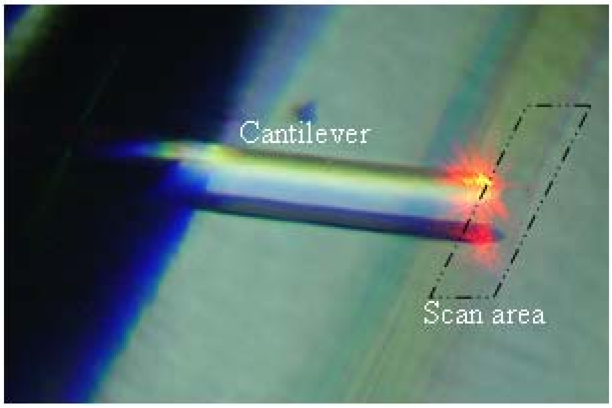
A simple line-scan micro-SPM is presented in this paper, which was realized by post-assembly of a micro-positioning stage and a separate conventional cantilever. Since one of the most important components, i.e. the cantilever and its tip can now be mounted and removed from the micro-stage, design, fabrication and calibration of the micro-SPM can be significantly and economically simplified. Moreover, the lifetime of the micro-SPM is essentially extended, which effectively improves the practicability of the MEMS device.



(a) Scheme of the experimental system

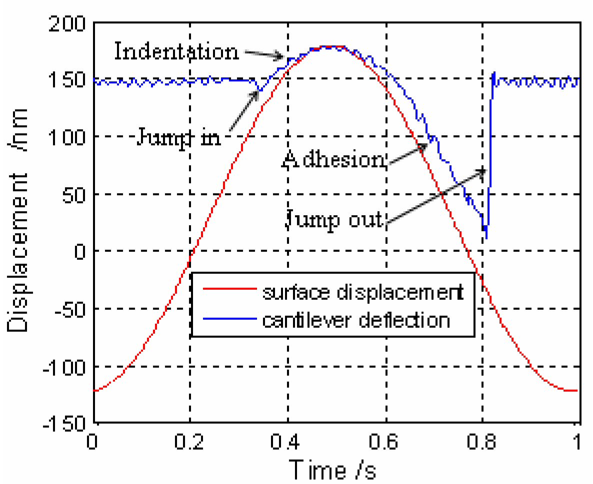


(b) Experimental setup

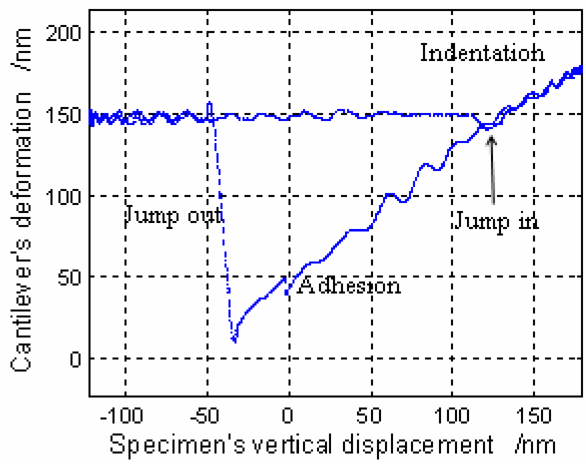


(c) Specimen and cantilever

Fig. 4. Experimental investigation of the micro-SPM.



(a) Time response



(b) Cantilever deflection during engagement

Fig. 5. Experimental investigation of the engage procedure of the micro-SPM.

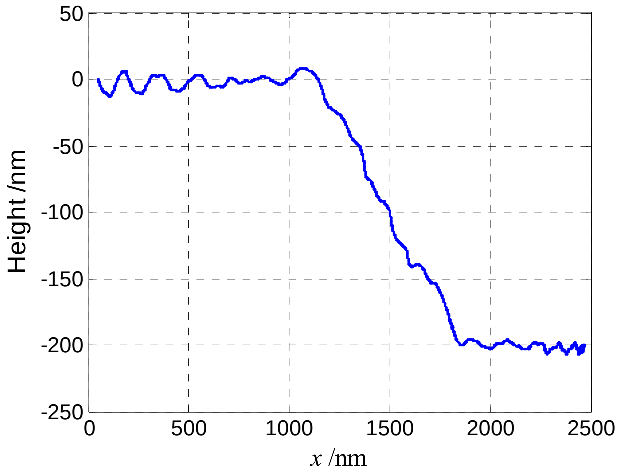


Fig. 6. Measured profile of the step height specimen by the experimental setup.

It is expected, that with improved design of the MEMS scanning stage, cantilever deflection sensing unit, control strategy and of the algorithm for surface scanning and experimental setup, the micro-SPM will become a practical instrument in order to measure one-dimensional specimens, like step height standards and one-dimensional gratings.

Acknowledgement

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