Prototype Reference Cantilevers for AFM Spring Constant Calibration

CNF Project # 1273-04
Principal Investigator & User: Richard S. Gates, PhD

Atomic Force Microscopy Introduction:

Atomic force microscopy (AFM) is widely used today to image surfaces and measure nanoscale forces. To accurately convert the measured AFM cantilever deflection to force, however, requires accurate cantilever spring constant (stiffness) calibration. Large variations in cantilever stiffness can occur even within a processing batch of cantilevers and without calibration, force conversion based on manufacturers nominal specifications can induce unacceptable errors. An accurate AFM test cantilever calibration method is sorely needed.

Reference Cantilever Calibration Method:

There are several methods for calibrating AFM cantilevers but they are usually limited in scope to specific cantilever types or spring constants. The absolute accuracy of the methods is unknown since none of them are currently traceable to the Système International d'Unité (SI). One of the most widely applicable methods (reference cantilever method [1,2]) relies on pushing the unknown cantilever against a cantilever of known stiffness and measuring the deflection. If the stiffness of the unknown cantilever is reasonably close (within a factor of 10) to the stiffness of the reference cantilever, the spring constant of the unknown cantilever can be calculated. Commercial reference cantilevers are available with nominal spring constant values but their accuracy is unknown since they cannot be traced to the SI.

Standard Reference Cantilever Prototype:

The objective of this project is to investigate the feasibility of creating very accurate reference cantilevers that could be used to calibrate the spring constants of AFM cantilevers. This requires very uniform cantilevers that could be calibrated using an SI-traceable technique using statistical sampling. The key to cantilever uniformity lies in careful dimensional control during microfabrication. Since the spring constant (*k*) of an ideal, uniform, rectangular cantilever can be described by an Euler-Bernoulli model [3] (equation 1) that depends on elastic modulus (E) and width (b) to the first power but the cube of the thickness (t) and length (L), it is especially important to control these last two characteristics.

$$k = \frac{Ebt^3}{4L^3}$$

equation 1

$$f_{vac} = 0.1615\frac{t}{L^2}\sqrt{\frac{E}{\rho}}$$

equation 2

The microfabrication processes included the use of silicon-on-insulator (SOI) wafers in which the device layer thickness is very uniform. Anisotropic back side wet etching was used to define the die on which the reference cantilevers were patterned. E-beam lithography was used to pattern the cantilevers and served two purposes: 1) very high dimensional accuracy when properly calibrated; and 2) careful pattern alignment of the cantilever onto the die by imaging the leading edge of the die through the membrane formed in the back side etching step. Since the cantilever resonant frequency (equation 2) depends on the same key parameters of thickness and length as the spring constant (just to different powers), resonant frequency was used as a measure of uniformity of the cantilevers from different parts of a wafer. The standard deviation of the mean resonant frequency for 22 cantilever arrays was less than 1.0 % suggesting excellent uniformity control. The spring constants of cantilevers made by this process were also measured using a special apparatus designed and fabricated at NIST to provide SI traceable force calibration at the nN scale [4] with a precision of 2 % for a stiffness as low as 26 pN/nm. The results confirm the feasibility of microfabricating SI-traceable reference cantilevers that could be made available to the AFM community.

References:

[1] "A method for detemining the spring constant of cantilevers for atomic force microscopy," A Torii, M. Sasaki, K. Hane, and S. Okuma, Meas. Sci. Technol., 7, 179 (1996).

[2] "Characterization of application specific probes for SPM's," M. Tortonese and M. Kirk, SPIE, 3009, 53 (1997).

[3] S. P. Timoshenko and J. N. Goodier, Theory of elasticity, Third ed. (McGraw Hill, Tokyo, Japan, 1983).

[4] "Progress toward Système International d'Unités traceable force metrology for nanomechanics," J. R. Pratt, D. T. Smith, D. B. Newell, J. A. Kramar, and E. Whitenton, J. Mater. Res., 19, 1, 366 (2004).

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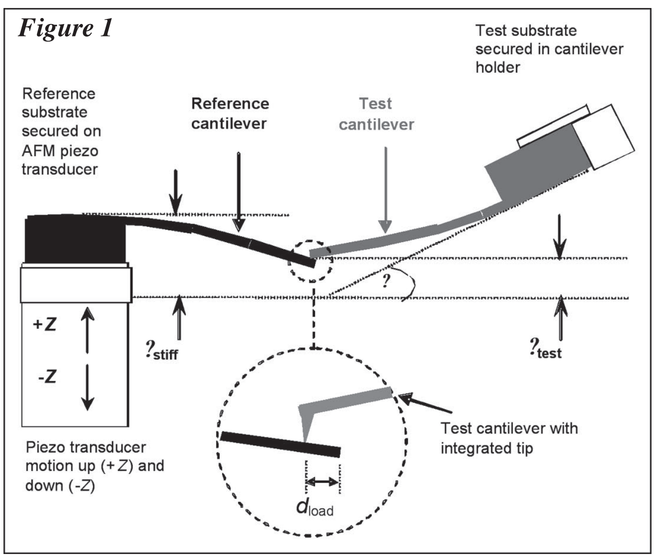
- Reference cantilevers of known stiffness can be used to calibrate spring constants of AFM cantilevers.
- Uniform rectangular cantilevers are patterned onto SOI wafers using e-beam lithography.
- Deep reactive ion etching (DRIE) is used to etch the exposed pattern.
- Stiffness of the released cantilevers is validated using an electrostatic force balance, constructed at NIST, capable of nN sensitivity and traceable to the SI.

Figure 1



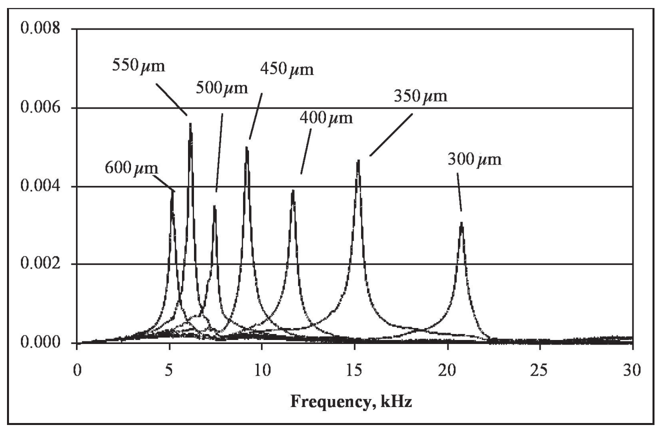


Figure 3

Figure 2

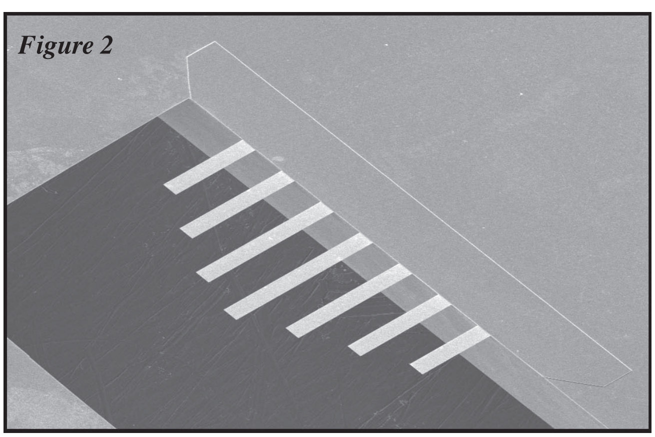


Figure 1, top left: Schematic side view of cantilever deflections for pushing a test AFM cantilever against a reference cantilever.

Figure 2, bottom left: An initial prototype of reference cantilevers patterned on SOI by e-beam lithography. The cantilevers are 1.4 µm thick and 50 µm wide. The lengths range from 300 µm to 600 µm.

Figure 3, above: Resonant frequency measurement of the prototype cantilevers.