SAND2014-17142D

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Comparative Study of $LiNbO_3$ Crystal Cuts for use as High-Voltage Acoustic Wave Sensors

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Abstract

A comparison study between Y+36° cut and 0° X-cut lithium niobate ($LiNbO_3$) was performed to determine crystal cut influence on a piezoelectric high-voltage (HV) sensor's performance. Direct current (DC), alternating current (AC), and pulsed voltages were applied to the crystal. Data suggest $LiNbO_3$ has a frequency sensitive response to voltage and the crystal cut angle did not significantly influence the response when AC and pulsed voltage was applied to the crystal.

I. Background, Motivation, and Objective

•High-voltage (HV) measurements are traceable to the SI via a NIST developed resistive voltage divider, NIST-N1 (0.5% uncertainty at k=2.). This work seeks to lower measurement uncertainty by removing the divider.

•$LiNbO_3$ has an electrical breakdown strength of 20 kV/mm and can be grown thick enough to handle voltages reaching 500 kV.

•The voltage response of the device can be tailored based on $LiNbO_3$'s anisotropic properties.

II. Experimental Setup and Procedure

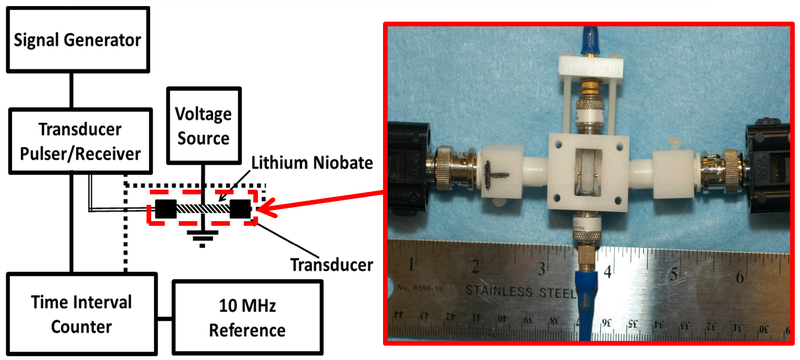


Figure 1. Experimental setup with crystal fixture outlined by red box.

Temperature Characterization:

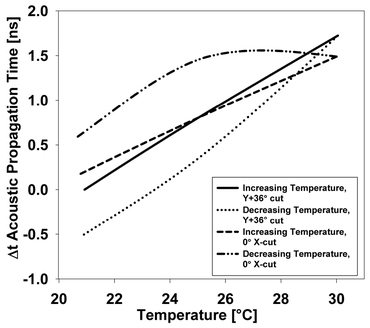
•Temperature was varied from 20 - 30 °C and propagation time monitored with no applied voltage.

Voltage Characterization:

•DC, AC, and pulsed voltage was applied to each crystal. Both crystals are 15 mm (l) × 5 mm (w) × 5 mm (h).

•The acoustic wave propagation time was monitored prior, during, and after applying voltage using a time interval counter.

III. Crystal's Temperature Dependence



From Data Analysis:

•A ±0.5 °C lab temperature fluctuation yields a shift of 49 ps.

•Joule heating of crystal after applying 1100 V DC for 1 hour amounted to 0.01 °C temperature change in crystal or 0.14 ps change in acoustic wave propagation time.

IV. Wave Propagation and Delay with Voltage

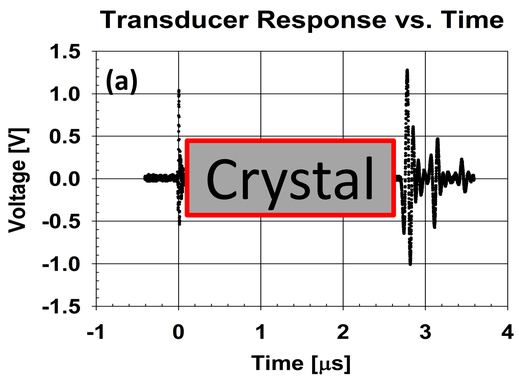


Figure 3.(a) Time dependent voltage transducer response output through the 15 mm $LiNbO_3$ crystal.(b) Representative voltage response data outputted from time interval counter.

Calculated Acoustic Velocity:

•**0° X-cut:** ~6700 m/s

•**Y+36°cut:** ~7300 m/s

•Two 1.5 mm pieces of glass contributed to acoustic wave propagation time.

•Settling time of crystal between applying voltage to crystal was at least 2 minutes for DC and AC measurements.

•Voltage was applied to crystal for at least 2 minutes for DC and AC measurements.

•5 measurements were taken at each voltage and frequency.

V. $LiNbO_3$ Response vs. Voltage Results

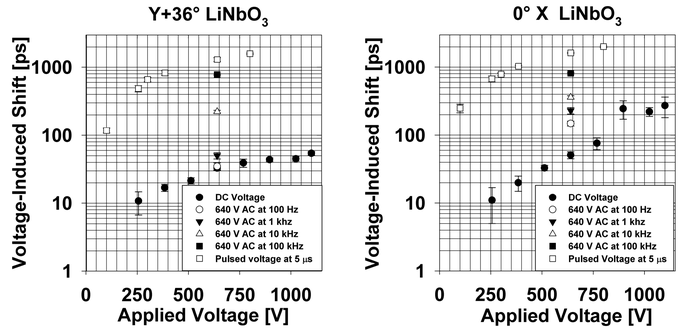


Figure 4. Experimental results of crystal response of two $LiNbO_3$ crystal cuts after applying AC, DC, and pulsed voltages to crystal.

IV. Uncertainty Budget

Table I. Estimated Uncertainty Table for HV Measurements based on Crystal Cut

Uncertainty Description	Y+36° cut	0° X-cut
Crystal Response	37 ppm	18.8 ppm
Temperature	217 ppm	118 ppm
Time Interval Counter	8.02 ppm	8.02 ppm
10 MHz Timebase	Negligible	Negligible
Crystal Dimension	2.33 ppm	2.33 ppm
Error in piezoelectric strain term, d_{ij}	0.30	0.16
Expanded Combined Uncertainty, U_{95}, (k=2.03) including d_{ij} error	60%	32%
Expanded Combined Uncertainty, U_{95}, (k=2.03) excluding d_{ij} error	0.045%	0.024%

VI. Summary

•Pulsed measurements yielded a 32-fold increase in response versus DC voltage response at 640 V for the X-cut crystal and 39- fold increase for the Y+36° cut crystal.

• d_{ij} terms are insufficient to predict crystal response vs. voltage.

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