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Technical Report
Performance of Polytec NLV Measuring Thin PZT Butterfly Loop
Rev A

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Introduction:
Radiant Technologies, Inc. now bundles Polytec's NLV Laser Doppler Vibrometer (LDV) with Radiant's Precision family of testers. The NLV has a bit resolution of 0.3 Ångstroms with a bandwidth of 2 MHz. Radiant's Precision LC II, Premier II, Multiferroic II, and pMEMS Analyzers all operate near the digital noise limit for their 18-bit Analog-to-Digital converters, allowing piezoelectric displacement measurements acquired through the NLV to reach a resolution of 0.2Å with averaging. Clean 20Å butterfly loops can be captured in a single pass.

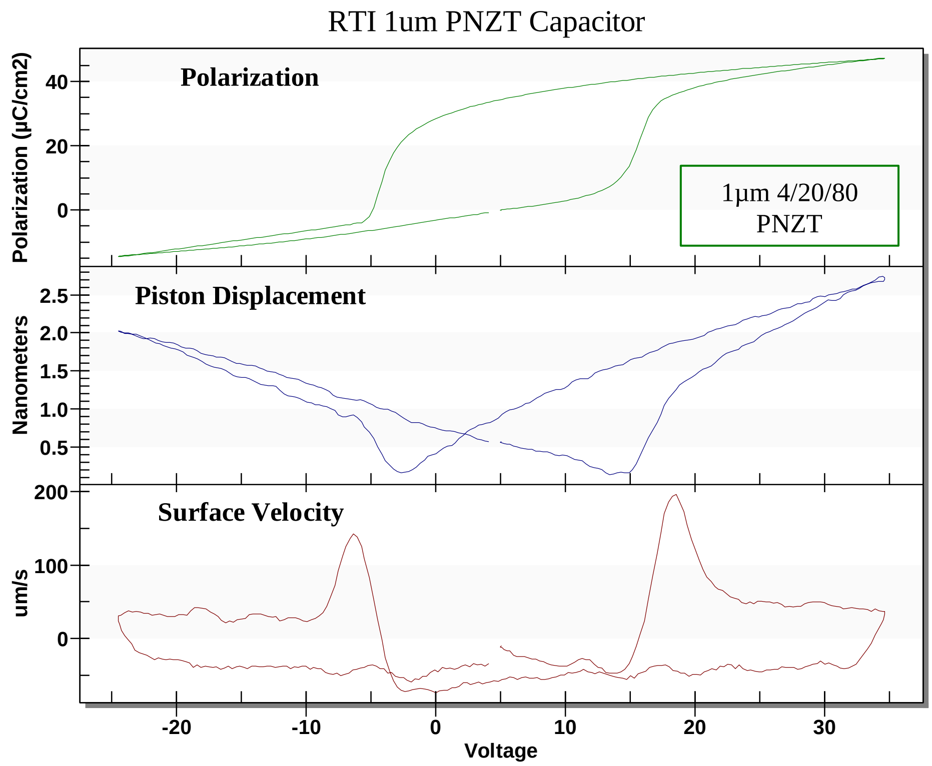

Fig. 1: Single pass (no averaging) simultaneous butterfly, velocity, and polarization loops

Test Configuration:
Radiant Non-linear Materials Analyzers precisely measure charge generated by any sample affected by such stimuli as pressure, temperature, or vibration. Most frequently, the stimulus is voltage applied to the sample by a 10MHz arbitrary waveform generator inside the tester. Polarization values down to a few femtocoulombs can be captured by the charge measurement circuitry. Each tester has two extra voltage measurement channels that are captured simultaneously point-per-point with the polarization measurement and the stimulus voltage. All four channels are synchronized to within 10 nanoseconds using an internal high-precision clock. The two voltage channels will capture displacement and velocity signals from the NLV as it measures the movement of a sample's surface during any test. That surface may be the arm of a MEMS structure or the top electrode of the capacitor itself.

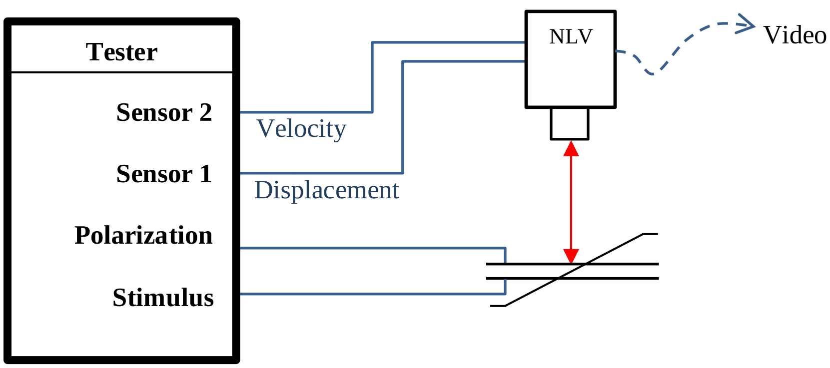

Fig. 2: Functional Diagram of an Ångstrom-level Piezoelectric Test Configuration

The spot diameter of the NLV is 20 microns using its standard optics. The working distance is approximately 8 inches or 20 centimeters. Microscope objectives can be inserted to increase magnification, reduce the spot size down to 2µm, and reduce the working distance to approximately 2 inches (5cm).

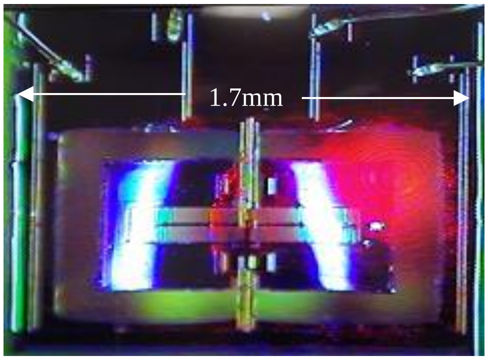

Fig. 3: 1.7mm pMEMS "Wings" as seen with microscope objective

The NLV is mounted on a tower looking down at the sample. The sample is placed on an X:Y:Tip:Tilt table which can be adjusted to position the laser spot at the desired location while ensuring that the laser beam reflects back into the NLV optics.

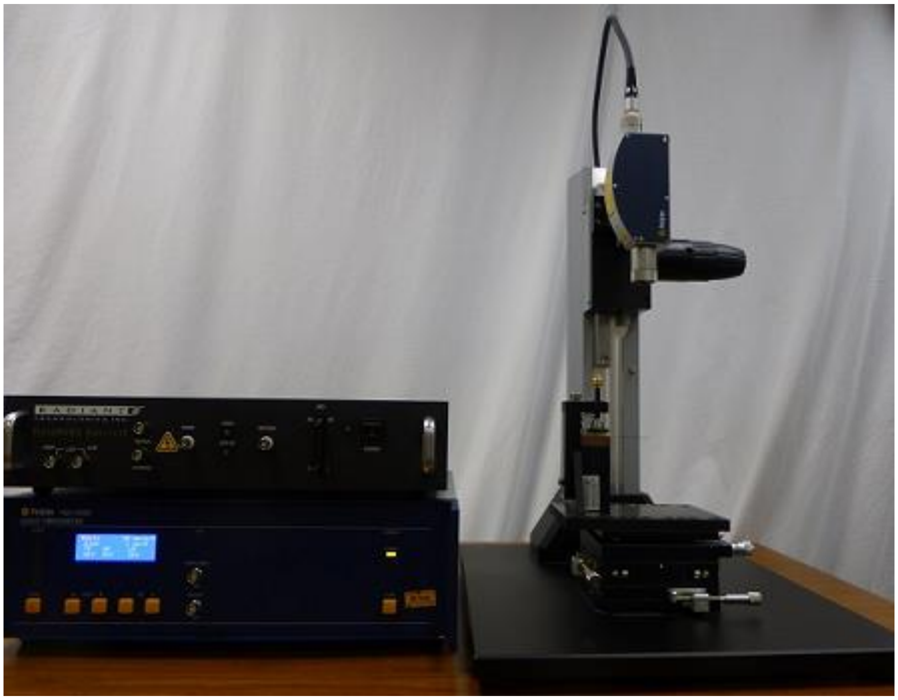

Fig. 4: NLV on tower with its control unit and a Precision pMEMS tester

The NLV contains an embedded camera sighted along the laser line. Using the microscope objective, the camera can image small features on piezoMEMS for positioning of the beam down to 10-micron resolution. (See Figure 3.)

The tower fixture may or may not need additional mechanical isolation from what is shown in Figure 4. For butterfly loops at or above 1 kHz in frequency, no extra isolation is necessary to reach 1Å resolution. For test periods slower than 1 kHz, an air table will be necessary to eliminate building motion and traffic noise transmitted through the building slab.

The NLV may also be mounted horizontally on an optical table resulting in an even lower noise floor than can be achieved with the tower fixture.

Fig. 5: NLV on optical table measuring piezoMEMS resonator

Butterfly Loop Measurement:

The data in Figure 1 are of the vertical d_{33} piston motion of the top surface of a 1µm-thick ferroelectric capacitor consisting of 4/20/80 PNbZT with platinum electrodes. The sample was wire-bonded onto a TO-18 transistor header so it could be inserted into a socket connected to the tester.

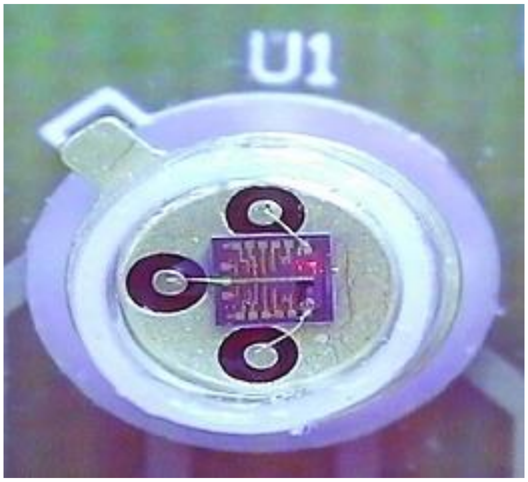

Fig. 6: Laser spot on 1µm-thick PNZT capacitor on test printed circuit board.

The capacitor is 400µm long by 250µm wide and is clamped to the silicon substrate. The clamping reduces the apparent piezoelectric coefficient of the capacitor to perhaps 1/4th of that of a free actuator. The speckle of the LDV laser beam on the top surface of the capacitor under test can be seen in Figure 6. The period for the single hysteresis loop in Figure 1 was 200 microseconds (5 kHz) captured by the Advanced Piezo Task in the Vision Research Management System. The plot in Figure 7 below is the same sample from Figure 1 averaged over four sequential loops.

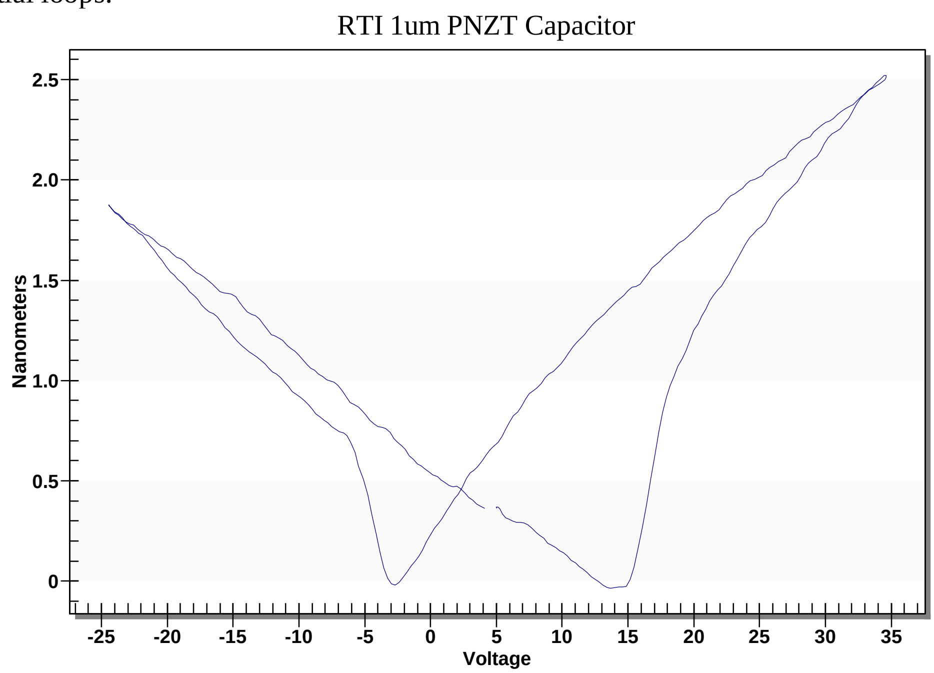

Fig. 7: The sample in Figure 1 averaged four times.

The Advanced Piezo Task in Vision provides tools for collecting and averaging multiple passes on the sample. Coupled with the NLV, Advanced Piezo makes it possible to approach the minimum resolution of the NLV LDV.

E31 Cantilever Fixture:

Radiant's E31 fixture is designed so an inexpensive photonic sensor can be used to detect the tip motion of 72-millimeter-long silicon cantilevers actuated by large-area capacitors on their top surfaces. The standard cantilever geometry for micron-thick ferroelectric thin film capacitors is in Figure 8.

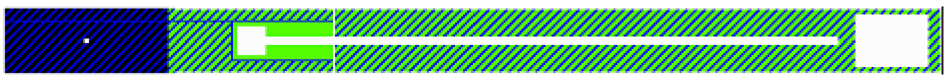

Fig. 8: Radiant standard 72mm cantilever for use with photonic sensor

For detailed information about the physics, operation, and test results for Radiant's standard E31 cantilever fixture, see "Proposal for Universal e31 system Rev A".

It is possible to measure the piezoelectric properties of very thin films on cantilever substrates or films that have low piezoelectric constants like aluminum nitride or PVDF derivatives. Two factors complicate results for these types of samples and force the use of an LDV for measuring their very small cantilever tip displacements.

1. The lower piezoelectric constants mean smaller tip motions below the sensitivity of the photonic sensor normally supplied with Radiant's E31 cantilever fixture.

2. In the case of very thin films, higher defect densities mean that the area of the actuator capacitor must be reduced dramatically in order to yield functional devices. Tip displacement scales linearly with actuator width and parabolically with actuator length.

Using an industrial version of the Polytec NLV (the OFV534 laser with OFV5000 controller) in place of the photonic sensor in Radiant's E31 cantilever fixture, it was possible for a Precision Multiferroic II to measure tip displacements of no more than 2.5 nanometers and verify that the e_{31} coefficient of Radiant's 4/20/80 PLZT films is the same from 1700Å up to 1µm thicknesses. The cantilever actuator capacitor was tiny in comparison to that on Radiant's standard cantilever.

Fig. 9: Top-Standard Cantilever. Bottom-Same cantilever with 40,000 square micron actuator capacitor

The fixture was placed on an air table at Polytec with the LDV looking down on the cantilever tip affixed to a version of the E31 cantilever fixture especially designed to work with lasers.

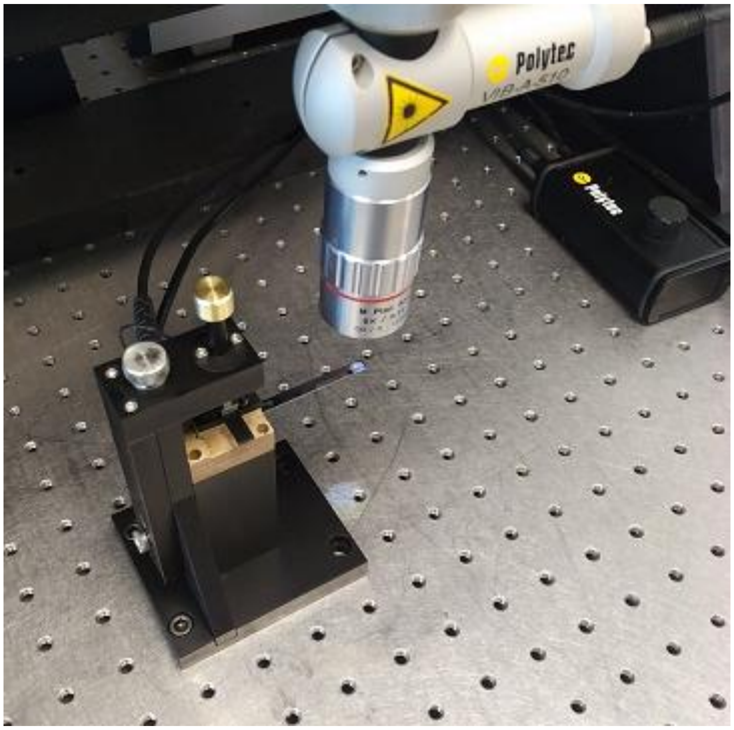

Fig. 10: LDV with E31 Tower Cantilever Fixture

The tips displacements for all samples in the experiment are plotted in Figure 11 atop a full butterfly loop executed on the one cantilever of the group with 1µm-thick PLZT.

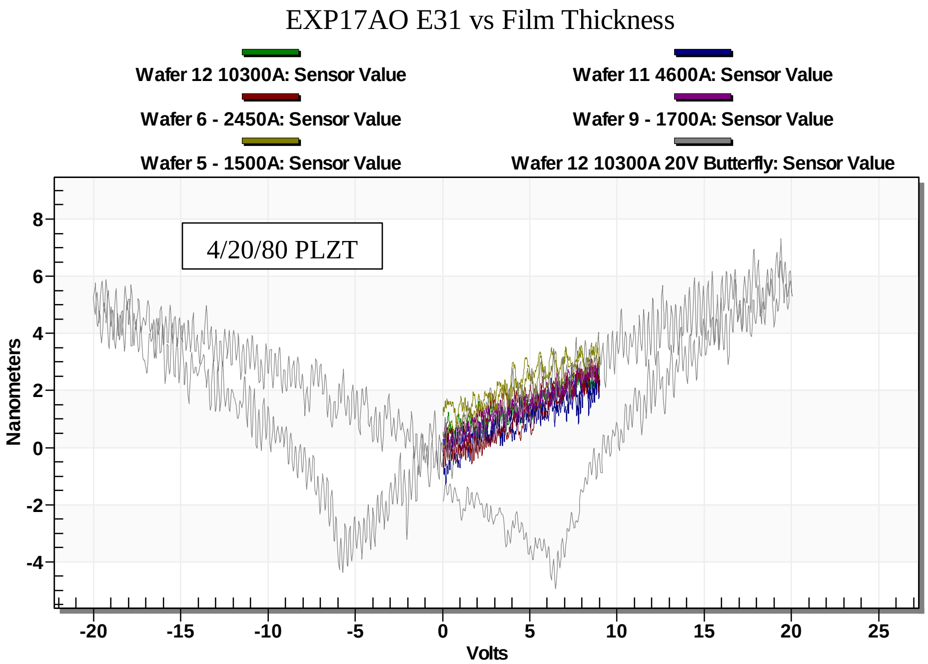

Fig. 11: Nanometer cantilever tip displacements vs piezoelectric film thickness.

For more detailed information concerning this particular experiment, go to Radiant's SUPPORT page on its website and download that application note: "Measuring $\boldsymbol{e_{31}}$ for Sub-micron Films – A Detailed Report".

Radiant's E31 Cantilever Tower integrates with the new NLV tower.

Fig. 12: E31 Tower integrated with NLV LDV

Piezoelectric Measurements over Temperature:
Radiant has explored an exciting new measurement technique that integrates Polytec's NLV LDV with the Linkam temperature chamber and a Radiant tester. Linkam has an excellent world-wide reputation for small, high-quality temperature chambers that fit under microscopes. A Linkam HFS600E-P chamber has a quartz top window through which the NLV may make piezoelectric measurements of bulk piezoelectric actuators, thin ferroelectric film capacitors, or piezoMEMS. The HFS600 has a temperature range of -195°C up to 600°C. It has four external BNC connectors wired to small micropositioner inside the chamber for making electrical connections to samples. The Linkam LTS420E-P is a larger chamber with a temperature range of -195°C up to 420°C and eight BNC/micropositioners. Both control to 0.1°C under supervision of Test Definitions run in Vision.

To verify that the NLV can measure piezoelectric displacements through the quartz window of an HFS600E-P chamber, Radiant mounted a reference ferroelectric capacitor onto a specially metallized substrate, wire-bonded the capacitors to large probe pads, and connected the capacitors to the BNC connectors using the internal micropositioners of the chamber.

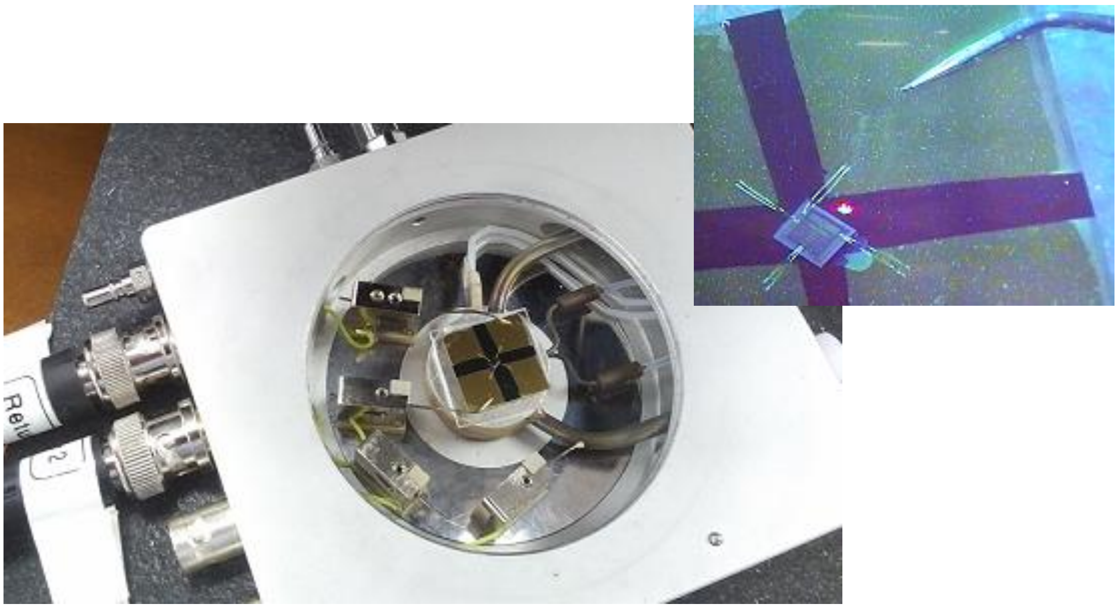

Fig. 13: View of sample mounted in the Linkam HFS600E-P thermal chamber (without window in place).

A Test Definition was constructed using the Vision Editor to measure converse $\boldsymbol{d_{33}}$ butterfly loops of 1µm-thick 4/20/80 PNZT as the sample temperature decreased from 90°C to 30°C. The results are plotted in Figure 14.

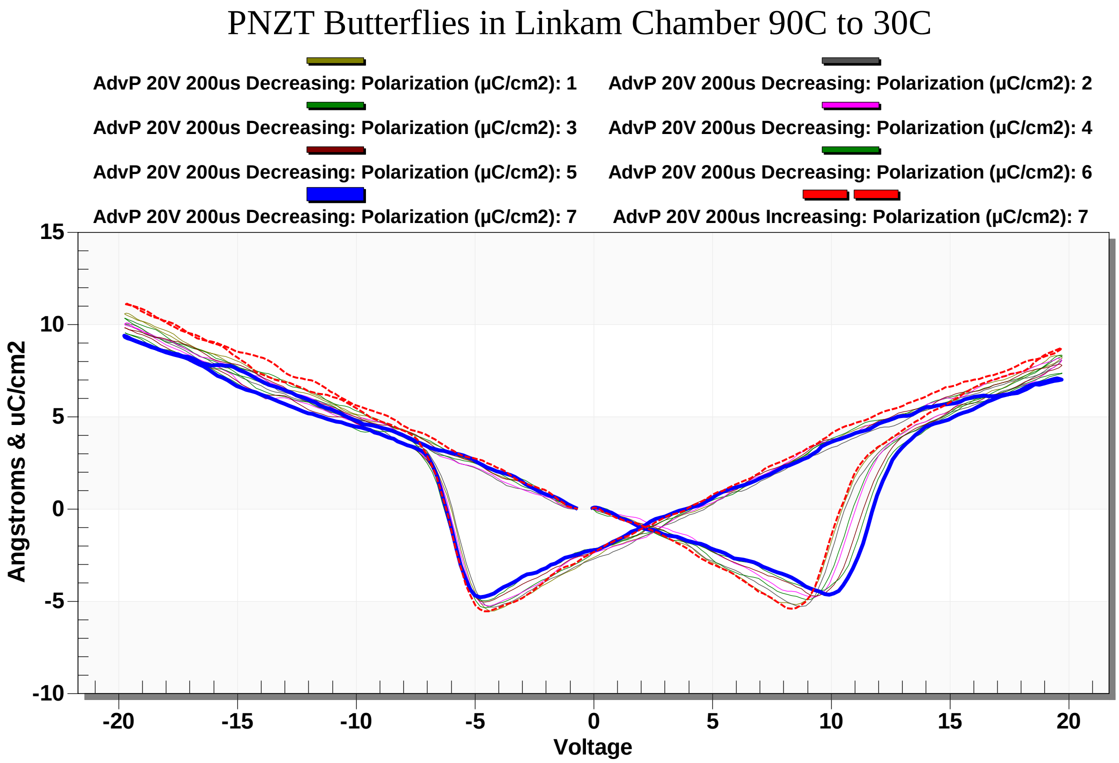

Fig. 14: Butterfly loops of 1µm-thick 4/20/80 PNZT/Pt capacitor in Linkam chamber

The red dashed line is the 90°C butterfly loop at the beginning of the decreasing temperature test loop. The remainder of the loops were acquired as the temperature decreased. The blue line is the 30°C measurement at the end of the test.

Conclusion:

Integration of the Polytec NLV with Radiant's advanced ferroelectric testers will measure d_{33} and e_{31} coefficients for thin ferroelectric or piezoelectric films with Ångstrom resolution. The super-quiet 18-bit ADCs inside Radiant testers enable such high displacement resolution above 1kHz with minimal vibration isolation. The NLV has a built-in camera co-linear with its 2µm to 20µm laser beam that allows characterization of tiny piezoMEMS features. Linkam thermal chambers with built-in micropositioners are compatible together with the NLV and Vision. A Linkam chamber mounted under an NLV with both controlled by Vision through a Radiant Precision tester creates an extraordinary piezoelectric evaluation system.