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Technical Report
Measuring the Piston Movement of 1μ 4/20/80 PNZT
Rev C

Date: January 3, 2010

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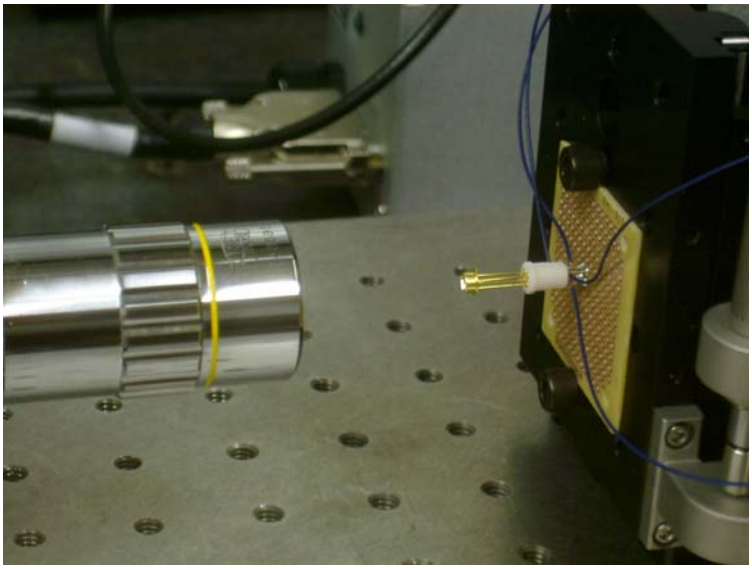
Discussion:
Polytec, Inc. loaned Radiant a sensitive laser vibrometer to test on Radiant's new Precision Displacement Test Stand. The Polytec Model OFV534 laser with the OFV5000 controller is sensitive enough that it can measure the piston movement of the top electrode of 1μ-thick PNZT capacitor on a silicon substrate. The measurements were executed using the Advanced PIEZO task in Vision. Advanced PIEZO was designed specifically to acquire displacement measurements at the Ångstrom scale within which the Polytec laser vibrometer or an Atomic Force Microscope (AFM) operate. For more information see the following reports:

"Application Note for Advanced PIEZO"
"Application Note for the Precision Displacement Test Stand"

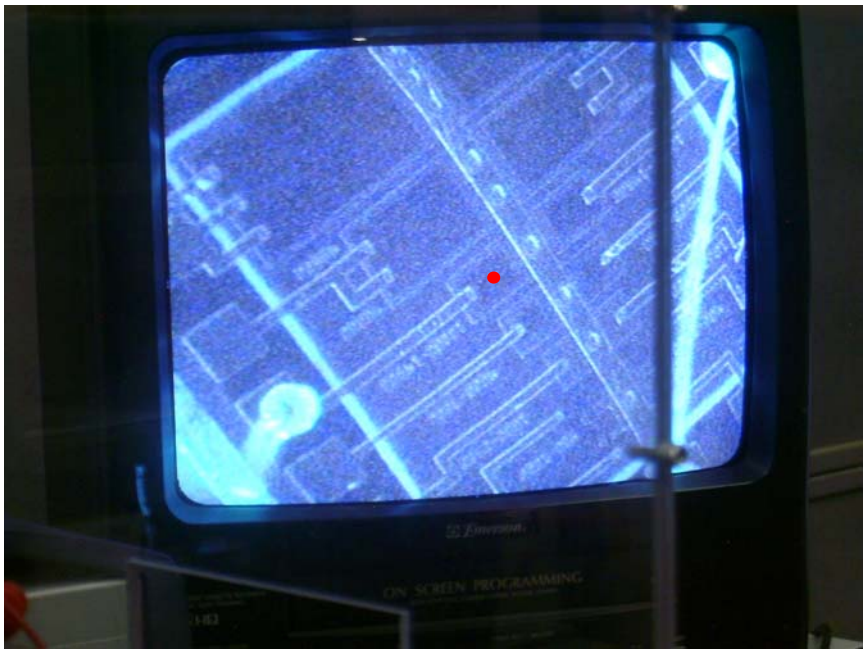
Both documents may be found at www.ferrodevices.com/displacement.html.

Sample Information:
The capacitor tested was a Type AC WHITE capacitor mounted on and bonded to a TO-18 header without a lid. The Type AC capacitors have 1μ 4/20/80 PNZT with platinum top and bottom electrodes. The WHITE capacitor has dimensions of 125μ by 80μ, giving it an area of 10,000μ^2. A capacitor this small cannot be seen with the naked eye. Fortunately, the Polytec OFV534 laser head has an internal camera looking along the optical measurement path. Using the image generated by the camera, the laser sensor spot was aligned to be in the geometric center of the capacitor. The silicon substrate on which the capacitor is fabricated is 550μ thick. Since the WHITE capacitor has dimensions less than the thickness of the substrate, the bending moment of the PNZT on the substrate should be significantly reduced, thereby reducing any error in determining the piezoelectric response of the thin PNZT film. For all practical purposes, the smaller the dimensions of the capacitor relative the substrate thickness, assuming that the film and the substrate are of roughly equal stiffness, the less chance that the measured piezoelectric displacement will be amplified by substrate bending. Figure 1 shows the Polytech Laser/Camera in position to measure the TO-18 packaged PNZT capacitor.



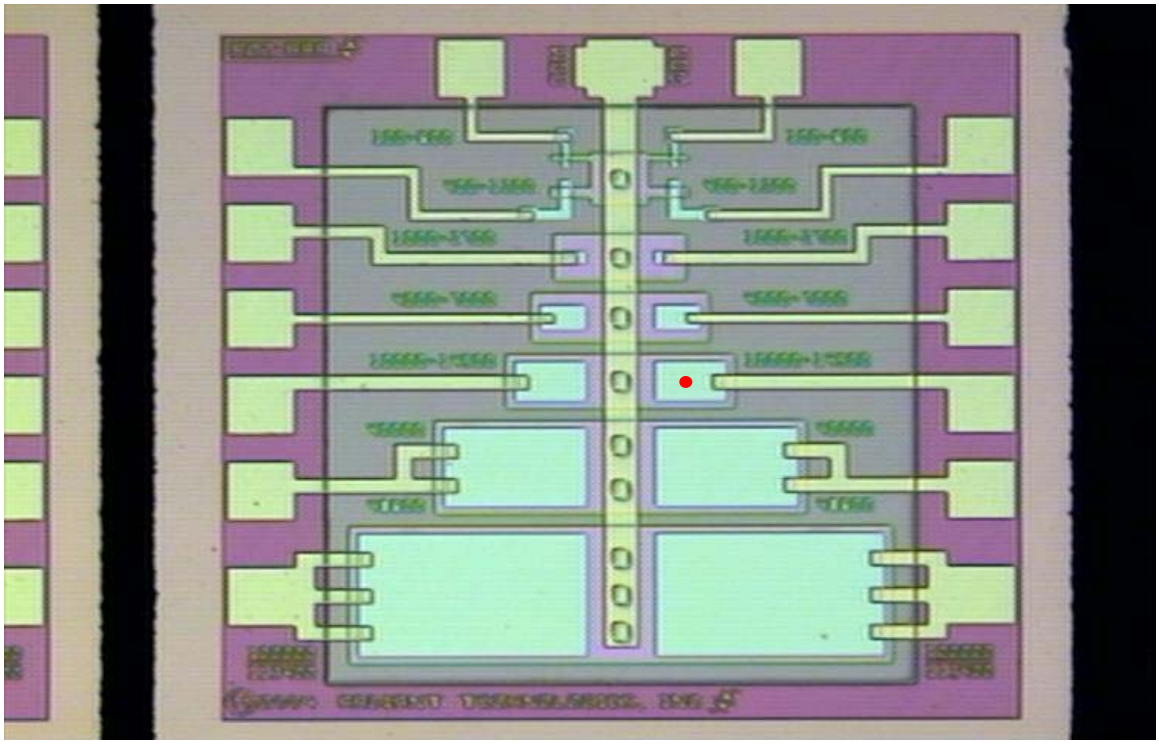
TO-18 Header with the Capacitor Die in Front of Polytec Laser Sensor Head
Figure 1

Figure 2 shows the camera image produced by the Polytec Laser/Camera.



Camera Image of the Capacitor to be Tested
Figure 2

The red dot in the image marks the measurement point. A photograph of a Type AC die is displayed in Figure 3 for reference.

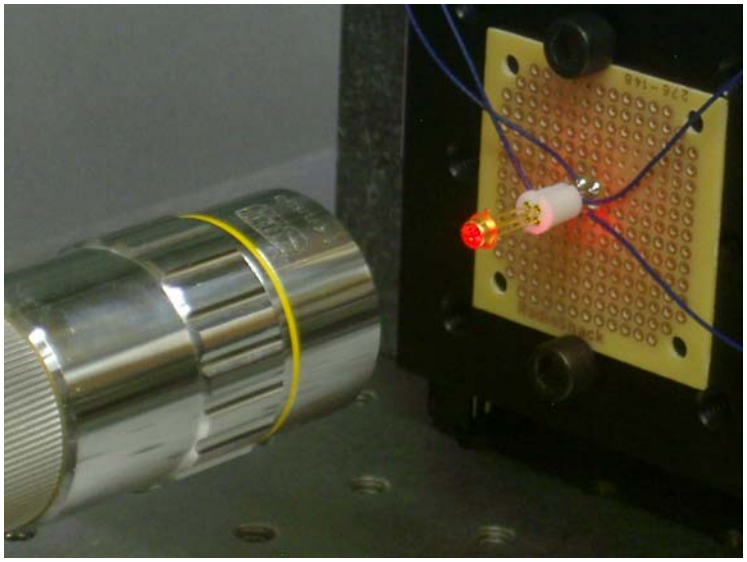


Photograph of a Type AC Die
Figure 3

To synchronize the output of the Polytech sensor with the data capture by the Radiant Premier II tester, the SYNC output of the tester was connected to the enable input of the Polytec OFV5000 controller.

Note that the laser vibrometer measures the velocity of the surface being tested. The velocity is then integrated into displacement either by an accessory to the vibrometer or by the tester itself. Since velocity is the measured quantity, the sensitivity of the measurement is determined by speed with which the surface moves. For cyclic hysteresis measurements, that speed is determined by the period of the stimulus signal. To reach Ångstrom resolution with the Polytec laser vibrometer, the test speed should be on the order of *kilohertz* or faster. The measurement in Figure 8 below was executed at 1 kHz.

Test Fixture Information:
The TO-18 header holding the test capacitor was itself soldered to an electronic perf board and small-gauge wires were soldered to the header pins. The perf board was then clamped to a translation stage mounted on the granite "Brick" of a Precision Displacement Test Stand (PDST). (See Figure 4) The Brick significantly dampened physical vibration of the mounted sample.



TO-18 Header Mounted on the PDST Brick
Figure 4

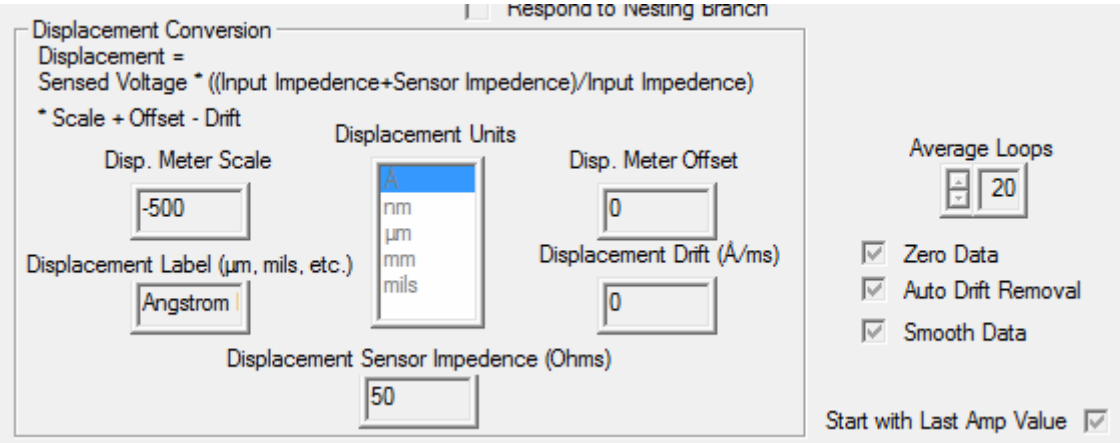
This form of mounting is informal but highly flexible and very quiet, making it possible to measure displacement on almost any thin ferroelectric film capacitor on any kind of substrate.

The Polytec vibrometer was mounted on the PDTS and the turbulence shield was placed over the stand as can be seen in Figure 5.

The Laser Vibrometer and Sample Mounted on the PDTS
Figure 5

The PDTS itself sat on the granite block liberated from what was originally an Ultratech stepper in the warehouse portion of Radiant's offices. For those without a handy granite block, a small vibration isolation table will suffice.

Test Settings:
The sensor settings on the first page of Advanced PIEZO as used for the measurements in this report are shown in Figure 6



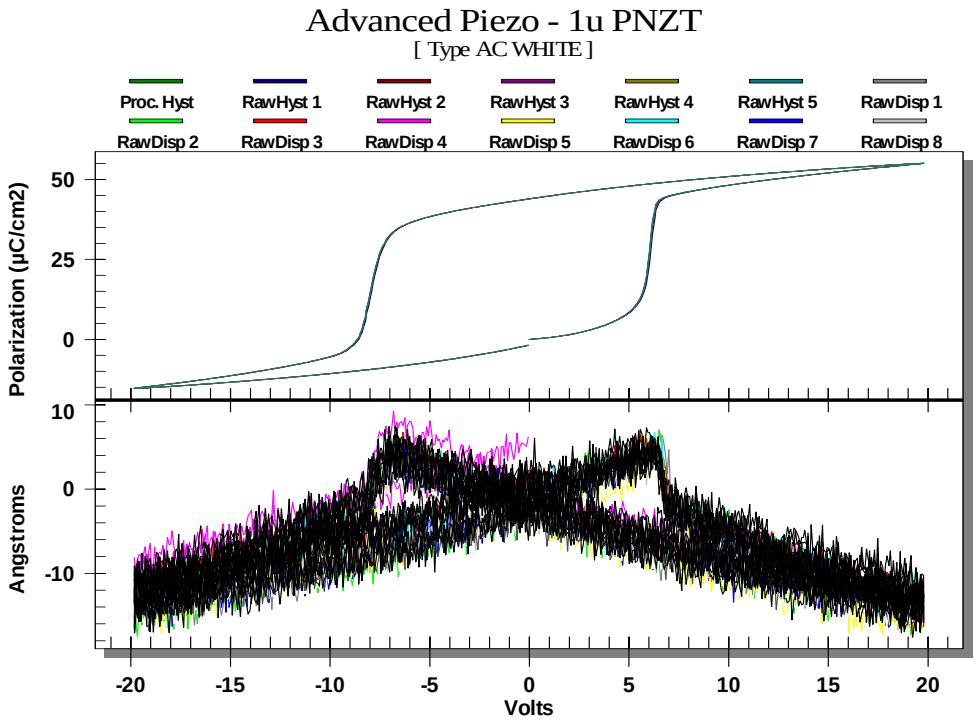
Advanced PIEZO Configuration for the Measurements in this Document
Figure 6

Note that Advanced PIEZO is set to zero the data, remove any Z-drift before averaging, and smooth the averaged data of high frequency noise.

The displacement scale for these measurements was set to -500 Ångstroms per volt coming from the Polytec sensor. With a negative polarity on the scale factor, the measurements plotted below have the orientation such that *down* along the negative Y-axis represents the direction *towards* the sensor and *away* from the substrate surface. To reverse the orientation in the plots, a positive scale value could have been used.

> Note: The polarity "+" or "-" of the scale factor flips the vertical direction of data captured in Advanced PIEZO or PIEZO. Every sensor made by different manufacturers has a different polarity requirement to achieve a specific orientation in the data plot. The user must determine how the polarity of the scale factor affects the plotted orientation of the data before taking data for analysis.

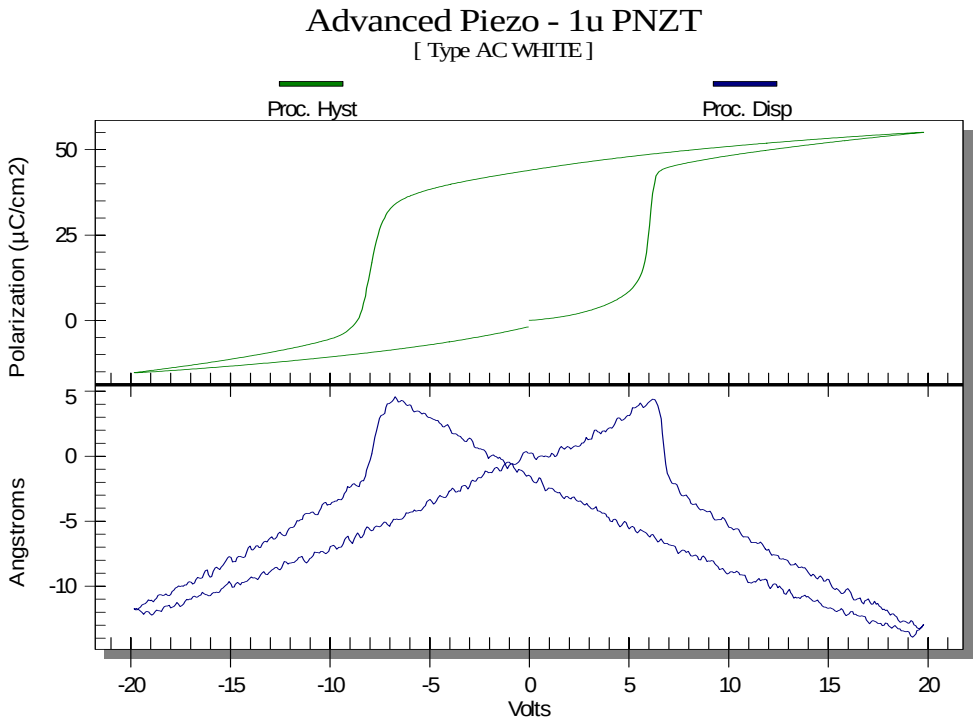
Results:
The twenty raw polarization and displacement loops measured by Advanced PIEZO on the 1µ PNZT capacitor surface are shown in Figure 7.



Twenty Raw Polarization and Displacement Loops from Advanced PIEZO
Figure 7

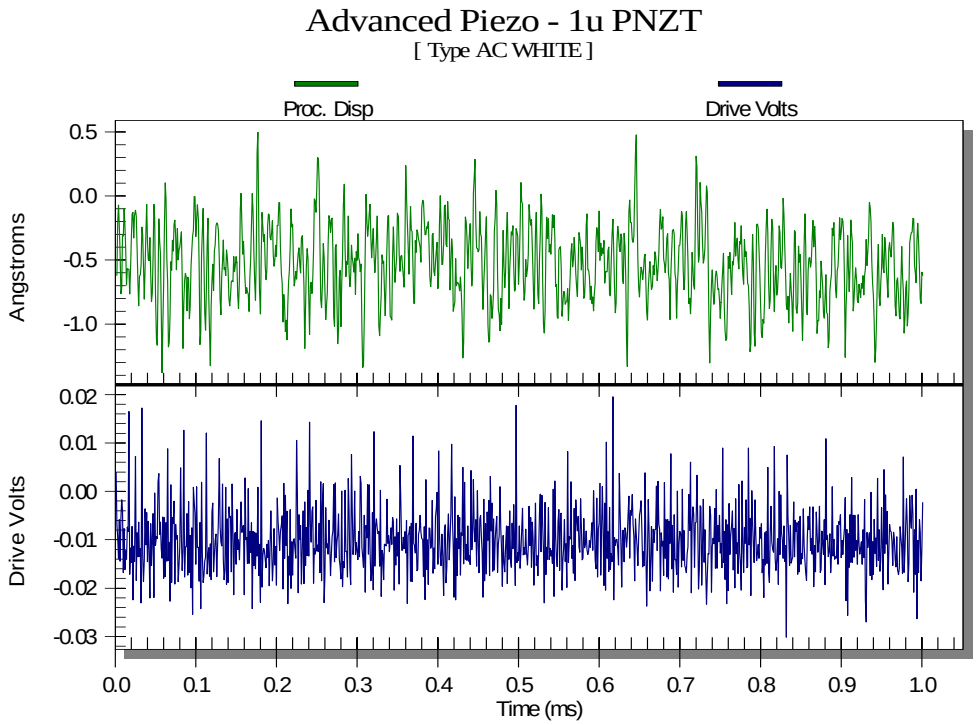
The displacement loops in Figure 7 have been zeroed vertically but are un-filtered and have not had Z-drift removed.

Figure 8 displays the polarization loop and the butterfly loop for the sample in Figure 4 after corrections by Advanced Piezo. The polarization loop in Figure 8 is the average of the twenty polarization measurements in the upper portion of Figure 7. The butterfly loop in Figure 8 is the average of the twenty zeroed loops shown in lower portion of Figure 7 after those butterfly loops have been de-sloped for Z-drift. The butterfly loop in Figure 8 was smoothed by Advanced Piezo after the averaging. (See Figure 6 for the Advanced Piezo Task settings.)

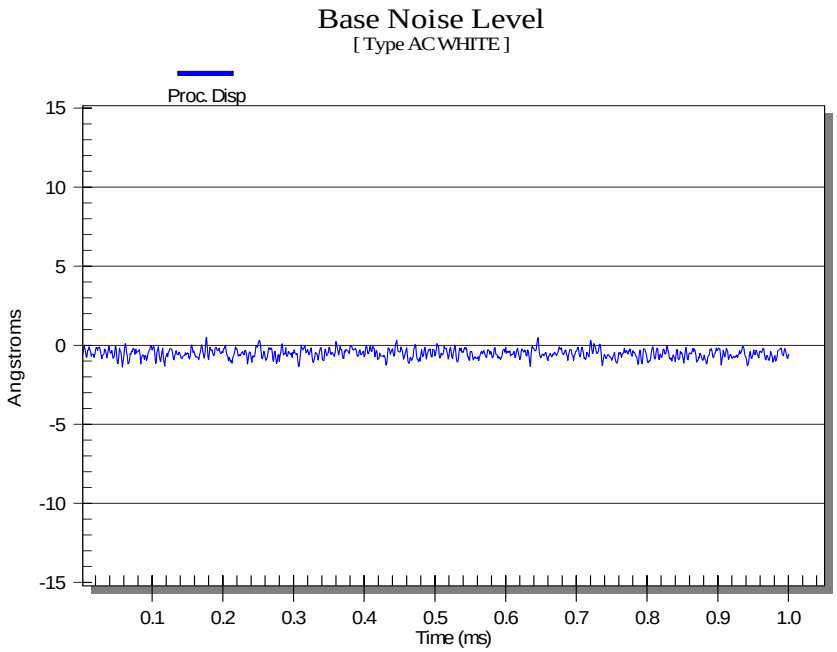


Corrected Output of Advanced PIEZO for the Measurements in Figure 7
Figure 8

To evaluate the sensitivity of the Polytec on the PDTS, a1000-point measurement was made with zero volts applied over 1 millisecond. The noise level for x20 averaging with this test fixture configuration was 0.5Å peak-to- peak as seen in Figure 9 and 10.



Drive Voltage and Displacement for Sensitivity Check
Figure 9



System Sensitivity Scaled against Piston Motion
Figure 10

The piezo constant measured in Figure 8 is 60pm/volt. This is consistent with the values measured in the past on Radiant 1μ PNZT.

Conclusion

The Polytec OFV534 Laser Vibrometer coupled to a Radiant tester is capable of producing high quality measurements of the piezoelectric piston motion of thin ferroelectric films using the Advanced PIEZO task and the Precision Displacement Test Stand.