Measuring Absolute Piezoelectric Displacement with an AFM

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Research into applications of the piezoelectric properties of thin ferroelectric and piezoelectric films is growing exponentially while at the same time the characterization of these same properties remains expensive or difficult or both. One technique for characterizing thin piezoelectric film displacement is performed using an Atomic Force Microscope by placing the AFM cantilever tip in contact with the sample surface while exciting the piezoelectric capacitor at a resonant frequency for the cantilever. The technique, called Piezo Response Force Microscopy (PFM), takes advantage of the fact that the vibration amplitude of the cantilever as seen by the laser reflected from the cantilever top surface will be larger than the displacement of the sample surface by the quality factor "Q" of the cantilever. This amplification by the Q factor makes it possible to image small piezoelectric movements of the capacitor surface. The stimulus frequency is typically 100 kHz or higher to match the resonant frequency of the cantilever. This frequency is far too fast to fully actuate the sample through a saturated hysteresis loop so PFM is relegated to be a small-signal measurement. Use of the PFM technique for researching thin piezoelectric films has greatly expanded our understanding of these films, especially with respect to domain geometries and dynamics. However, the PFM technique suffers from an inability to measure absolute displacement of the sample surface during actuation. This difficulty arises from two physical limitations: 1) the Q factor of the cantilever is not known with precision so its amplification factor is not know with precision and 2) resonant overtones excited in the cantilever cause the amplitude and phase of the measured signal to depend upon the precise location of the laser reflection point on the top surface of the cantilever. Classic AFM measurements suffer from the same limitation. The AFM is most precise in non-contact vibration mode but the uncertainty of the cantilever Q leads directly into uncertainty of the measured value of absolute displacement.

The limiting factors associated with resonant cantilevers disappear when the cantilever is in direct contact with the sample surface and is not vibrating. Piezoelectric actuation of the sample while monitoring the movement of the laser reflection from the cantilever in non-vibration mode, i.e. DC mode, eliminates the errors introduce by the uncertainty of the cantilever Q factor or the effects of resonant overtones. Displacement measurements captured in DC contact mode will directly correlate the measured voltage from the laser sensor with the actual displacement of the sample surface. One issue arises: what is the scale factor to convert the sensor voltage to surface displacement? While it is possible to calculate, that value using the Force-Distance curve characterized for that cantilever, the F-D results must be back propagated through the mathematical translation algorithms of the AFM to arrive at the scale factor to apply to the laser sensor output voltages. This is a difficult calculation even for the engineers that designed the AFM and will differ between AFM models.

The authors have developed a technique to calibrate the output of the AFM laser sensor against a known-good physical sample for DC contact mode displacement measurements. The technique is executed by an X:Y surface scan in contact mode of a calibrated step reference while capturing the output of the laser sensor of the AFM. The known-depth of the pits in the step reference can be used to properly scale the voltage output of the laser sensor to Ångstrom resolution. Feedback control to the piezoelectric chuck of the AFM through the PID filter must be turned down or completely off during the scan so the chuck does not move during the scan. The authors will describe how such a calibration is set up and executed on a Radiant Precision Nano Displacement System PNDS. The PNDS is optimized for this type of absolute displacement measurement but the technique is applicable to any AFM model.