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Bending Curvature Measurement Using a SAW Sensor Fabricated on a Polyvinylidine Difluoride (PVDF) Substrate

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Abstract

SAW (surface acoustic wave) sensors have been used in chemical sensing and various other fields of sensing. In this research a SAW sensor has been studied as a bending curvature sensor. For this purpose, a highly piezoelectric flexible substrate of PVDF has been used and promising results were obtained. The bending curvature can be expressed as a function of the phase shift and amplitude of the received signal with respect to the input signal. A dynamic surface profile mapping system is proposed based on a network of this type of sensors. This has a high potential in human body movement sensing in the future.

Keywords: Flexible SAW sensors, PVDF, bending curvature, flexible substrate

1 Introduction

Bending angle sensing is a research problem addressed by many researchers and there are various products available in the market. Most of these high precision bending angle sensors are based on laser beam or optical sensing principles. Almost all these sensors measure the bending angle of a sharply bent flat object like a metal sheet. However, there are situations where the bending curvature is of interest rather than a sharp bending angle.

Motions of the human body incorporate with a lot of bending, but not sharp like in the case of a sheet metal bending. These soft or blunt bends are to be exactly mapped if it is aimed to model or imitate these motions. There are various attempts by different research groups[1],[2], however the resolution is the problem. One group proposed a smart fabric which contains polypyrrole (a conducting polymer) or a mixture of carbon and rubber[2],[3]. This type of piezoresistive sensor network is very good as a wearable system but the resolution is in question for delicate operations.

The proposed sensor is developed with the focus of developing a high accuracy tele-operational robotic hand. Therefore the resolution of the sensor is very important rather than just identifying whether it is bent or not. Further, in the future tele-operational robotic hands are expected to be operated by artificial organic polymer muscles rather than electric motors. Therefore, a sensor which can easily be integrated into such a polymeric system as a feedback sensor is in high demand.

SAW sensors have been used in various fields of sensing with very high accuracy. In most of the cases, solid piezoelectric materials such as Quartz (SiO_2), Lithiumniobate ($LiNbO_3$), Lithiumtantalate ($LiTaO_3$) or Langasit ($La_3Ga_5SiO_{14}$) are being used as substrates[4]. However, in our application the substrate should be a flexible one to follow the bending object and should be a good piezoelectric material to work with surface acoustic waves. Polyvinylidine Difluoride (PVDF) is one of the obvious solutions for all these requirements.

This is an initial experimental study to investigate the feasibility of a PVDF substrate to fabricate a sensitive bending curvature sensor. The experimental results showed that the PVDF substrate responded to the bending curvature very sensitively. After obtaining these test results, a surface profile sensing system is proposed to map a dynamic surface.

2 Experimental

The proposed sensor was fabricated using a PVDF substrate and then tested with soft bending. Special precautions made to make it free from top surface loading. However, the intrinsic radial and tangential pressure components due to bending cannot be avoided. The output signal is buried in noise and therefore a lock-in amplifier was used to recover the signal.

2.1 Sensor Fabrication

PVDF substrate was obtained from Sigma Aldrich (P-0807) and used without further cleaning. The Gold electrodes were deposited using thermal vapour deposition method. The deposition was done at a high vacuum of 4.2 x 10^{-6} Torr (measured with ULVAC G1-TL3 Ionization vacuum gauge) and the deposition thickness was measured with ULVAC CRTM-1000 deposition control and measurement system. The deposited Au electrode thickness was 50nm and figure 1 shows the fabricated sensor. Finally lead wires were attached to four electrodes using a Silver conducting adhesive.

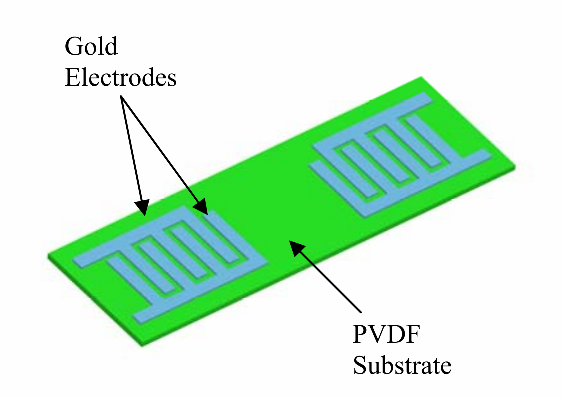


Figure 1. Flexible SAW sensor for bending curvature measurement.

This sensor was then attached to a flexible plastic strip using a double sided adhesive tape. All the banding force was applied on this secondary plastic foil which was much longer than the sensor substrate. So that the direct force application on the sensor surface was avoided.

2.2 Measurement Setup

Sensor performances were measured with the following test circuit illustrated in Figure2. The sensor output signal is extremely small compared to the input signal and buried in noise. Therefore the use of a Lock-in amplifier is eminent. In this experiment NF Instruments' NF 5610 Lock-in amplifier was used. The signal generator used was a NF1941 High precision waveform synthesizer.

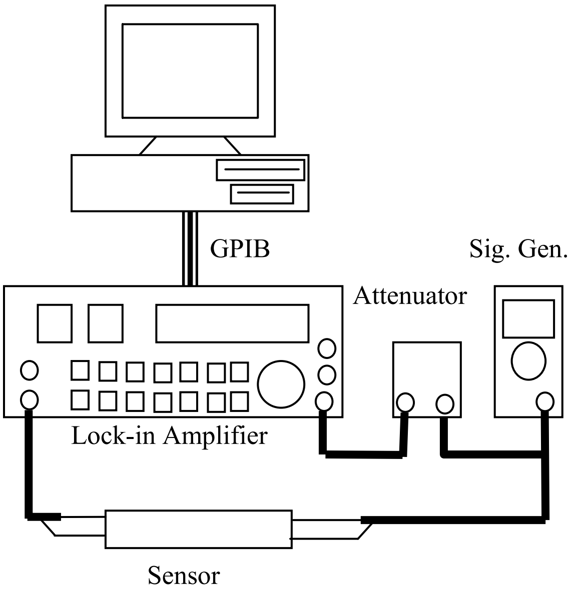


Figure 2. Sensor performance measurement setup.

A 4kHz, sinusoidal signal with 4V peak to peak was fed to one set of sensor electrodes and one tenth of that signal obtained through the attenuator was fed to the Lock-in amplifier reference input. The output from the electrodes in the opposite side of the sensor was fed to channel A of the Lock-in amplifier. Lock-in amplifier was set to pass only the fundamental frequency of the reference signal. The sensor was mounted on different cylindrical platforms with known radii and the sensor output was measured through the Lock-in amplifier. Longitudinal axis of the sensor was placed to follow the curvature of the cylinder. Both amplitude and phase angle difference of the output signal were measured at each curvature.

3 Results and Discussion

Resonating frequency of the IDT pair fabricated on an isotropic piezoelectric material is mainly determined by the physical dimensions. The output voltage can also be expressed as a function of these parameters. Feng and co-workers have formulated the output voltage as follows[5],[6].

$$\dot{v}_{out}(t) = h\sum_{n=0}^{N}\sum_{m=0}^{M} v_{in}\left(t - \frac{L + ma + na}{V_R}\right) \qquad \text{--(1)}$$

Where, h is a constant related to material and physical parameters, t is time, V_R is the propagation velocity of Rayleigh wave and other symbols are as shown in figure 3.

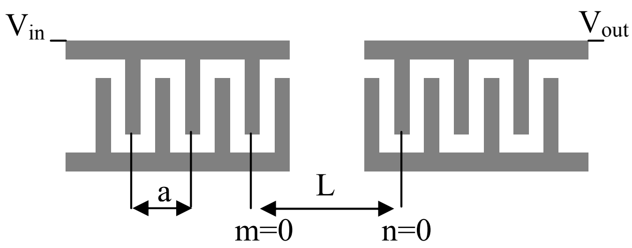
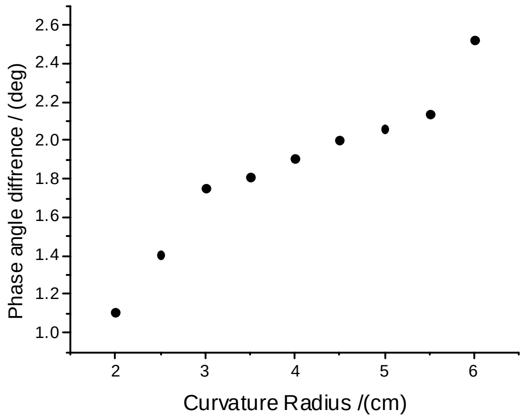


Figure 3. Schematic of the IDTpair.

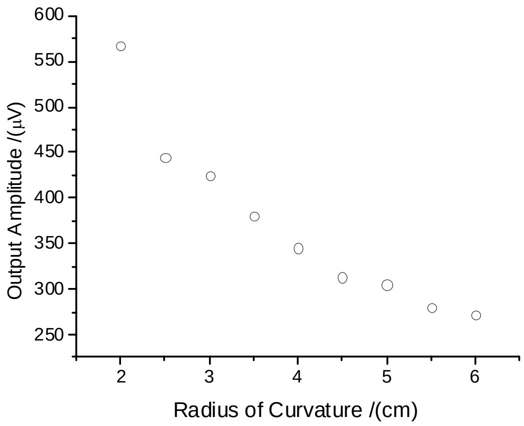
Equation (1) shows that the output voltage varies on the magnitude of *a* and *L*. Not only that, the bending of substrate causes it to behave as an anisotropic material where the equation (1) is no longer applicable. Therefore, this has to be modelled using a multi-layered structure and we are currently working on such theoretical model.

The experiment was carried out at ambient temperature and pressure where the sensor is going to be utilized. Sensor output showed good relationship with the bending curvature.

The phase angle difference of the sensor output signal with respect to the input signal has the following relationship shown in graph 1.



Graph 1. Variation of output amplitude with sensor curvature.



Graph 2. Variation of phase angle of output with sensor curvature

Amplitude of the sensor output has the relationship shown in the Graph 2. These data proposes that the output voltage is proportional to the curvature (inversely proportional to the radius).

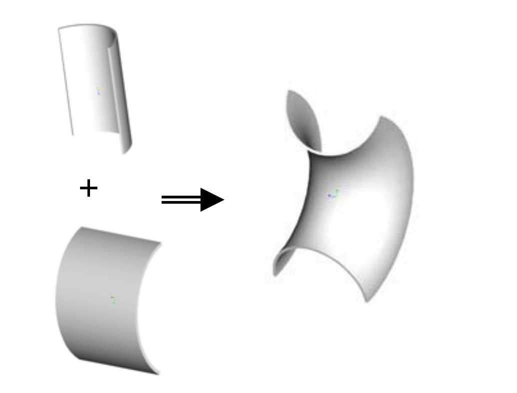


Figure 4. Composing of 3-D bending using two 1-D bending surfaces

The ability of this flexible sensor to measure the bending curvature suggests the possibility of devising a dynamic surface profile sensor. Such dynamic surface profile sensor has a lot of scope in bio-medical applications.

Any non overlapping three dimensional surface profile can be decomposed into two 2-D surfaces with single directional bending. Inversely, if we have two such surfaces, the 3-D surface can be produced using the superposition theorem. Figure 4 shows the graphical presentation of this.

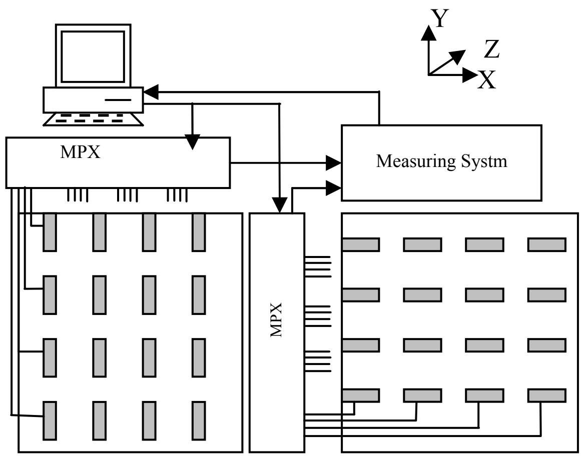


Figure 5. Proposed surface profile sensing mechanism.

Therefore we propose to have two independent sensor network attached on to the same surface in order to prodece the surface profile. Figure 5 shows the proposed system using a network of PVDF sensors. Each sensor is attached on a plane surface at fixed coordinates. Suppose the sensors were attached to a plane (XY) on lines parallel to Y axis, then these will provide information only on any bending in parallel to the YZ plane where Z is perpendicular to XY plane.

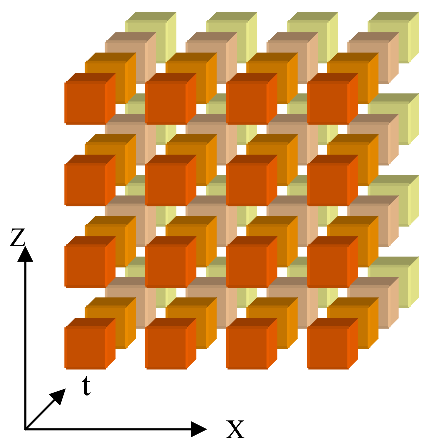


Figure 6. Temporal data from one sensor network.

Scanning one sensor network provides a two dimensional data set at t=0 and the next scanning at t= Δt provides another similar dataset. Therefore a three dimensional data array is available from each sensor network over time. Figure 6 shows the time domain data array from one sensor network.

The sensed surface profile can be reconstructed using a suitable reconstruction algorithm.

4 Conclusion

Results show that both the amplitude and phase angle are varying with the variation of curvature. Therefore, the proposed sensor can be used to measure the curvature of a bending surface. Further, PVDF can easily be integrated onto an artificial muscle made with conducting polymers. Further work is on this to calibrate the sensor and to improve the performance by changing the electrode pattern dimensions and electrode deposition thickness. Further, the frequency dependency is also another interested area to be investigated.
The proposed surface profile sensor network provides a temporal data and hence dynamic surface profile sensing becomes possible.

5 Acknowledgements

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