Reference Cantilevers for AFM Spring Constant Calibration

CNF Project # 1273-04

Principal Investigator(s): Richard S. Gates, Ph.D.

Atomic Force Microscopy Introduction:

Atomic force microscopy (AFM) is widely used today to image surfaces and measure nanoscale forces. To accurately convert the AFM cantilever deflection to force, however, requires accurate spring constant calibration. Large variations in cantilever stiffness can occur even within a processing batch of cantilevers and without calibration, force conversion based on manufacturer's nominal specifications can induce unacceptable errors. A reliable, accurate calibration method and associated artifact that can enable cantilever calibration 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. There is also no International System of Units (SI) traceability in these methods. 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 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. The key to accuracy relies on careful dimensional control. Since the spring constant (k) of an ideal, uniform, rectangular cantilever 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.

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

The microfabrication processes used included the use of silicon-on-insulator (SOI) wafers in which the device layer uniformity can provide very uniform cantilever thickness. Back side etching using either anisotropic etching or Bosch 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. The spring constants of cantilevers made by this process are being measured using a special apparatus designed and fabricated at NIST to provide SI traceable force calibration at the nanonewton scale [3]. We are also participating in an international round robin of National Metrology Laboratories from Germany, Japan, UK and the USA through the Versailles Advanced Materials and Standards (VAMAS) organization to determine the best methods and procedures for calibrating the normal spring constants of AFM cantilevers.

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] "Progress toward Système International d'Unitès 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 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 nanonewton sensitivity & traceable to SI.**

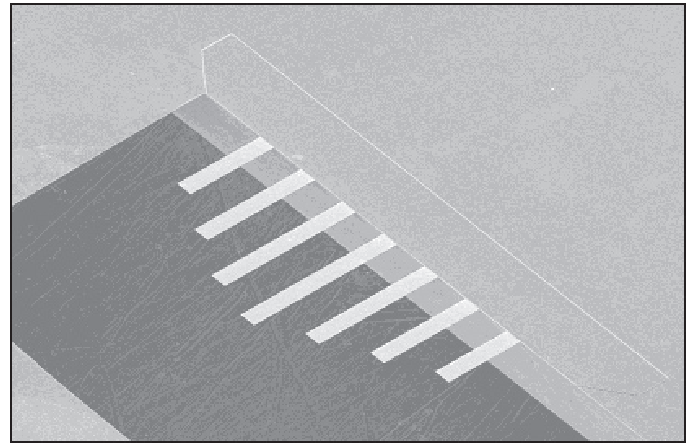

Figure 2: An initial prototype of reference cantilevers patterned on SOI by e-beam lithography. The cantilevers are 1.4 µm thick & 50 µm wide. The lengths range from 300 µm to 600 µm.

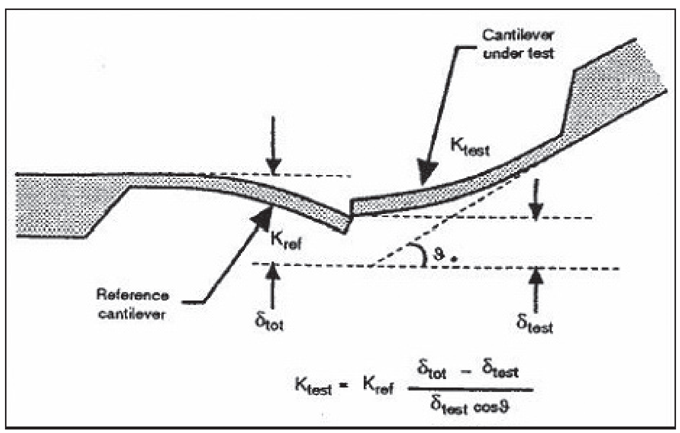

Figure 1: Side view of cantilever deflection schematic for pushing a test AFM cantilever against a reference cantilever. From reference [1].

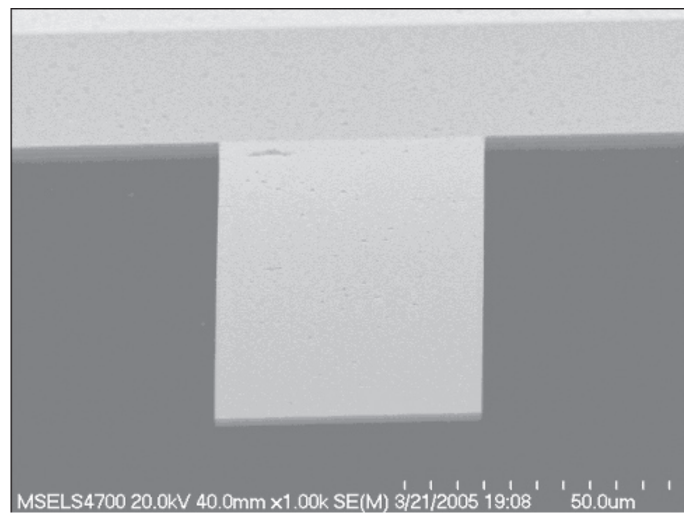

Figure 3: End on view of one of the 1.4 µm thick rectangular cross-section cantilevers.