LITHIUM NIOBATE BASED PIEZOELECTRIC TRANSDUCER

OZGUR YAVUZCETIN, MICHAEL DORN-REED, BISHOP FREEMAN

1,2,3Department of Physics, University of Wisconsin--Whitewater, Whitewater, WI 53190, USA
E-mail: yavuzceo@uww.edu

Abstract- Strain gauges indicate the strain of a structure and convert it into electrical signal. Current electrical strain gauges are vulnerable to electromagnetic noise and require off-set circuitry for temperature fluctuations. Lithium Niobate (LN) is a piezoelectric crystal used extensively in high speed optical communication devices like optical modulators. In this work, we have fabricated and demonstrated a piezoelectric transducer with LN sensing element, for measuring dynamic strains and vibrations. This work can be implemented in high speed dynamic vibration measurements, merging electrical and optical signals for higher sensitivity in noisy environments.

Keywords- Lithium Niobate, Piezoelectric, Transducer, Strain Gauge.

I. INTRODUCTION

Strain gauges are extensively used in civil, mechanical engineering and automotive technology. These gauges can indicate the amount of strain of a structure and convert this into electrical signal using a Wheatstone type of resistor network. However due to the nature of environments, resistive strain gauges are vulnerable to electromagnetic noise which can couple to measurement signal. An alternative is fiber optical strain gauge with increased resolution and accuracy. Due to their dielectric nature, the electromagnetic noise is does not affect these sensors.

Lithium Niobate (LN) is a piezoelectric crystal that can convert vibrations into electrical signals. It also exhibits optical properties and has been used in optical data communication for decades. In this work, we have fabricated and demonstrated a highly sensitive piezoelectric transducer consisting of a LN based sensor and a signal conditioning circuitry which can pick up small vibrations and output these as electrical signals. Due to its dielectric nature, this transducer can be potentially used in electromagnetically noisy environments, merging optical and electrical measurements increasing the accuracy.

II. DETAILS EXPERIMENTAL

2.1. Preparing Cantilever Setup

We started with mounting a commercial strain gauge (from Omega) on an aluminum cantilever using a cyanoacrylate adhesive by applying common procedures as given in literature. Since the cantilever was aluminum, we chose our sensor’s resistive material to be aluminum as well in order to minimize temperature effects. Our strain gauge had a nominal resistance of 350 Ohms and we used a Wheatstone bridge, offsetting variable resistors and an instrumentational op-amp (INA114) to get a linear output. We gradually increased the weight on the edge of the cantilever and observed a linear behavior confirming the linear response of our cantilever system.

2.2. Fabrication of LN Sensor

We used X-Cut LN (commercially available) which were 10mm by 10mm square shaped samples cut from a wafer using dicing saw as shown in Fig.1.

One of the shear modes with axis of maximum sensitivity occurs at an angle of about 32° from the Z-axis under tensile stress. Therefore we marked and rotated the samples to be metallized carefully since the samples are all transparent and rotationally symmetric.

We started by cleaning all samples after removing the blue adhesive film. Our cleaning cycle consisted of isopropyl alcohol, acetone and deionized water. After the final rinsing step, the samples were placed on a lab wipe and blow dried. We masked the samples using electrical tape, by preserving the angle of maximum piezoelectric sensitivity. Then we sputter coated gold of a thickness of 100 nm and removed the tape. This gave us square samples with two edges metallized with gold Fig.2.
2.3. Constructing the Transducer

The LN chip was carefully mounted on the cantilever using the same technique as the commercial strain gauges. A perforated printed circuit board (PCB) with contact solder joints was also mounted in order to reduce strain. We used colloidal silver paint to mount fine wire and dried it to form contacts from the gold surface of LN chips and the other end of the wire was soldered on PCB. On the same PCB we soldered 22 gauge wires connected to electronic circuitry. The overall wiring resistance per contact was measured to be less than a few ohms.

![Fig.3. Electronic circuitry to read charge buildup.](image)

Since piezoelectric crystals create charge buildup with large potential differences, a circuit was constructed to harvest the charge to be read by the instruments. The wiring from the LN chip was first connected to a resistor (R1) in parallel with the electrodes, in order to dissipate the charge (Fig.3.3). For our chip, a resistor in the order of a few hundred kilo ohms gave a time constant less than a few milliseconds. The two Zener diodes connected with opposite polarities are to absorb the high potential difference buildup and we used two 5 V Zener diodes. The potential buildup was connected to an op-amp (MCP6002) through a resistor (R2) of 100 kΩ. The op-amp served as a trans-impedance amplifier with unity gain since the inverted input was connected to the output and to the oscilloscope.

2.4. Dynamic Testing of the Transducer

We connected the output of the op-amp to an oscilloscope and recorded the measurements as triggered by a tapping causing the cantilever to vibrate. The vibrations were recorded as voltage and time. Each tapping on the cantilever, caused it to vibrate as an underdamped oscillator and the signals were recorded. The measurements were repeated to minimize error. The plot of the data captured by the oscilloscope is shown in Fig.4.

![Fig.4. Underdamped oscillations of the cantilever measured by the LN Transducer. The peak to peak readings are 300 mV and the period of the oscillations are around 10 ms.](image)

The results were compared to the theoretical calculations. For a cantilever beam, the spring constant of the beam is given by:

\[ k_{\text{beam}} = \frac{E_{\text{Al}}wt^3}{4L^3} \]

Where \( E_{\text{Al}} \) is the Young’s modulus of aluminum (69 GPa) and \( w, t, L \) are the width, thickness and the length of the beam respectively. The natural vibrational frequency is given by:

\[ f_{\text{natural}} = \frac{1}{2\pi} \sqrt{\frac{k_{\text{beam}}}{m_{\text{eff}}}} \]

Where \( m_{\text{eff}} \) is the effective mass of the cantilever which is 0.24 m if \( m \) is the total mass. The natural frequency of the vibrations were calculated and measured using our LN transducer and the results were in the same order of magnitude which showed that our LN transducer has enough dynamic bandwidth.

III. RESULTS AND DISCUSSION

We have successfully demonstrated a working LN based piezoelectric sensor and a transducer. The measured theoretical and experimental values for the frequency are consistent in the same order of magnitude. We used regular clamps to fasten the cantilevers on the surface, the irregularity of the system could be one of the measurement errors. We tested the LN sensor on another cantilever which was also made out of aluminum and we observed a similar behavior.

However the dynamic range should also be tested in order to evaluate how fast the sensor is going to respond. Since the charge buildup is stored on the electrodes, the capacitance plays a role in choosing the parallel resistor (R1) as seen in the circuit. As the sensor size gets smaller, the capacitance will drop however signal to noise ratio will increase. Another factor affecting capacitance is how small the electrode separation is. As the separation gets smaller, the potential difference will also be smaller.

This transducer can be potentially implemented to optics by fabricating waveguides on the LN chip. Therefore infrared light with Bragg patterns could serve like an optical sensor. This would improve the accuracy of the transducer. The reason why we chose LN as the piezoelectric sensing element is due to its well-known optical properties. More details on waveguide fabrication is given in the references below.

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