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Measuring DC Voltage using Acoustic Wave Propagation in $LiNbO_3$

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***Abstract*—Two different cuts of lithium niobate ($LiNbO_3$) were monitored with an acoustic wave prior, during, and after DC high voltage (HV) was applied to the crystal. The data show that the voltage (256 V to 1,100 V) induced shift in the acoustic wave arrival time scales quadratically for 0º X-cut and linearly for 36º Y-X cut. The amount of voltage induced shift measured ranged from 10 ps-273 ps for 0º X-cut and -2.6 ps to -17.2 ps for 36º Y-X cut. The response difference between the two crystal cuts was attributed to the type of mode propagation in each crystal. Measured DC data is compared to both theory and a 1-D impedance matrix model. This presentation describes progress towards developing a new high voltage sensor.**

Keywords-DC High Voltage, Measuring Instruments, Electrical Measurements, Acoustic Waves, Lithium Niobate

I. INTRODUCTION

Performing high voltage (> 10 kV) measurements with a high degree of accuracy typically requires using a voltage divider. Piezoelectric crystals offer advantages for HV sensing, including relative high electric field breakdown voltage and operability over a large frequency range. The presentation focuses on using $LiNbO_3$ as a HV sensing element for direct voltage measurement without dividers or an electrostatic meter.

II. EXPERIMENTAL SETUP AND RESULTS

In this experiment, an acoustic wave propagated through the crystal and was monitored before, during, and after the HV was applied. Two transducers were controlled by a pulser/receiver system. A time interval counter was used to monitor the difference in the baseline acoustic wave propagation and propagation while a voltage was applied.

The voltage induced shift versus voltage was measured for two crystal cuts using a DC voltage range from 256 V to 1100 V. Figure 1 shows the results for both crystal cuts. The 36º Y-X cut, which propagates a longitudinal mode, showed good agreement with linear piezoelectric theory. For the 0º X cut case, the linear theory breaks down before 640 V. In order to explain the deviation in linear piezoelectric theory for the latter case, a 1-D impedance matrix model in the frequency domain was used to estimate the voltage induced shift in time by inputting a calculated change in length, Δl, due to voltage strain. For calculating strain, a simplified version of the linear piezoelectric constitutive strain relation was used:

$$S_i = d_{ji} E_j \qquad (1)$$

where the subscript i ranges from 1 to 6 and j ranges from 1 to 3, S is the strain, d is the piezoelectric constant, and E is the electric field. An inverse transform of the impedance was performed to extract the time response for the matrix model. The simplified equation assumes that the mechanical strain on the crystal is negligible compared to the strain from an applied electric field.[1]

For 36° Y-X $LiNbO_3$, a single d_{ji} term is needed, d_{21}, since only a longitudinal mode is excited at this cut angle. For the 0° X $LiNbO_3$ crystal, both a longitudinal wave and shear wave can be excited. It was found that between 256 V – 512 V, a longitudinal mode with d_{11} term was used to explain the measured data. In the range of 512 V – 768 V, a fraction of both the shear mode and longitudinal mode contribute to the response. For voltages >768 V, both modes fully contribute to the strain.

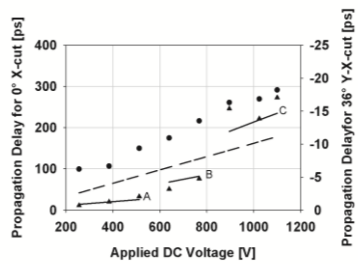

Figure 1: Measured response of 36° Y-X-cut $LiNiBO_3$ (circles, right axis) and 0° X-cut $LiNiBO_3$ (triangles, left axis) for DC voltages of 256 V-1100 V. The solid line segments (left axis) describe the calculated response from 1-D impedance matrix model over the same voltage range. The Δl term was used as the model input. Line A used the d_{11} term to calculate Δl. Line B used 50% of the d_{11} term and 50% of the d_{61} term to calculate Δl. Line C uses the full d_{11} and d_{61} term to calculate Δl. The dashed line (right axis) is the linear piezoelectricity theory used to describe the 36° Y-X-cut $LiNiBO_3$.

III. CONCLUSION

In summary, DC voltages were measured using a piezoelectric voltage sensor by monitoring acoustic wave propagation time changes with applied voltage. The measured crystal responses are consistent with linear piezoelectric theory for longitudinal mode propagation only. Shear wave propagation adds additional amplification to the response. Measurements using this method can be made with good sensitivity and low noise.

The work was performed at Sandia National Laboratories. 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. DOE's NNSA under contract DE-AC04-94AL85000.

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