A Calibration Technique for Thin Piezoelectric Film Displacement Measurements captured with an AFM

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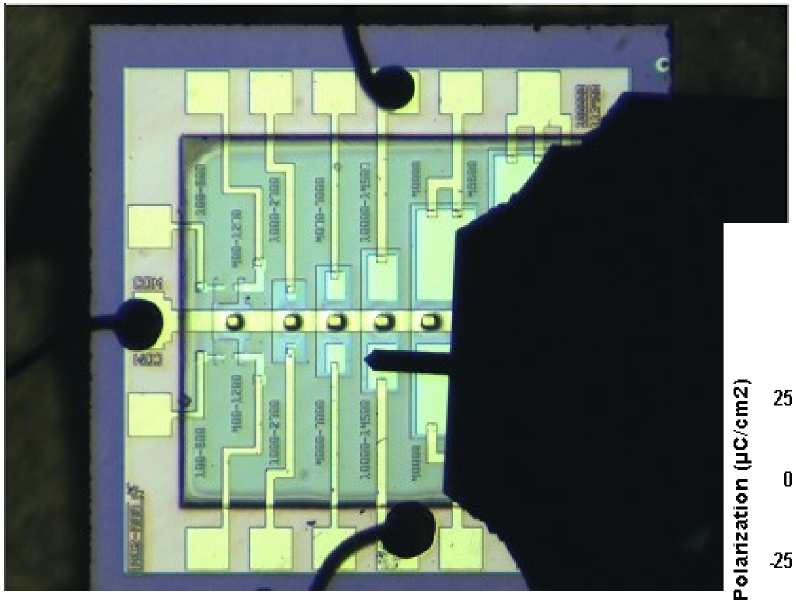
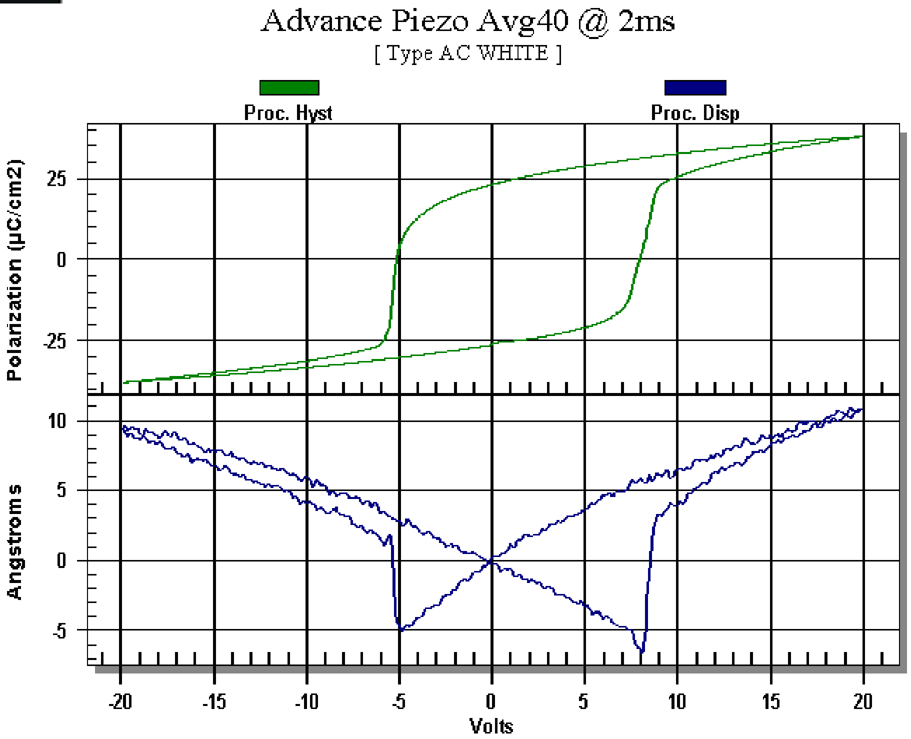
Summary

- The Atomic Force Microscope is one of the few instruments with the sensitivity to measure the surface displacement of thin piezoelectric or ferroelectric thin films during voltage actuation.
- The scale factor for converting displacement of the AFM cantilever into voltage to be captured by a tester is not fixed and must be calibrated before each use.
- A method for quickly determining an accurate scale factor is proposed.

Piston Displacement

The vertical displacement of the top surface of the capacitor with voltage application: converse d_{33}.





Because the capacitor is clamped by the substrate, we can assume that a single-sided measurement is accurate if the capacitor area is small compared to the substrate thickness.

Contents

i. How to capture Ångstrom-level displacements with an AFM.

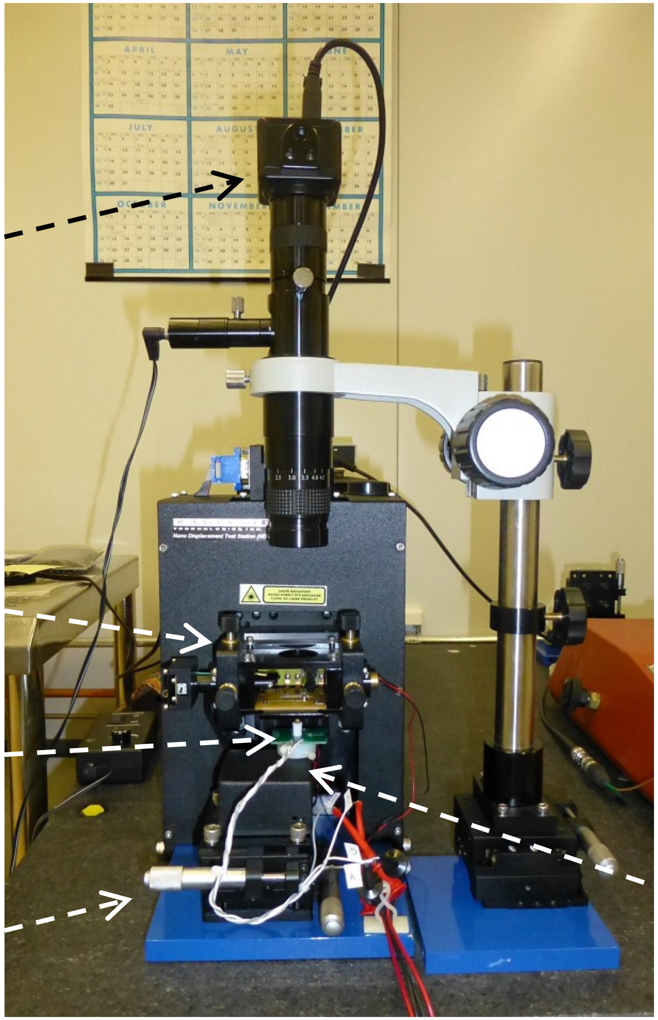
ii. How the displacement scale factor converts the AFM output into a voltage proportional to displacement.

iii. How the traditional calibration procedure for AFM cantilever tip displacement is performed.

iv. An improved calibration procedure for the scale factor for cantilever tip displacement.

System Architecture

Below is the Radiant PNDS. All AFMs use the same basic components:



Digital microscope camera

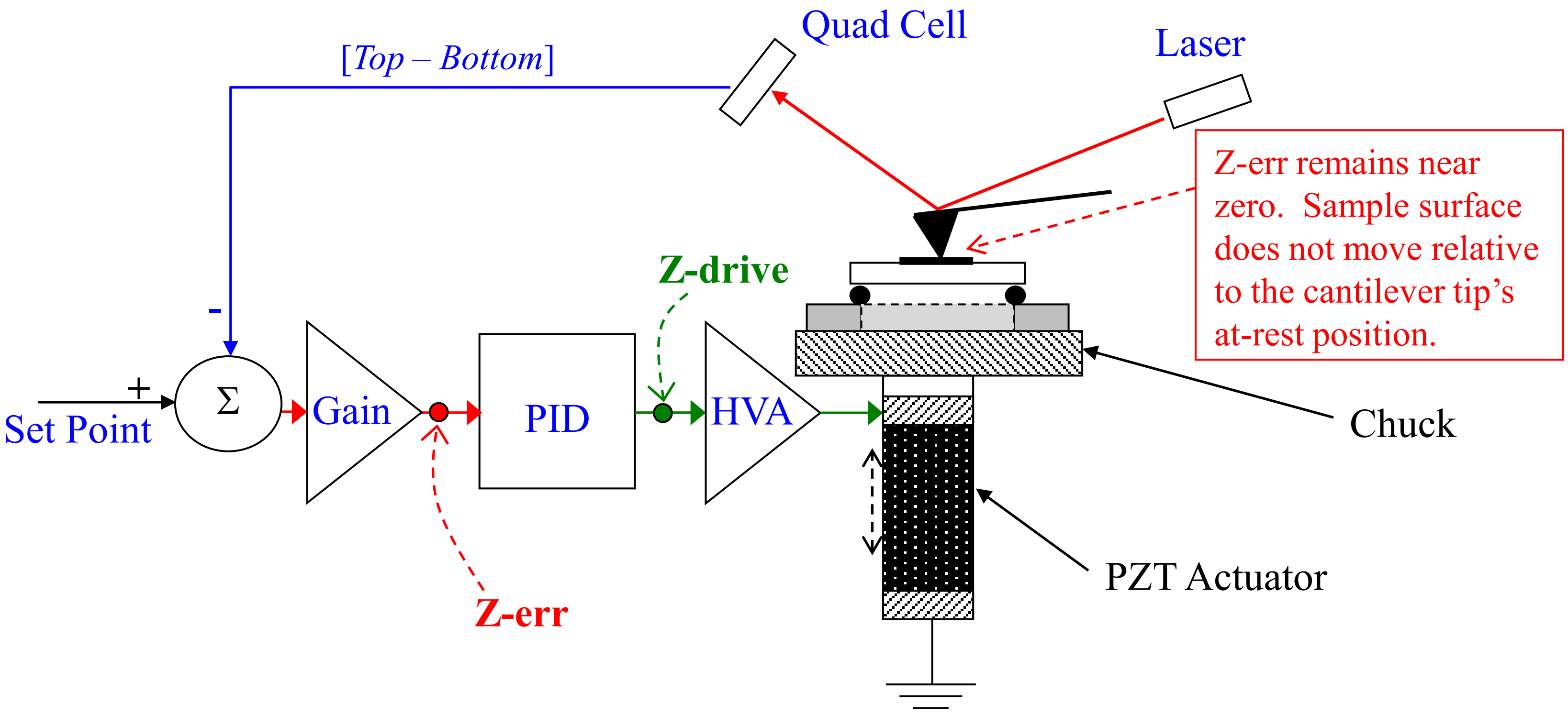
Light lever

Sample holder

Sample positioning

Z-piezo element

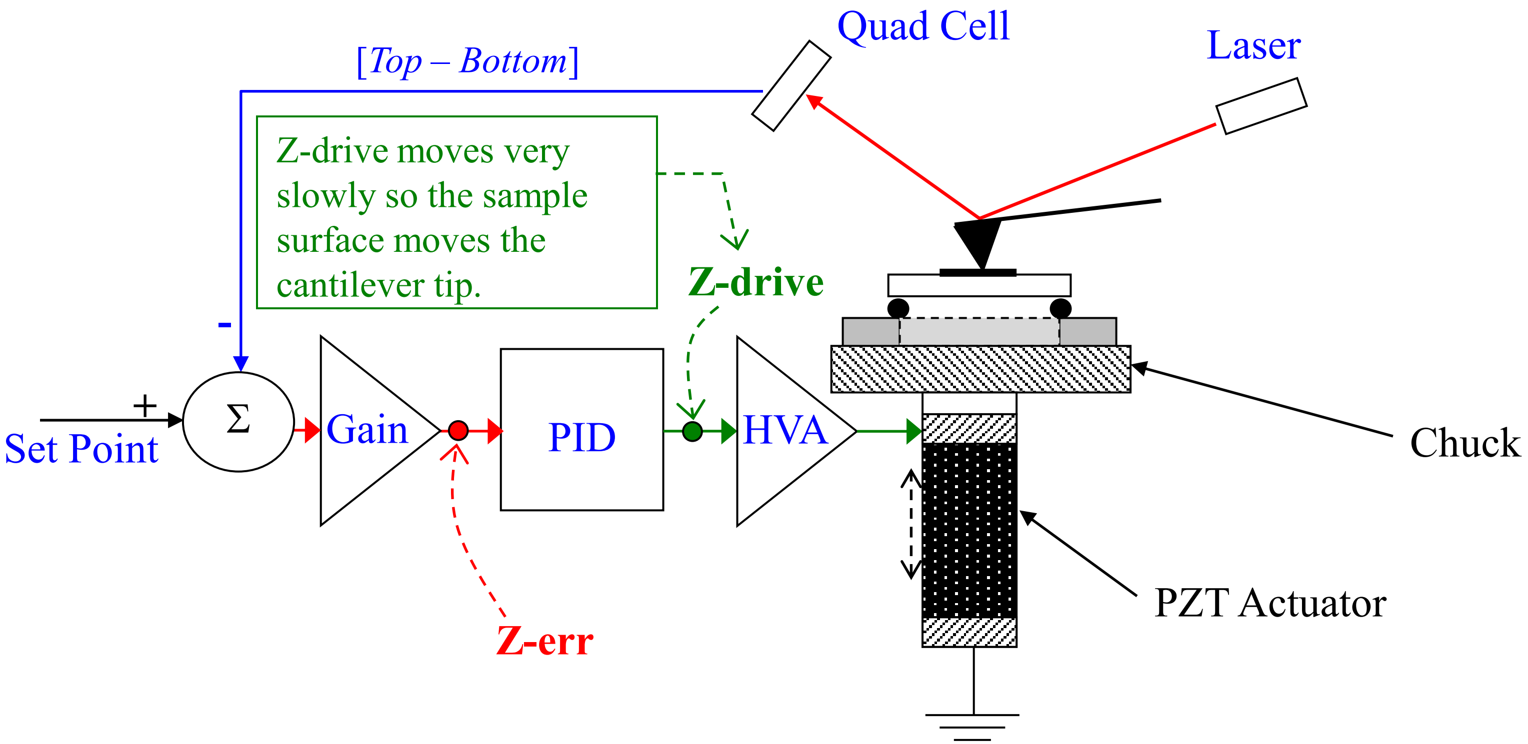
Normal System Operation



Z-err remains near zero. Sample surface does not move relative to the cantilever tip's at-rest position.

If the sample surface moves during normal AFM operation, the laser spot reflecting from the cantilever tip moves on the quad cell face, creating a non-zero Z-err. Z-err is filtered by the PID and fed back to the AFM piezoelectric actuator to move ***the entire sample*** in the ***opposite*** direction to make Z-err equal zero again → *The tip remains fixed in space.*

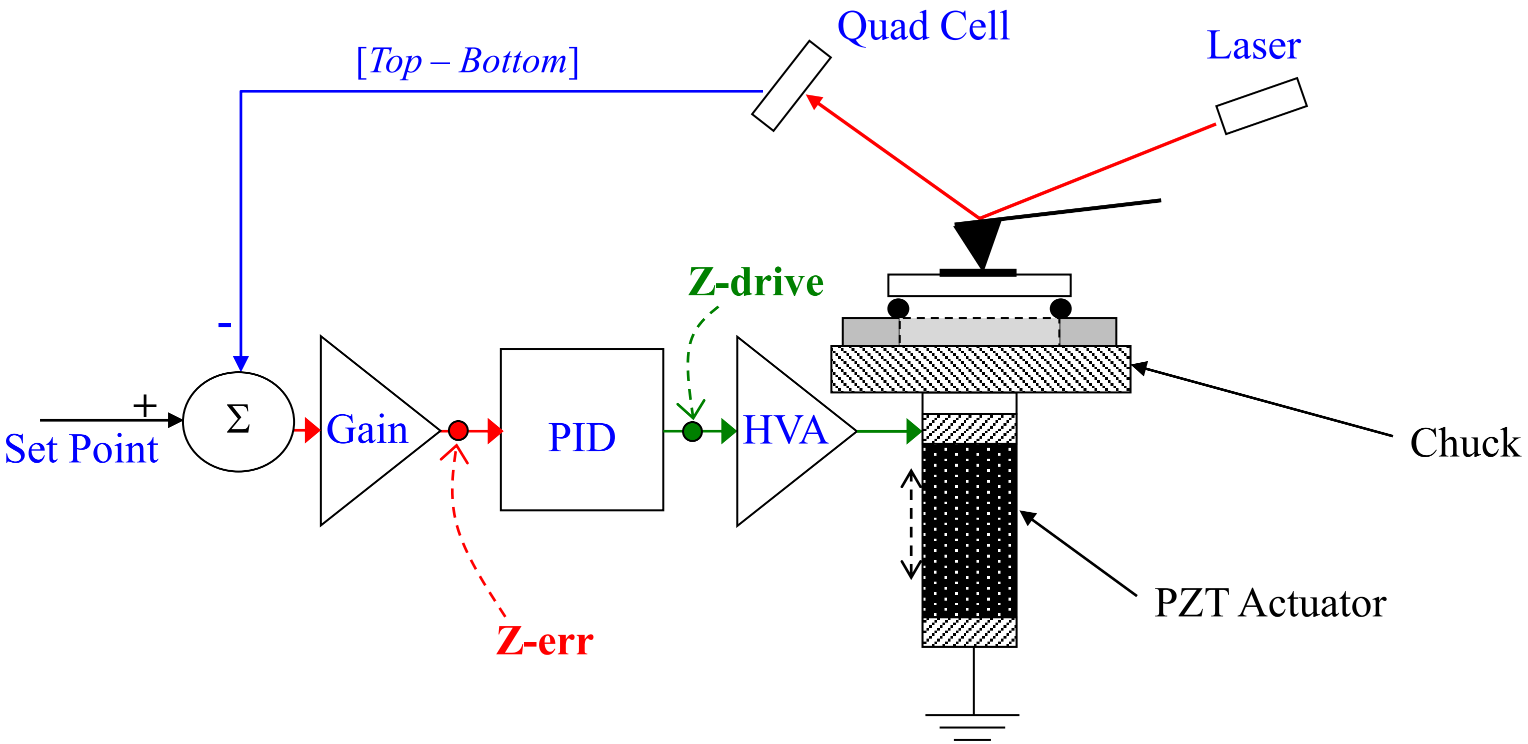
Small Displacement Operation



If the PID coefficients are set very small, the AFM piezoelectric actuator is frozen so the sample chuck does not move during a hysteresis loop. The AFM cantilever tip will move up and down with the sample surface.

Z-err will be the motion of the sample surface!

Small Displacement Operation



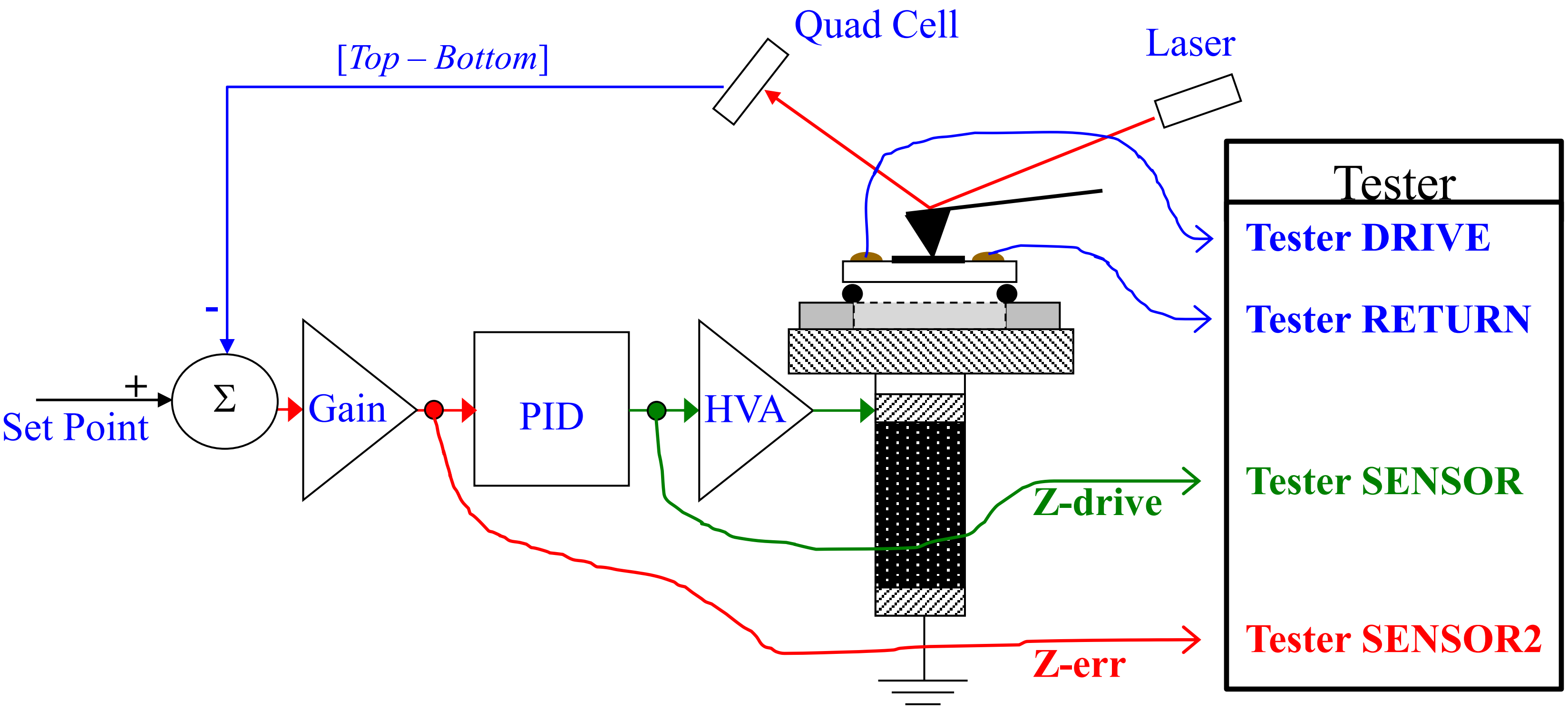
To measure the thin film capacitor butterfly loop:

a. Freeze the AFM chuck in place with ***small PID coefficients***.

b. Capture the AFM cantilever tip motion (Z-err) **as it moves with the sample surface**.

c. Return the PID to its normal mode to allow the chuck to center.

Tester-AFM Configuration

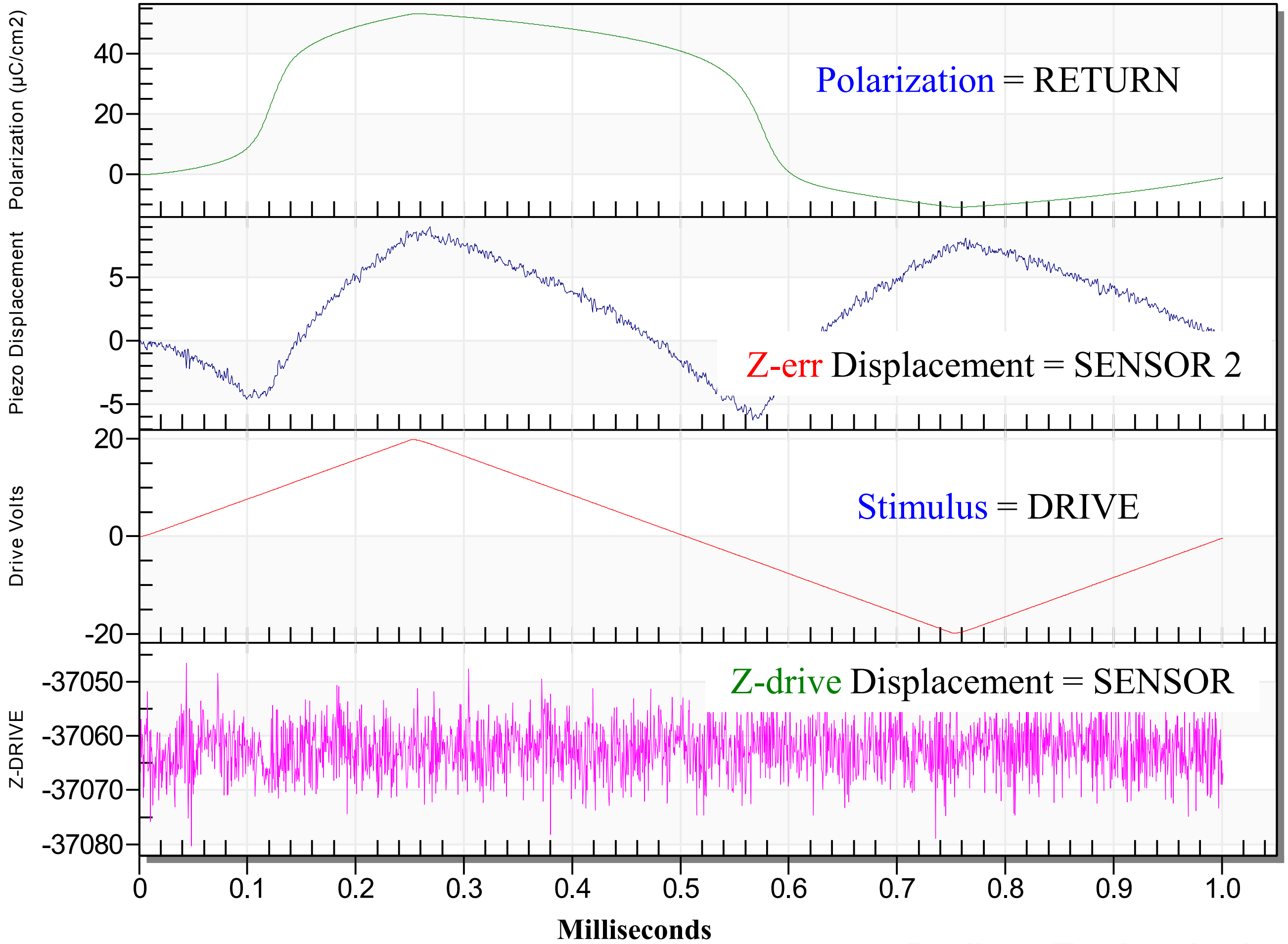


For any AFM operation, there must be four signals connected to a tester.

1. Capacitor stimulus
2. Capacitor current or charge measurement
3. The AFM Z-drive signal from the piezoelectric chuck
4. The AFM Z-err signal from the laser photo-sensor.

4-Channel Result

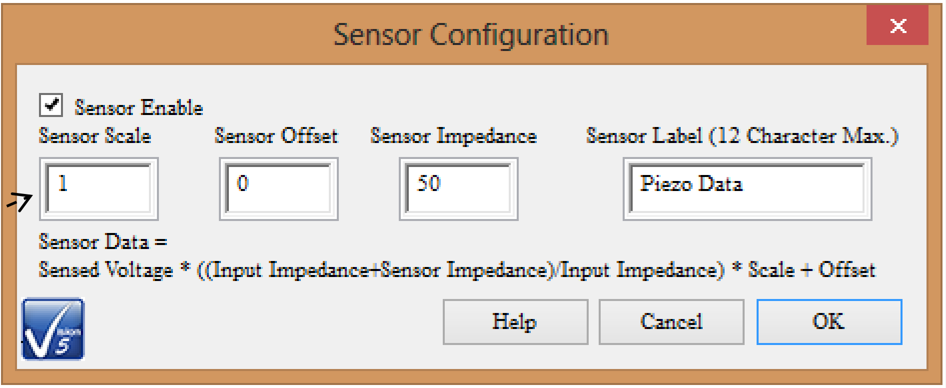
A plot of all four channels from a classic thin film butterfly loop. In this case, Z-err contains the signal so Z-drive should not move.



Sensor Scaling

- During any polarization measurement, the Z-err signal from the AFM should be captured synchronously with the hysteresis loop.

- That signal must be multiplied by a scale factor to convert it from volts to units of displacement.



Sensor Configuration

☑ Sensor Enable

Sensor Scale: 1

Sensor Offset: 0

Sensor Impedance: 50

Sensor Label (12 Character Max.): Piezo Data

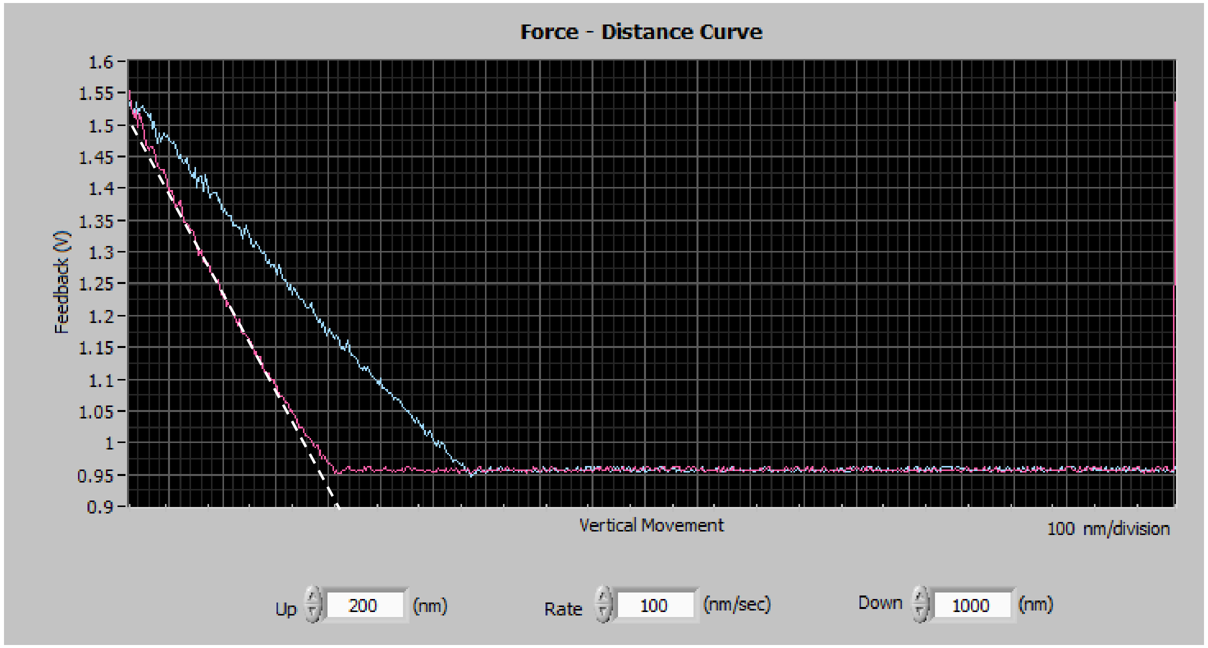
Sensor Data =
Sensed Voltage * ((Input Impedance+Sensor Impedance)/Input Impedance) * Scale + Offset

- ***Calibrating an AFM means executing the measurement against a known-good vertical step to determine the Sensor scale factor Z-err.***

Original Z-err Calibration

The traditional method of calibrating the Z-err channel is to execute a Force-Distance Curve to measure slope and then perform mathematics to derive the scale factor.

- The Force-Distance result shows the change in photosensor voltage as a function of vertical cantilever displacement when pushed by the AFM piezoactuator.



Up 200 (nm)

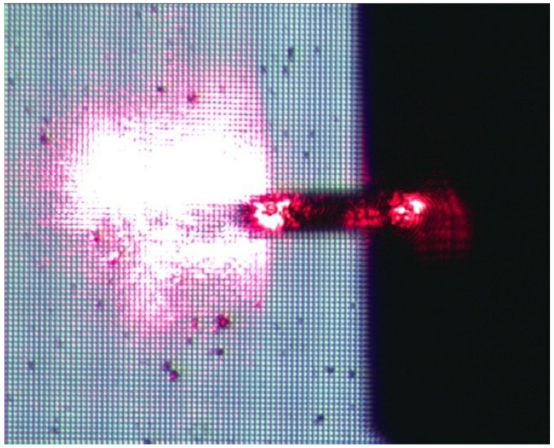
Rate 100 (nm/sec)

Down 1000 (nm)

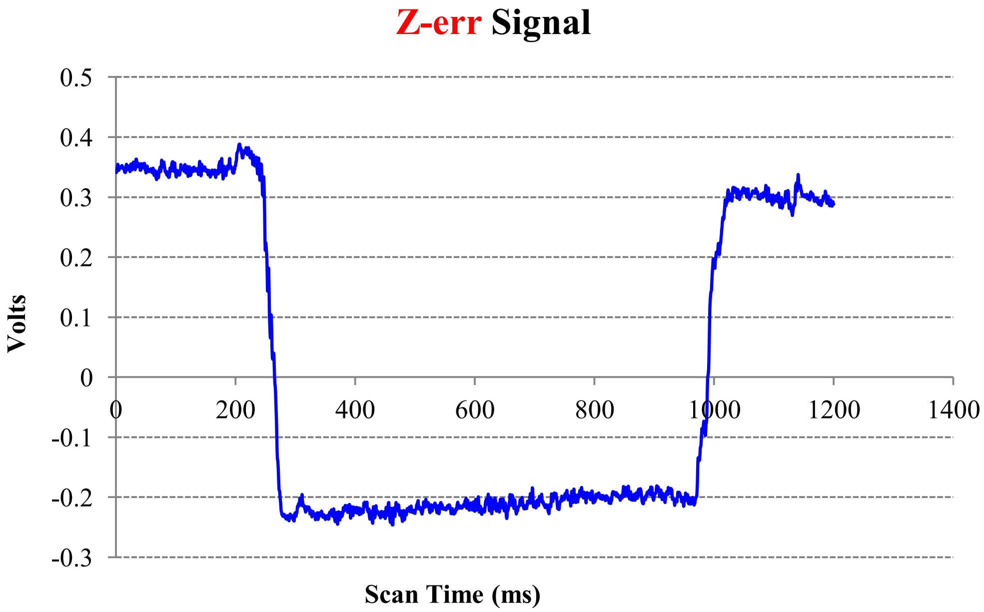
This calibration procedure depends on how well known is the displacement of the piezoelectric chuck. That error creates more error.

Proposed Z-err Calibration

Execute a surface scan of a known-good step reference while capturing Z-err.

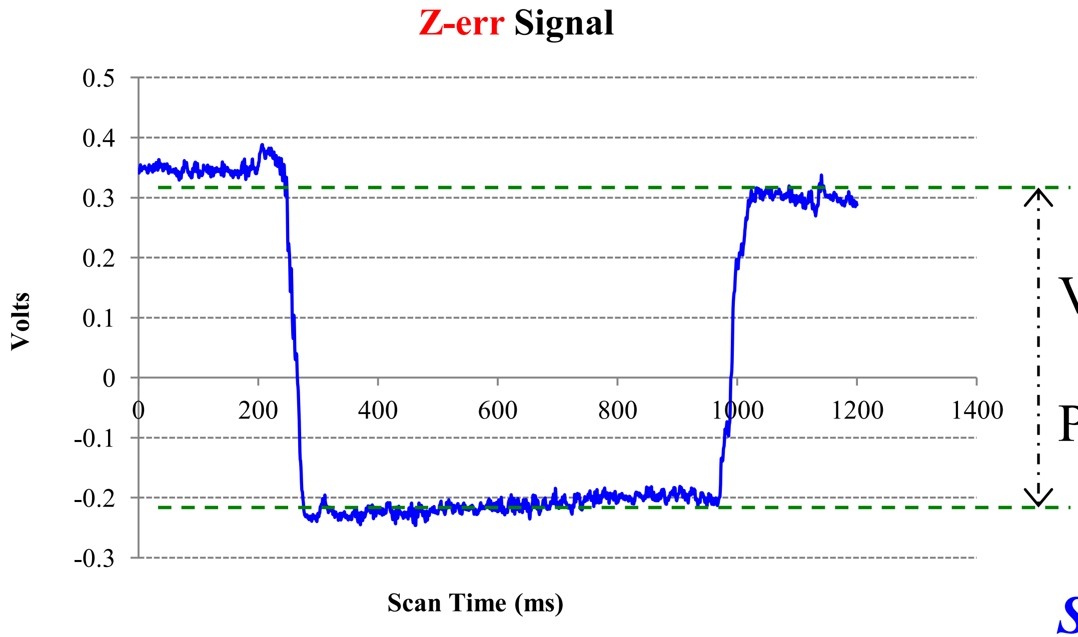


App Nano SHS-0.1-3 1000Å Reference Grid



Z-err Scale Calculation

Calculate an accurate Z-err scale factor from the Z-err signal captured while the cantilever traverses a calibrated pit.



Vstep = 0.54V

Pit Depth = 1040Å

Scale Factor = 1,926Å/V

This calculation is good only for that cantilever in that mounting condition. If the same cantilever is remounted or a new cantilever is substituted, the calibration must be executed again.

Conclusion

- It is now possible to execute accurate Ångstrom-level butterfly loop measurements of thin piezoelectric or ferroelectric films using an AFM by calibrating the AFM Z-err signal against a known-good step reference.
- The procedure requires setting the AFM PID so the piezoelectric chuck does not move and then capturing the Z-err signal from the AFM photosensor during a surface scan of a calibrated step reference.
- This procedure is a direct calibration of the AFM cantilever against a known standard and should produce more accurate results than using the Force-Distance curves.
- A similar procedure can be used to calibrate Z-drive, the AFM piezoelectric chuck.