Prototype Cantilevers for AFM Lateral Force Measurement

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Abstract:

One of the major difficulties in calibrating the lateral forces measured with optical lever atomic force microscopy (AFM) is in determining the lateral optical lever sensitivity. Novel cantilevers have been designed and fabricated to simplify this measurement and pave the way for accurate calibrated cantilevers in which normal and lateral forces (e.g. from friction) can be more easily measured.

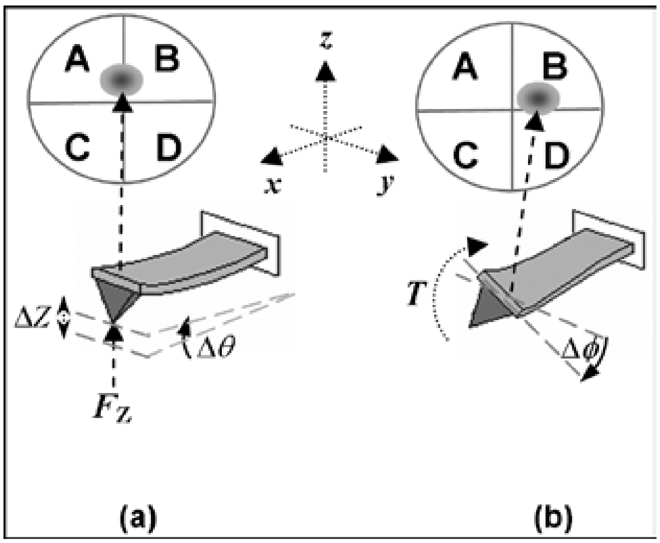

Figure 1: Normal (a) and torsional (b) deflection of an AFM cantilever.

Summary of Research:

Atomic force microscopy (AFM) is widely used today to image surfaces and measure nanoscale forces. The most widespread form of AFM relies on a laser beam reflecting off the back of a cantilever onto a position sensitive detector (PSD) in order to provide feedback on interaction of the cantilever tip with the surface of interest. The two most common deflections measured during surface interaction in contact mode AFM are normal and torsional, as depicted in Figure 1 (a) and (b), respectively. To accurately convert the observed AFM cantilever deflections to normal force and lateral force (e.g., friction) using contact mode AFM requires both accurate cantilever spring constant (stiffness) calibration for both normal and torsional cantilever deformations, as well as the determination of the normal and lateral sensitivities of the optical lever. Calibration of the normal spring constant and normal optical lever sensitivity is relatively straightforward using the reference cantilever technique and suitable SI traceable cantilever artifacts [1]. Calibration of the torsional spring constant and torsional optical lever sensitivity, needed for lateral force measurement, is more difficult.

One of the most elementary methods of applying a known torsion to a cantilever involves fixing a lever perpendicular to the long axis of the cantilever and applying a force to the end of the lever arm as in the technique of Feiler et al. [2]. More recently, a refined version of this technique was demonstrated by Reitsma [3] in which a cross piece was glued to a cantilever forming a double lever arm. Applications of a series of forces at different lever arm distances on both sides of the cantilever were performed and the data fitted to more precisely determine the torsional optical lever sensitivity (by a factor of 5 over Feiler). Both of these techniques, while simple in concept were quite cumbersome in actual execution, since a small mechanical lever must be carefully glued to the end of the microcantilever.

More recently, a new "Hammerhead" cantilever has been designed that incorporates the cross piece into a monolithic microfabricated cantilever beam (Figure 2a). The basic design of the handle die (Figure 2b) allows the device to be easily utilized in a commercial AFM. The entire device can be removed from the wafer by scribing it at the legs joining it to the wafer and snapping

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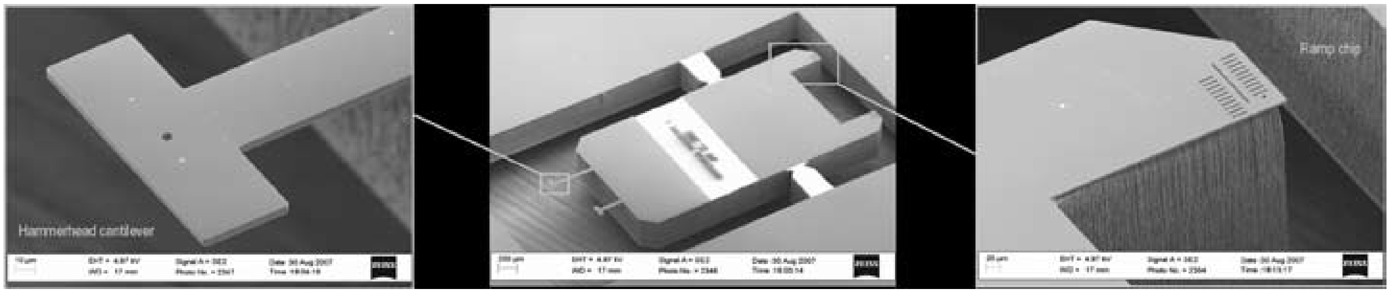

Figure 2: Microfabricated "Hammerhead" cantilever prototype.

it out with tweezers. A cutout (Figure 2c) at the back end of the chip is used in conjunction with the Hammerhead portion on a different chip to perform the calibration. Two cantilevers with different normal and torsional spring constants extend over the front edge of the handle die as seen on the left portion of the middle image. The spacing of the cantilevers and the widths of the cutout legs are dimensioned so that the unused cantilever straddles the cutout leg when the other one is being calibrated. This allows calibration of either "Hammerhead" cantilever without damaging surface contact for the unused one.

A cantilever is calibrated by lining up the wing of the cantilever on a fiducial mark on the cutout leg of a second chip as shown in Figure 3. Pressing down on this edge produces a lateral deflection as well as a normal deflection signal on the PSD.

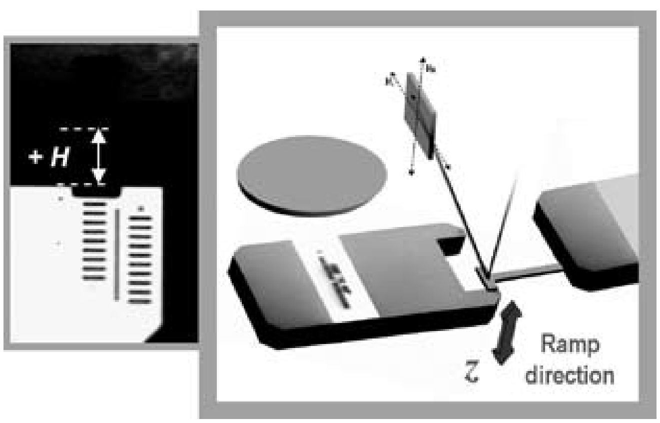

Figure 3: Procedure for determination of lateral optical sensitivity of the "Hammerhead" cantilever.

A series of these measurements taken at different torsional lever arm lengths (H) and using both sides of the Hammerhead then defines the torsional optical lever sensitivity in a precise way. An example of the data series, shown in Figure 4, actually plots the ratio of the lateral versus normal PSD voltage signals (V) against the torsion lever arm length (H), normal spring constant (k_z) and normal optical lever sensitivity (SN). A line of best fit is then used to extract the torsional optical sensitivity from the slope.

The Hammerhead device was patterned on silicon-on-insulator (SOI) wafers using optical lithography and etched using deep reactive ion etching (DRIE). Back side alignment was used to match the handle chip to the front side pattern. Final release of the structure was accomplished with buffered oxide etch (HF).

The microfabricated prototypes are currently being evaluated for their ability to measure the torsional optical lever sensitivity precisely using refinements in the new calibration method. Torsional spring constants, measured using a calibrated instrumented indenter, will also be compared to Euler-Bernoulli theoretical models based on dimensional measurements and material properties for these experimental cantilevers to evaluate the accuracy of the devices.

References:

[1] R.Gates, and J.Pratt, "Prototype cantilevers for SI-traceable nanonewton force calibration," Meas. Sci. Technol. 17 No 10 2852-2860 (2006).

[2] Feiler, A., Attard, P., Larson, I., "Calibration of the torsional spring constant and the lateral photodiode response of frictional force microscopes," Rev. Sci. Instrum. 71(7):2746-2750. (2000)

[3] Reitsma, M., "Lateral force microscope calibration using a modified AFM cantilever," Rev. Sci. Instrum. 78, 106102 (2007).

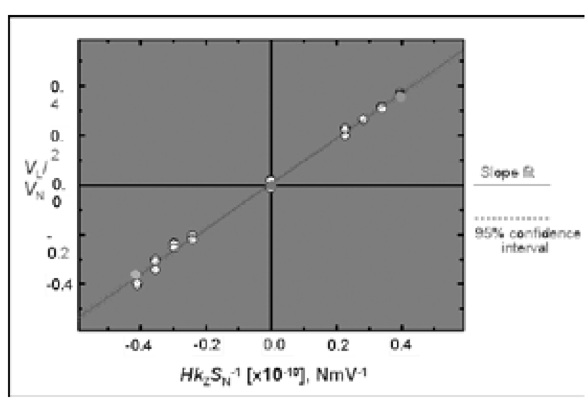

Figure 4: Plot of the lateral optical sensitivity pf the "Hammerhead" cantilever.