

Update on Progress: High Voltage Sensing using Piezoelectric Crystals

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1/27/2015

Acknowledgements

All the work in this document has been performed at Sandia National Laboratories in Albuquerque, New Mexico. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Research plan from Comprehensive Exam and Resulting Conclusions

May – August 2014 (ran into late October)

- Perform AC and pulsed experiments on 36° Y-cut – **Completed.**
- Work on journal paper comparing both crystal cuts under DC, AC, and pulsed voltage conditions – **Revisions are being made for submission to Review of Scientific Instruments. This paper will be my 2nd first author manuscript.**
- Design and build Sawyer-Tower Circuit and Oscillator Circuit and refinement – **The Sawyer-Tower Circuit was not pursued because it was determined that the lack of polarization switching in lithium niobate would not yield meaningful results. In terms of the oscillator circuit, several oscillator configurations were explored (RC, Colpitts, etc.). The built circuits did not achieve oscillation as observed in models designed in PSpice.**
- Perform impedance measurements **Impedance measurements using an LCR (inductance, capacitance, resistance) meter were performed over frequency. Inadequate fixturing and a low quality factor crystal (~ 15) made it difficult to see significant changes in frequency with respect to impedance.**
- Begin designing HV fixture – **Did not pursue because measured data and theoretical data did not match for voltage ≤ 1000 V. I decided to measure material constants over voltage in hopes of better explaining the mismatch in data sets.**

-August 2014-November 2014

- write up impedance measurement results for journal – **Did not pursue**
- order crystal (can take 2 months) – **Ordered crystals for different measurements (December 2014)**

November 2014 – May 2015

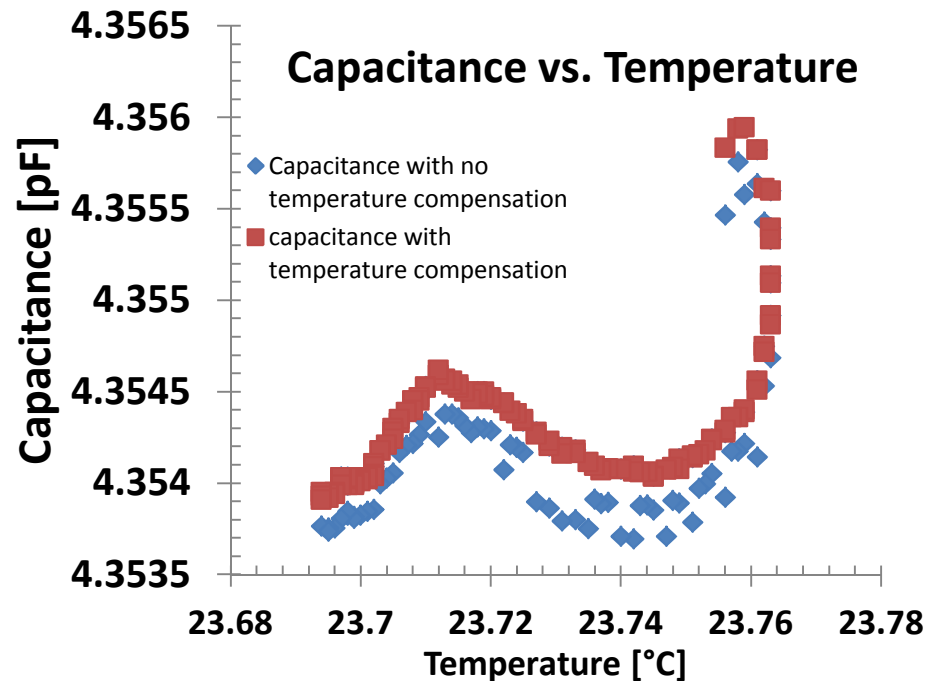
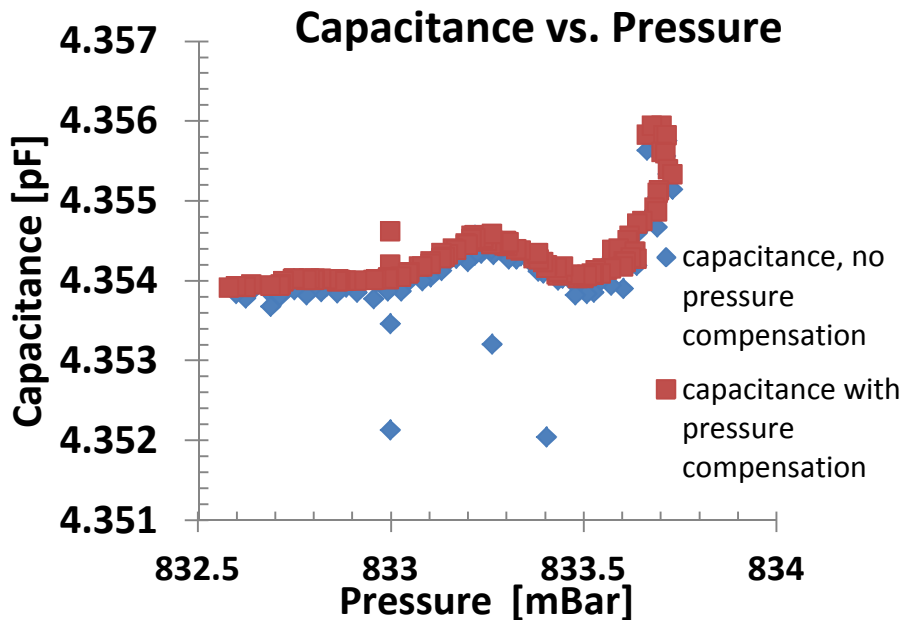
Tasks during this time frame involved pursuing HV (> 1 kV) measurements. This will no longer take place in the current plan.

Revised Goals of Research Project

Here are the changes I will make to what was proposed during my Comprehensive Exam:

- Measure material constants with respect to DC voltage using acoustic velocity measurements.
 - Velocities with x,y,z polarization directions and x,y,z acoustic propagation are determined from Christoffel's equation. The velocities are comprised of the crystal's material constants – electrical, elastic, and piezoelectric.
 - Determination of Dielectric Constant over voltage: I am using a commercial capacitance bridge at 1 kHz. This bridge has ppm level accuracy and can accept a 100 V (DC) external bias.
 - Elastic and piezoelectric constants as a function of voltage will be determined from voltage dependent acoustic velocity measurements. The acoustic velocity will be determined using a transmitting and receiving transducer (pitch and catch method).
- Using measured constant data, recalculate crystal response.
 - Currently there is a 32% error between theoretical and measured data for X-cut Lithium niobate and 60% in 36+Y-cut lithium niobate. This error is attributed to the piezoelectric constant, d , used to make the theoretical calculations.
 - Measuring constants as a function of voltage should reduce the error down by at least a factor of 10.
- Apply above methods to scalability of voltages greater than 1 kV for DC, AC, and pulsed voltage.

Initial Capacitance Measurements @ 15 V of LiNbO₃



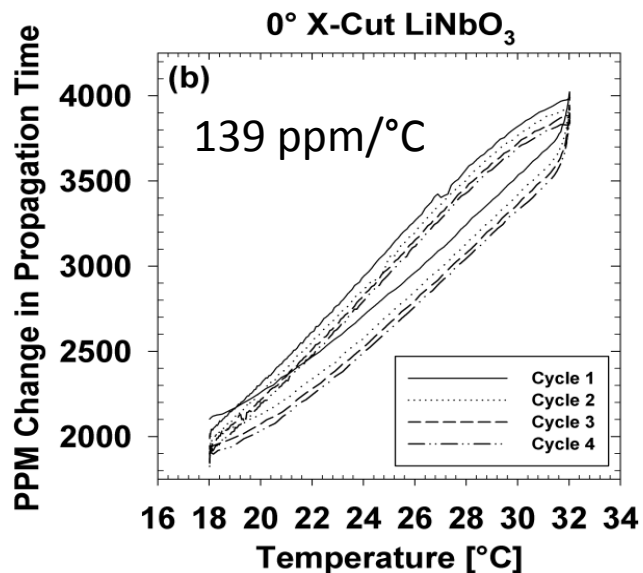
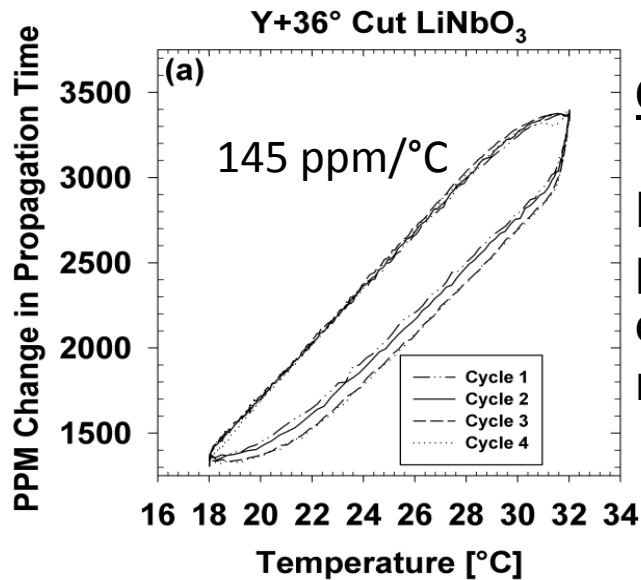
Goals:

Determine dielectric constant as a function of voltage. Measured data will aid in predicting voltage sensor response.

Findings:

Initial capacitance measurements were taken with capacitance bridge in atmospheric conditions. The above plots show effect of monitored pressure and temperature on capacitance using automated program. Fluctuations warrant a measurement of the pressure coefficient and temperature coefficient of crystal.

Temperature Coefficient of Lithium Niobate



Goals

Develop method to better monitor acoustic propagation time over temperature excursion. This experiment was performed in response to a manuscript reviewer's concerns (for Rev. Sci. Instrum.).

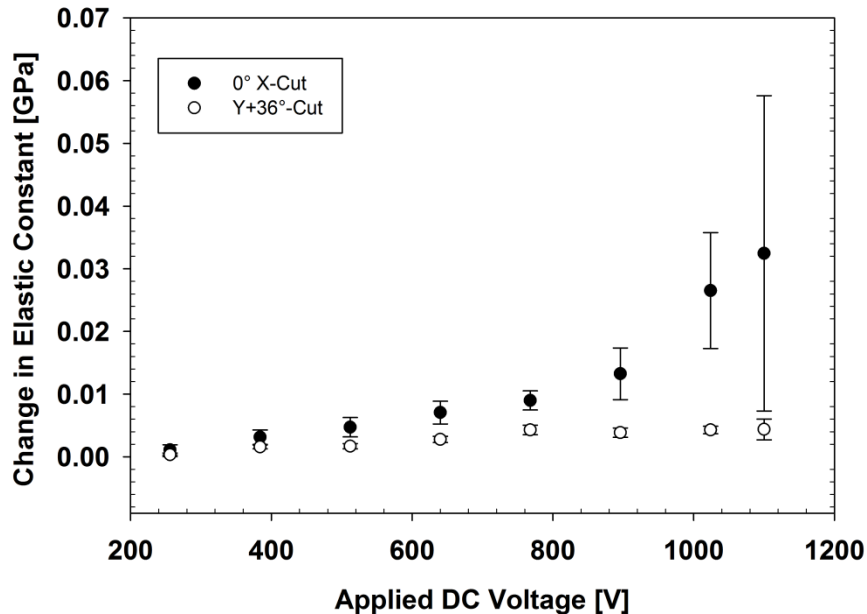
Findings/Accomplishments

Developed automated GPIB data acquisition system in VBA to monitor propagation time of two LiNbO₃ cuts from 18-32 °C. Code also allows multiple cycles to take place.

Will be used as temperature coefficient values in capacitance measurements.

Resubmission to Review Scientific Instruments is underway.

Change in Elastic Constant vs. Voltage



Measured $c_{11} = 20.34 \times 10^{10}$ Pa

Selected Literature values:

- 20.3×10^{10} Pa – Warner (1967)
 - 20.3×10^{10} Pa - Smith & Welsh (1971)
 - 20.0×10^{10} Pa - Nakagawa (1973)
 - 19.9×10^{10} Pa - Kovacs (1990)
- (other papers fall in this range)

Goals:

- Determine the effect of voltage on material constants.
- Determine if measured voltage-dependent constants improve the correlation between measured and calculated values for acoustic sensor.

Findings/Accomplishments:

- Change in the elastic constant between crystal cuts is observed for $V > 640$ V.
 - These findings are consistent with crystal response data (linear up to 640 V)
- Other elastic constants & piezoelectric constants still need to be measured.

Remaining Research Plan

Today – February 2015 (end)

- Continue with Capacitance Measurements @ 1 kHz (most stable).
 - Measure capacitance vs. pressure in pressure chamber at 75-101.325 (sea level) kPa in increments to determine pressure coefficient of crystal.
 - Measure capacitance vs. voltage: 1 V, 5 V, 10 V, 20 V – 100 V (in 10 V increments).
- Receive order of different lithium niobate crystal cuts to measure remaining elastic and piezoelectric constants (DC measurements 256-1100 V (128 V increments)).
 - Y-cut (x,y,z acoustic propagation), Z-cut (x propagation only) and 163° rotated about x axis.
 - Perform measurements of capacitance and temperature coefficient for Y-cut and Z-cut.

March 2015 – Mid April 2015

- Continue and complete measurements of voltage dependent velocity measurements. Start data analysis.
- Data analysis of velocity measurements
 - Measured data will replace previously used constants. The theoretical sensor response will be recalculated and compared to previously measured sensor responses.
 - Predictions will be made for use at higher voltages (such as 10 kV).

Late April – Mid May/Early June

- Complete data analysis.
- Write dissertation – Draft completion May 25.

Graduation: July/Aug time frame.

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