Method for Measurement of an AFM Cantilever Spring Constant

This Application Note describes a method by which Xidex’s NanoBot® nanomanipulator can be used to calibrate the spring constant of an atomic force microscope (AFM) cantilever by deflecting the AFM tip with a calibrated force sensor module mounted as an end effector. The method as described here uses a NanoBot system installed in a scanning electron microscope (SEM). However, the method can also be applied in air using a high resolution optical microscope. Spring constants determined by the method apply directly to situations where static deflection is of primary importance. These involve contact mode and colloidal probe AFM measurements, and other measurements involving interfacial forces or bonding forces between atoms or molecules. Descriptions of the NanoBot system and the available force sensor attachments can be downloaded from the Products section of Xidex’s web site (www.xidex.com). This Application Note is also the subject of a YouTube video, which can be accessed from the Applications section of the web site.

The NanoBot nanopositioner, which has low drift of < 1 nm/min, is able to hold the AFM cantilever stationary in its fully deflected position while the corresponding static force is displayed and recorded by a LabVIEW™ software application provided with the product. The measured force is divided by cantilever deflection, recorded from the SEM image, to determine the spring constant. The accuracy of the measurement is limited by small nonlinearity of the force sensor calibration curve, which typically ranges from 3-4% for the force sensor modules provided for use with the NanoBot system. Higher measurement accuracy could be obtained, if needed, by taking advantage of the user-programmability of the fully LabVIEW-based NanoBot system to replace the linear calibration constant of the force sensor with a quadratic or higher power fit to raw sensor calibration data.

NanoBot System with Force Sensor Attachment

Figure 1 shows a NanoBot Model NX-1000 outfitted with a force sensor attachment. The force sensor can also be mounted on one of the two nanopositioners provided with the NanoBot Model NX-2000.
The force sensor operates as a load cell for measuring forces with nanoNewton resolution. The Model FS-2000 force sensor accommodates loads up to 2000 µN. The Model FS-180 accommodates loads up to 180 µN. Both compression and tension forces can be measured. The sensor element, which is based on single crystalline silicon, measures small forces with high precision. Unlike other load cells based on strain gages, the force sensors available for use with the NanoBot system measure the load by a change of capacitance. The readout electronics integrated in the sensor package convert the load into an output voltage proportional to the force. A LabVIEW™ based application for force feedback display is installed on a laptop computer running Windows OS which is provided with the system. Users can also create custom LabVIEW applications and add these to the applications library provided with the NanoBot system.

Setup for Spring Constant Measurement

Figure 2 shows the setup for measuring the spring constant. The chip to which the AFM cantilever is attached is mounted on a fixture attached to an SEM stage. The Cantilever is a Budget Sensors model Tap 300 G (www.budgetsensors.com) for which the spring constant has a nominal specified value of 40 N/m and is specified to lie in the range 20-75 N/m. The fine motion mode of the NanoBot system is used to bring the 50 x 50 micron square end of the Si force sensor probe near, but not quite touching the AFM tip. Figure 3 is an expanded view showing the end of the force sensor probe and the AFM tip in their initial positions, for which there is no cantilever deflection.

Cantilever Deflection

The LabVIEW application for displaying and recording the force measured by the sensor is started with an on screen command, or by using the joystick trigger. This starts a real time recording of force vs. time. With the LabVIEW Action running, the NanoBot nanopositioner is commanded to move the stage carrying the force sensor module so as to deflect the AFM cantilever from its initial position (Figures 2 & 3) to a new position, as shown in Figure 4, at which point the motion stops and the static force remains constant. Figure 5 is an expanded view showing the force sensor probe and AFM tip with the cantilever at maximum deflection.
Figure 6 shows the force vs. time history displayed by the LabVIEW application provided for use with the force sensor module. The measured force increases from zero to a maximum value $F_{\text{MAX}} = 197.38 \, \mu\text{N}$.

Calibration data for the individual force sensor, like that shown in Figure 7, determines a linear calibration constant $C_{\text{FS}}$, in Volts/µN, for the individual module. A calibration constant determined this way has been entered into the LabVIEW Action prior to conducting the experiment.

### Spring Constant Determination

The maximum cantilever deflection, $D_{\text{MAX}}$, is determined by importing the captured video frames used to create Figures 3 and 5 into Adobe Photoshop, finding the deflection in units of pixels, and then converting to µm using the pixel count associated with the scale bar provided with the SEM image. The result of this exercise is $D_{\text{MAX}} = 10.9 \, \mu\text{m}$. The spring constant, $k$, is then determined as

$$k = \frac{F_{\text{MAX}}}{D_{\text{MAX}}} = 18.1 \, \text{N/m}$$

This measured spring constant is just below the 20-75 N/m range specified by the AFM tip manufacturer.

Large deviations from the nominal spring constants provided by AFM tip manufacturers are not unusual. For example, a study [1] involving multiple laboratories and different methods for spring constant determination showed similar large deviations of measured spring constants from manufacturers’ specifications. Inspection the reference cantilevers used in the study revealed chipping damage on the edge of the handle chip and debris particles on surfaces of the test cantilevers. The inference is that these two are related and chipping damage produced during handling of the test chips generated the debris particles.

Users of a NanoBot system equipped with a force sensor can measure the spring constant of an AFM cantilever intended for use in an application that requires accurate knowledge of its spring constant in a few minutes using the method described here. If no
SEM is available, the same technique can be used in air with a high resolution optical microscope equipped with digital image capture. Unlike alternative methods for determining the spring constants of AFM cantilevers [refs 2 to 5], there is no need to measure the resonant frequency of the cantilever, add test masses, perform finite element analysis, or make detailed measurements of cantilever geometry.

References


Xidex Corporation

Xidex manufactures and sells the NanoBot® system, an easy-to-use, highly versatile, user-programmable nanomanipulator built for use inside scanning electron microscopes (SEMs) and focused ion beam (FIB) tools. The NanoBot transforms a SEM or FIB into a workshop for nanodevice fabrication and testing.

Xidex Corporation was founded in 1997 as an Austin-based Texas Corporation by Vladimir Mancevski, President and Chief Technology Officer and Dr. Paul F. McClure, CEO.

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