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Technical Report
PZT-Silicon Cantilever Benders

Subject: Displacement Measurements of Silicon Cantilevers Driven by PZT Actuators

Date: July 20, 2001 (Edited June 13, 2002)

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Discussion:

Introduction

Micro-Engineered Machines are fast becoming a product area with explosive growth potential. The MEMs require a power source to make them move. While electrostatic drives have proven functional, piezoelectric actuators can apply far more force at lower voltages. In order to design MEMs with matched piezoelectric actuators, the piezoelectric properties of the ferroelectric capacitors must characterized. To that end, Radiant has designed a process flow and mask set to build large cantilever devices. The displacement of the tips of these cantilevers will be large enough to measure with such instruments as the MTI2000 Photonic Displacement Sensor. This report describes the samples and the results of the first measurements of the cantilever displacements using a Precision Premier Test System and an MTI2000 Photonic Sensor.

Summary

Radiant created a standard mask set for manufacturing very large cantilever benders of silicon. Radiant then fabricated benders with several different compositions of PZT and measured two of them for displacement of the cantilever tip during electrical actuation. The cantilevers consisted of a long slice of 400µ thick single crystal silicon with a ferroelectric capacitor on one surface. The tips moved up to 22µ during a 30V hysteresis loop. Also, only small differences occurred in the displacement trajectory of two different compositions.

Test Procedure

The displacement measurements were made using a Precision Premier Ferroelectric Test System under the control of the Vision Data Management System. Programs were created for capturing the polarization of the ferroelectric capacitors while simultaneously measuring the output of a displacement meter connected to the SENSOR input of the Precision Premier. An MTI2000 2032R Photonic Sensor was used as the displacement sensor. The 2032R has a minimum resolution of approximately 25Å in its most sensitive setting and a maximum range of ~125µ. MTI makes a more sensitive model, the 2032RX which has 10 times the resolution of the 2032R. A block diagram of the tester architecture is shown in Figure 1.

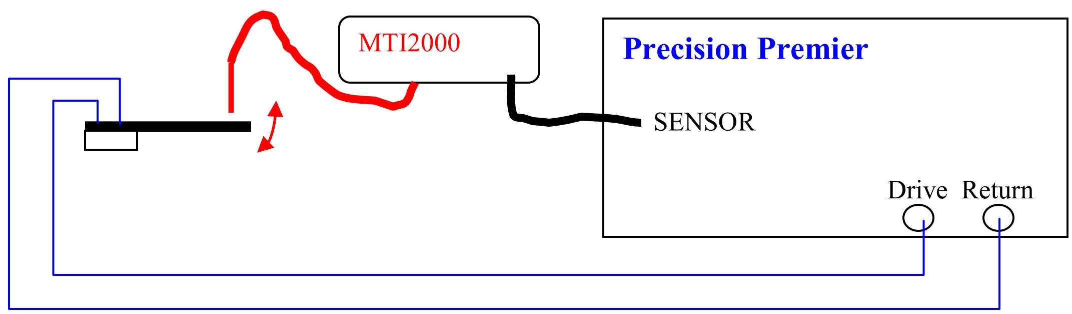

Figure 1
The Precision Premier Configured to Measure Cantilever Displacement

The measurements were accomplished using the Hysteresis Task in a Vision Test Definition. SENSOR can be turned on in the Hysteresis menu page. The SENSOR input has a range of ±10V and is measured with a 14 bit precision DAC, giving it a minimum input voltage resolution of 1.22mV. Unconnected to any external device, the SENSOR input has ±0.5 bits of random noise. The MTI2000 2032R module has an output scale factor of 21.54µ per volt. The minimum displacement resolution of the test setup in Figure 1 was therefore 0.026µ or 260Å. The measurement setup had roughly a 1000 to 1 signal to internal noise ratio. Any noise seen in the measurement either originated in the test environment or came from the sample itself.

NOTE: The SENSOR input associated with any standard task measurement is a general purpose measurement. No general purpose task in Vision understands the meaning of the data and only raw data is reported. The PIEZO task is a specialized task in the Vision library that understands that the SENSOR input is reporting displacement information. The PIEZO task can thus report more information about sample such as the Displacement vs Polarization, the piezoelectric constants, and the de-convolved electrical hysteresis from the displacement butterfly loop.

Sample Preparation

The sample was prepared using Radiant's standard PZT integration process. 5000Å of silicon dioxide were grown on the surface of <100> prime silicon wafers. The silicon dioxide was covered with 400Å of titanium dioxide to act as a diffusion barrier between the capacitors and the silicon dioxide. The capacitors themselves were fabricated with 1500Å of platinum, 1µ of PZT, and 1000Å of platinum. Two compositions of PZT were tested in this project: 1) 4% niobium doped 20/80 PZT (a.k.a. PNZT) and 2) 4% lanthanum doped 52/48 PZT (a.k.a. PLZT). After fabrication of the capacitors, the wafers were diced into chips with specific dimensions, one capacitor per die. The cross section of the cantilevers is shown in Figure 2.

The bottom electrode and PZT were not patterned. Only the top electrode was patterned. Therefore, bottom electrode and PZT extend to the edges of each cantilever.

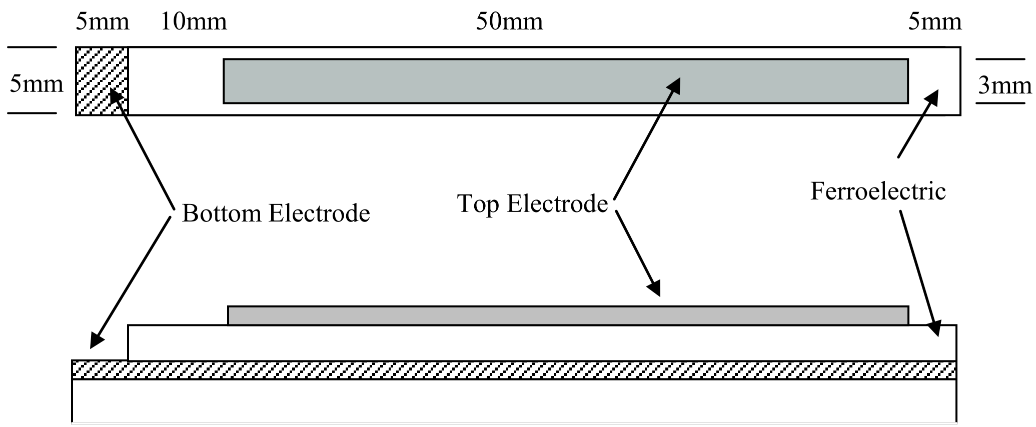

Figure 2
Cross Section of the Benders After Fabrication

The cantilevers were mounted such that 50mm of the length extended into free space beyond the edge of the mount. The cantilevers were not clamped into position so that they could bend over the mounting point. Consequently, the vertical displacements of the cantilevers during actuation cannot be taken as absolute data for the calculation of d_{31} coefficients since the bending length is not know precisely. The purpose of this experiment was to determine the general displacement distance and performance of the benders. Future work at Radiant will include more precise clamping of the cantilevers in order to generate accurate coefficients.

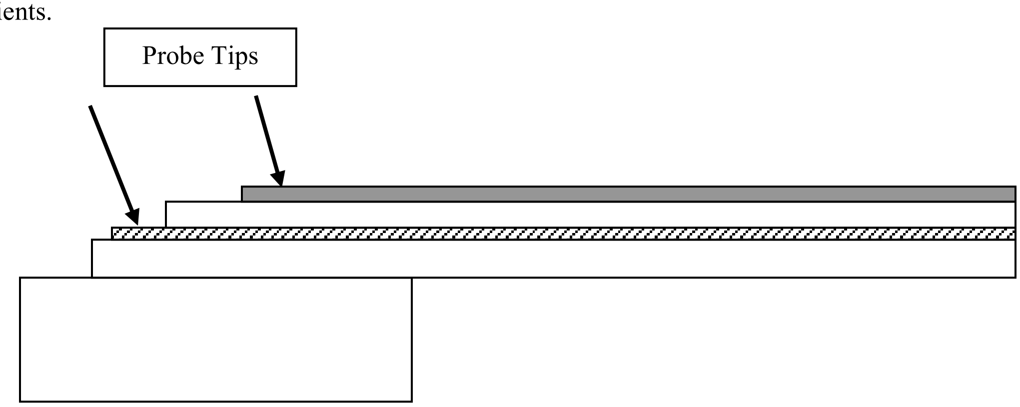

Figure 3
Mounting of the Cantilevers during Testing

Results

The benders exhibited significant tip displacement during actuation. Figure 4 displays the polarization hysteresis and the tip displacement for the 4/20/80 PNZT bender during a 300ms, 30V triangle wave actuation. Total displacement amplitude was 22 microns. The plot was exported directly from the Vision software to this document.

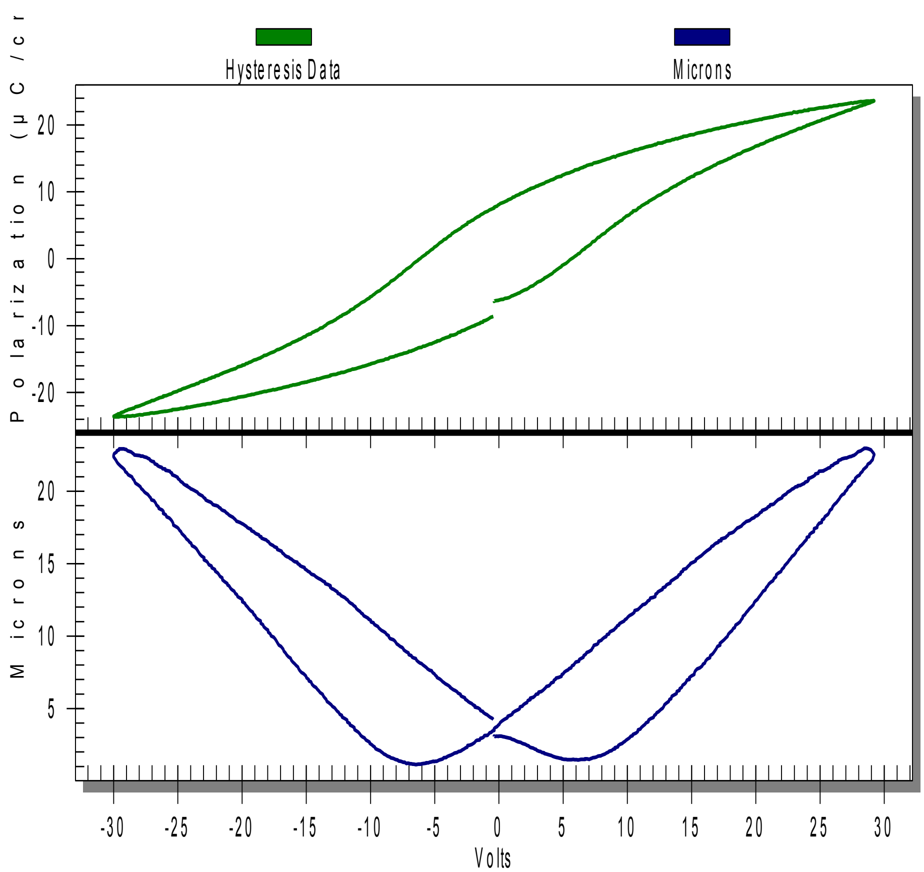

Figure 4
4/20/80 PNZT Bender at 30V, 3Hz.

The bender itself had a significant resonance close to middle C, approximately 250Hz. Figure 5 shows a 20V measurement at 100ms period. The resonant oscillation of the bender is clearly visible in the displacement plot.

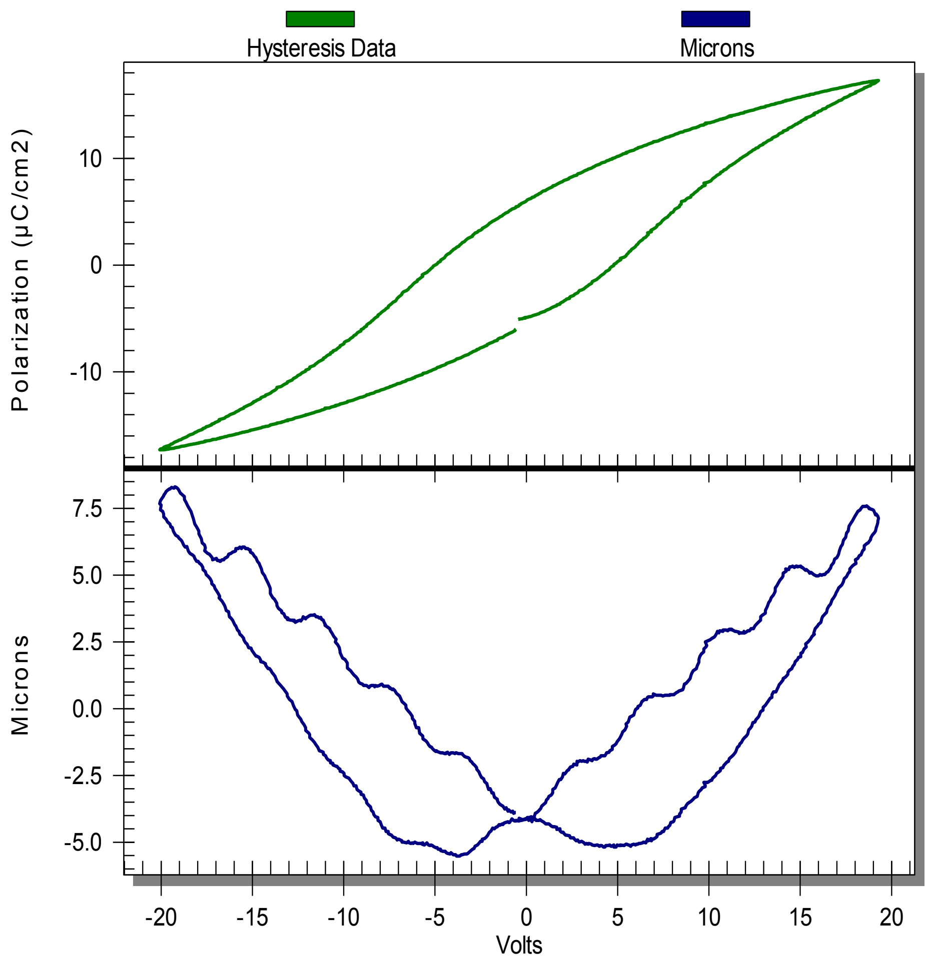

Figure 5
4/20/80 PNZT Bender at 20V, 10Hz.

A surprising result was that there was only a small difference in displacement achieved by the two different compositions of 4/20/80 PNZT and 4/52/48 PLZT.   Figure 6 displays the overlay of displacement curves for the two bender types.

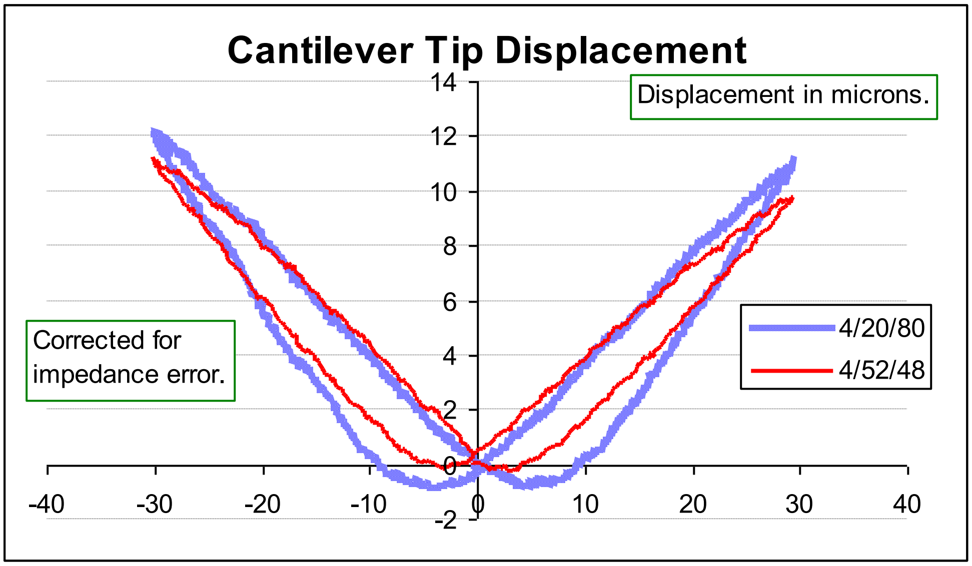

Figure 6
4/20/80 PNZT Bender vs 4/52/48 PLZT Bender.

An important issue with displacement measurements is the error introduced into the data by impedance mismatch between the displacement meter and the Precision Tester. For instance, with the version of the Precision Premier used to take the data shown in this paper, the input impedance of the SENSOR input was 4KΩ. The output impedance of the MTI 2032R sensor as 100Ω. This combination of impedances caused a 2.5% drop in the voltage measured by the Premier at the SENSOR input from the voltage output by the MTI2032R. The data shown in Figure 6 has been corrected for this mismatch. The Vision software running on the Radiant Precision Testers automatically prompts the user for the output impedance of the displacement sensor being used and corrects the displacement data accordingly.

Conclusion

Using a Precision Premier Nonlinear Materials tester coupled with an MTI2032R displacement meter, Radiant successfully demonstrated piezoelectric benders using its standard PZT integration process. The benders achieved 22µ tip displacement on 5cm lengths at 30 volts. The 4% niobium doped 20/80 PZT (PNZT) achieved nearly identical performance as the 4% lanthanum doped 52/48 PZT (PLZT) despite the difference in composition. The 52/48 composition would normally be expected to have higher piezoelectric constants. Absolute d_{31} parameter values were not achieved in this experiment because the samples were not clamped in a manner to prevent additional bending of the devices near the electrical contacts. The experiment should be repeated with additional fixturing to ensure proper d_{31} determination. Additionally, the 20/80 PZT and 52/48 PZT compositions (without doping) should be tested.