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# Force-calibrated AFM for Mechanical Test of Freestanding Thin Films

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**Key words:** AFM (Atomic Force Microscope), mechanical test, freestanding thin film, Au, calibration, cantilever

**Abstract.** Atomic force microscope (AFM) is a powerful tool for exploring a nano-scale world. It can measure a nano-scale surface topography with very high resolution and detect a very small force. In this paper, we propose a novel AFM cantilever and its calibration scheme to utilize AFM as a mechanical testing machine. We call this AFM with a new cantilever as a force-calibrated AFM. The feasibility of the AFM cantilever is validated through measurement of mechanical properties of freestanding Au thin films.

## Introduction

The accurate measurement of mechanical properties of the thin films is crucial as the thin films are closely related to the performance and reliability of microelectronic mechanical systems (MEMS) and semiconductor devices [1, 2]. The variety of methods for evaluating mechanical properties of thin films has been devised and reported [3, 4, 5]. It is known that development of the testing machine for measuring mechanical properties of micro/nano scaled thin film is very difficult. AFM is commonly used for measuring surface topography with high resolution. In this study, we focus on the AFM capability of measuring force with high sensitivity. AFM is a highly sensitive force sensor and can be utilized as a mechanical test machine. It is found that the following issues should be solved for the successful use of AFM in mechanical tests. 1) Lateral (asymmetric) motion of AFM cantilever, 2) stiffness calibration of AFM cantilever, 3) nonlinearity of position-sensitive photodetector (PSPD) and piezoelectric scanner, etc. To overcome these problems, we propose a novel design of AFM cantilever and a calibration scheme for AFM-based mechanical test. The nonlinearity of PSPD and scanner is a hardware dependent problem and is beyond the scope of this paper.

## AFM and Novel Design of AFM Cantilever

AFM is not very accurate for mechanical tests due to its inherent structural problems. The leaf spring cantilever deforms asymmetrically when the force is applied perpendicularly to the sample surface, and the cantilever assembly is set up with an inclination of approximately 12 degrees. These configurations create lateral movement ($X_0$) at the tip during indentation as shown in Fig. 2, which results in imprecise experiment and data. Therefore a symmetric cantilever has been designed and fabricated which will resolve these issues during mechanical tests.

Rhombus shaped cantilever which is symmetric about the Z-axis was fabricated with stainless steel using laser cutting machine. And then Cu thin film mirror was attached on the cantilever for reflecting the laser beam. The indent tip was mounted on the cantilever after that. The length of the cantilever is approximately 5mm, and the width is 200μm. Fig. 3 (b) shows the SiC wire (diameter: 100μm, length: 300μm) which is used instead of the sharp diamond tip for strip bending test. To uniformly apply the line load on the strip specimen, wedge shaped indenter tip (SiC wire) was integrated on the cantilever. Cantilever assembled on the inclined plane of steel head which has angle of 12 degrees and this compensates for the inclination of AFM head when applying vertical loads on the sample.

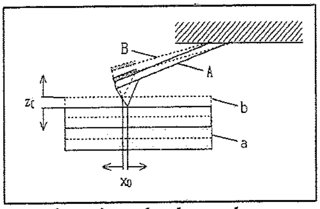



Fig. 2 Schematic diagram showing the lateral movement of the probe at indenting

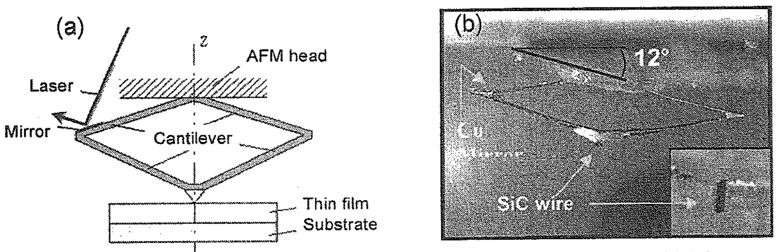



Fig. 3 (a) Rhombus shape cantilever for mechanical test (b) Photograph of the rhombus cantilever probe, The Inserted picture shows a magnified view of the SiC tip

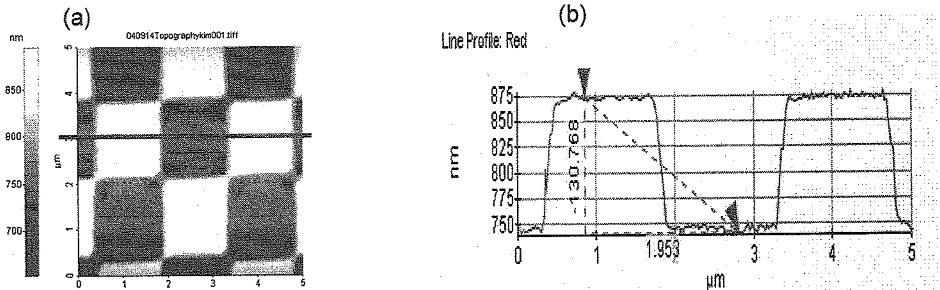


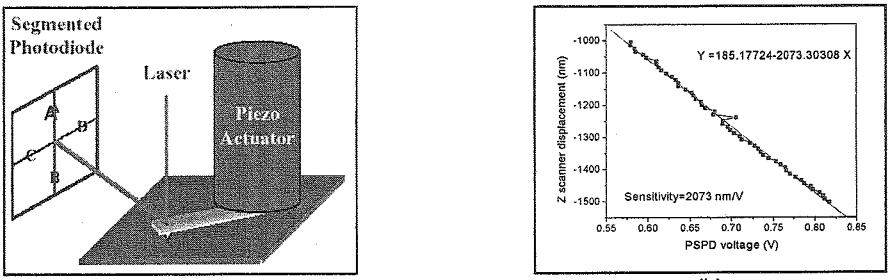

Fig. 4 (a) Topographic image of standard grating sample and (b) its section profile along the A-B

**Calibration of AFM**

The Z-scanner is operated by piezo-electric actuator along the Z direction. The displacement of Z-scanner is calibrated using 3µm*3µm*130nm standard grating sample. The topographic image of grating sample is shown in Fig. 4 (a) and its line profile data along the A-B line is shown in Fig. 4 (b). The calibrated height of the sample is very close to the reference height (130nm) of the grating sample.

The deflection of cantilever during scanning on the sample is measured by PSPD board segmented into 4 parts. The difference of voltage value between A and B area (A-B) on PSPD board is translated as quantity of cantilever deflection along the Z-direction (Fig. 5 [a]). The sensitivity calibration of PSPD is operated by impressing the cantilever onto a rigid sample surface. In Fig. 5 (b), the linear relationship between PSPD voltage and Z-scanner displacement is illustrated, and its slope indicates the PSPD sensitivity which is 2073 nm/V for our cantilever. This value is fitted on the AFM system again.

For micro/nano mechanical test, it is necessary to have low stiffness of cantilever. The force constant of typical cantilever ranges from 0.2 to 40N/m. In order to calibrate the stiffness of AFM cantilever, we use a standard sample of a bridge structure in which the stiffness is measured by a commercial nanoindentation system (Nanoindenter XP). The bridge structure is loaded by AFM and the resulting load-deflection curve is measured. By comparing the load-deflection curve (Fig. 6 [b]) with that (Fig. 6 [a]) of Nanoindenter XP, we can determine the stiffness of our new AFM cantilever. The stiffness of the cantilever is calculated as 19.7N/m.




(a) (b)

Fig. 5 (a) Schematic diagram for basic principle of PSPD and (b) the PSPD voltage vs. Z-scanner displacement plot with a linear fit

(a) (b)

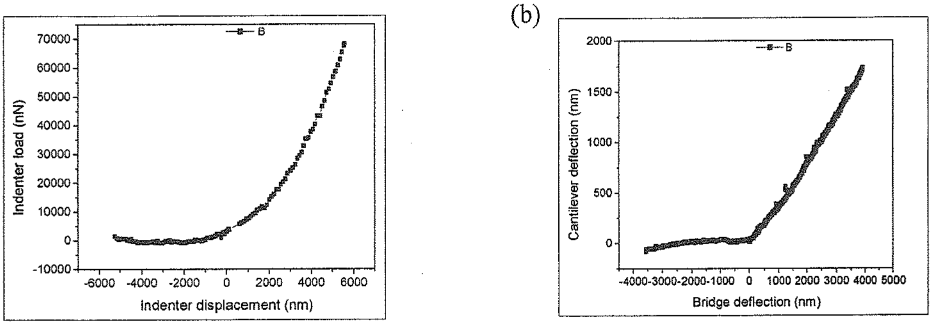



Fig. 6 The load-deflection curves of the standard test structure by (a) Nano Indenter XP and (b) new AFM cantilever

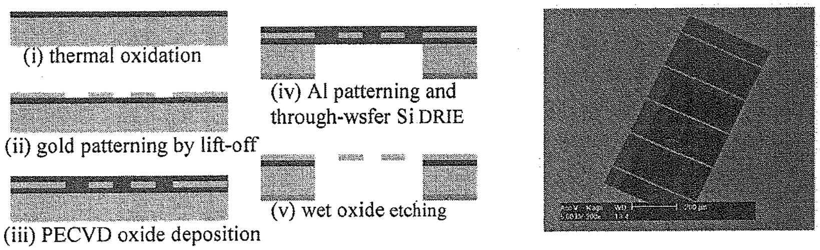



Fig. 7 Fabrication process for freestanding Au bridge structure using MEMS process and SEM image of the fabricated Au specimen

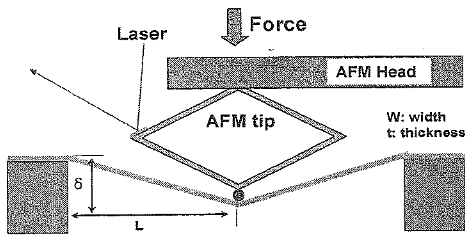



Fig. 8 The test principle of a freestanding thin film bridge with novel AFM cantilever

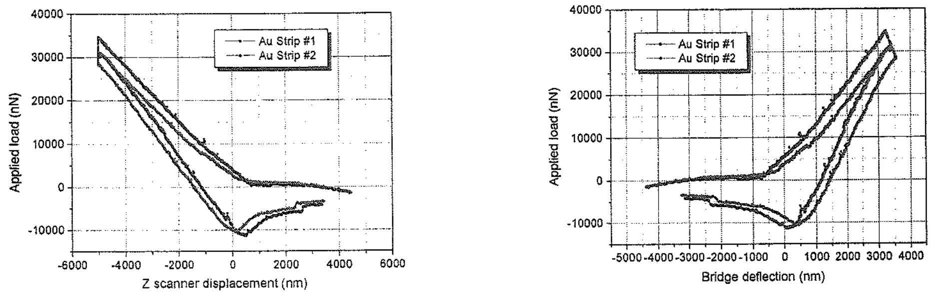



Fig. 9 (a) is applied load vs. Z-scanner displacement curve,
and (b) is applied load vs. bridge deflection curve

## Sample Preparation and Mechanical Test

Fig. 7 shows the freestanding fixed-fixed gold beam structures for the strip bending test fabricated using MEMS technology. Thickness of the film is 1μm which is much smaller than width of 40μm and length of 400μm. To keep the specimen in its elastic region, length of the specimen must be larger than the displacement under loading. If the strain is 0.4% at the yield point of the specimen, length of the strip should be 12 times larger than the maximum displacement. Therefore dimensions of the specimen are carefully determined and designed.

In order to exemplify the use of force-calibrated AFM, we perform an AFM-based mechanical test on the freestanding Au films. The test principle is illustrated in Fig. 8. If we can accurately measure the applied load (P) and the corresponding bridge deflection (δ), we can estimate the mechanical properties of the film. The test procedures are given as follows: 1) locate the AFM tip on the center of the thin film bridge, 2) move the Z-scanner downward to apply a load to the bridge, 3) move the Z-scanner upward to release the load. The raw data measured by AFM are the Z-scanner displacement and the PSPD voltage signal. The relationship between the PSPD signal (V) and the load (P) applied to the bridge is given by

$$P = A \times S \times V . \tag{1}$$

where A is a PSPD sensitive (= 2073nm/V) and S is a cantilever stiffness (=19.7N/m). Now the graph of the applied load and Z-scanner displacement shown in Fig. 9 (a) can be obtained. The Z-scanner displacement (Z) is not equal to bridge deflection (d). Since the Z-scanner displacement is the sum of the bridge deflection and the cantilever deflection, the bridge deflection can be expressed such as

$$\delta = Z - P / S . \tag{2}$$

Using this relationship, we can obtain the graph of the applied load vs. the bridge deflection as shown in Fig. 9 (b). Calculation of the mechanical properties from Fig. 9 (b) will be discussed in future paper since sensor nonlinearity issue is beyond the scope of this paper.

## Summary

A novel AFM cantilever and its calibration scheme are proposed. The new AFM cantilever is made of stainless steel and shaped by a laser cutting machine. A SiC wire is attached to the cantilever for the mechanical test. For the calibration of AFM, we perform the following three steps: 1) Z-scanner calibration, 2) PSPD sensitivity calibration and 3) cantilever stiffness calibration. For the cantilever stiffness calibration, we adopt an Au structure with known stiffness. The measured stiffness of the AFM cantilever is 19.7N/m. To exemplify the use of AFM-based mechanical test, we measure the load-deflection curve of thin Au freestanding films.

## Acknowledgement

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