Ångstrom-Level Piezoelectric Measurement

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Summary

• Motivation
• Equipment Architecture
• Calibration
• Piston Displacement
• MEMs Measurement
• Future Objectives

All of the test samples shown below were fabricated by Radiant.
Why Measure Ångstroms?

• Thin ferroelectric and piezoelectric films have great potential to impact the future economy.
  ➢ More sensitive sensors
  ➢ Tiny machines
  ➢ Autonomous memory

• Radiant already offers advanced piezoelectric tasks to interface existing AFMs, vibrometers, and other displacement meters with our testers.

• After years of looking, we have now found an affordable instrument to measure absolute Ångstroms.
Measurement Techniques

• Atomic Force Microscope

Displacement - Averaged
[Smoothed and Z-corrected]

Nanometers
Volts

Piston motion of capacitor surface.

• Laser Vibrometer

Displacement - Averaged
[Smoothed and Z-corrected]

Asylum SA

Polytec OFV534/OFV5000
Noise is Ever Present

- Averaged and Smoothed

Even on an exceptionally quiet commercial AFM, noise is significant.

- Original Data
Goal

• Find a method to
  
  ➢ *Inexpensively measure ferroelectric and piezoelectric displacement loops of thin films.*
  
  ➢ *Create a system that the average university lab could afford.*
  
  ➢ *Guarantee a level of absolute displacement accuracy.*
System Architecture

Digital microscope camera

Light lever

Sample holder

Z-piezo element

Manual sample positioning
• For Ångstrom-level displacements, the PNDS looks directly at the Error Function. *The test is run faster than the GPID can respond.*

• For MEMs-level displacements, the PNDS looks at the Control Signal. *The test is run slowly so the GPID can respond.*
Custom Sample Holders

Because the system is inexpensive, we can safely experiment with different mounting techniques for different samples.
We are interested in putting the cantilever in one spot in contact mode. A small in-contact surface scan capability allows small features to be found and targeted.
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 assume that a single-sided measurement is reasonably accurate.
The Polytec laser vibrometer has an absolute distance reference in the wavelength of its laser light. Amplitudes of the PNDS measurements when properly calibrated compare well with the laser vibrometer.

1µm-thick 4/20/80 PNZT with platinum electrodes – 1kHz.
Calibration

Step #1: Do a surface scan of a calibrated reference sample to calibrate the piezo Z-element.

Step #2: Execute a FORCE-DISTANCE curve pushing on the cantilever with the now calibrated piezo Z-element to calibrate the photo-sensor.
Noise Reduction

The measurements are noisy at such small displacements. Noise reduction procedure:

- Make multiple measurements
- Move each loop to the origin
- Remove “tilt” in the loop due to Z-drift
- Average all of the loops.
- Smooth the averaged loop.
Noise Filtering

Raw data vs filtered loop.

Advance Piezo Avg40 @ 2ms Before Recovery
[ Type AC WHITE ]

Volts

50
40
30
20
10
0
-10
-20
-30
-40

5
10
15
20

-5
-10
-15
-20
-25
-30
-35
-40

Advance Piezo Avg40 @ 2ms

Angstroms

10.0
7.5
5.0
2.5
0.0
-2.5
-5.0

-20 -15 -10 -5 0 5 10 15 20

Volts

Raw Disp 1
Raw Disp 2
Raw Disp 3
Raw Disp 4
Raw Disp 5
Raw Disp 6
Raw Disp 7
Raw Disp 8
Raw Disp 9
Raw Disp 10
Raw Disp 11
Raw Disp 12
Raw Disp 13
Raw Disp 14
MEMs Cantilever Measurement

1.2mm
Cantilever Motion

PNDS cantilever capturing butterfly motion of resonator edge.

Average of ten 1-second loops.
Complex Cantilever Motion

By measuring at different parts of the resonator as it is flexed in pseudo-static piezoelectric motion, more complex behavior is revealed.
Complex Cantilever Motion

Construct of cantilever motion. Single-sided voltage application should make the cantilever bend upwards in a smooth curve. This cantilever does not.
Complex Cantilever Motion @ 110kHz

Because the structure *and* the support arms are so thin, the device has very complex mechanical motion.
e_{31} Measurement

• Radiant is going to pursue a possible $e_{31}$ measurement using the Kanno method.\textsuperscript{1}

• The technique derives $e_{31}$ from the displacement of the tip of a cantilever due to voltage application.

• Accuracy depends upon the cantilever acting “perfectly”.

• For this technique to work, the silicon substrate under the cantilever must be thick enough to force proper “arching” of the cantilever.

Repeatability

pMEMs-1201 RS1 on TO-18

AdvP -15V 1s -Monopolar: Polarization (µC/cm²): 1
AdvP 15V 1s +Monopolar: Polarization (µC/cm²): 1
AdvP 15V 1s Bipolar: Polarization (µC/cm²): 1
True AFMs and Vibrometers

• The PNDS is intended to be an inexpensive system for small materials programs.

• All of the measurement techniques described here work with more advanced commercial AFMs and with sensitive laser vibrometers.
Future Efforts

• Calibration procedures must be fully verified.
• Custom sample mounts must be completed.
• Documentation and operating procedures must be finished.
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