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ENERGY HARVESTING USING PIEZOELECTRIC THICK FILMS FRABRICATED BY A SOL-GEL PROCESS

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ABSTRACT

The design, fabrication and evaluation of energy harvesting sensors consisting of a 38μm thick stainless steel membrane, a 60μm thick piezoelectric lead-zirconate-titanate (PZT) composite film and a silver paste top electrode are presented. The PZT composite film was made using a sol-gel spray technology that may be used to fabricate unimorph and bimorph sensors conveniently. A fabricated 20 mm diameter unimorph vibrating at a deflection displacement of 5mm generated a voltage of 13.6 volts peak-to-peak at 10Hz. With a load resistance of 150KΩ, the measured average power generated by the 20 mm diameter sensor was estimated to be 41μW. The durability evaluation result of a vibration test performed continuously for sixty days at a frequency of 10Hz and a displacement of about 1mm showed that the sensor is rugged.

***Keywords**:* Energy harvest, vibration, piezoelectric thick films, sol-gel process

$$\delta = \frac{3AB(1+B)}{1+A^2B^4+2A(2B+3B^2+2B^3)}\left(\frac{L}{t_{PZT}}\right)^2 d_{31}V = Z(A,B)\left(\frac{L}{t_{PZT}}\right)^2 d_{31}V \qquad (1)$$

where $A = E_{SS}/E_{PZT}$, $B = t_{SS}/t_{PZT}$, E_{PZT} and E_{SS}, and , t_{SS} and t_{PZT} are Young's modulus and thickness of the SS membrane and PZT film respectively. L is the length of the free area of the sensor between the clamping point and the free end and d_{31} is the transverse piezoelectric constant of the PZT film.

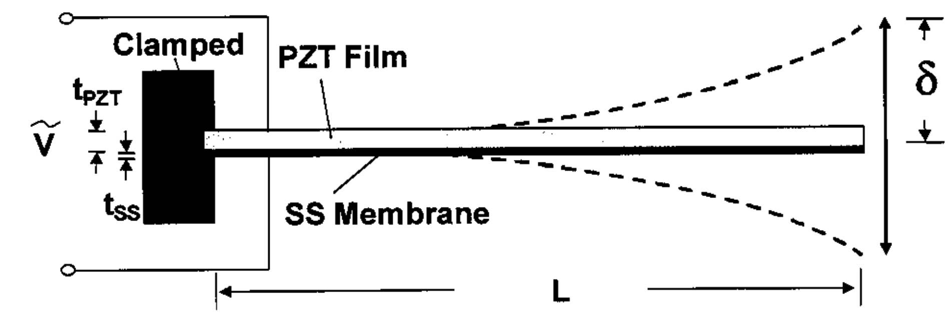


Fig. 1: Schematic of energy harvesting sensor

Equation (1) indicates that the thickness ratio B of the SS over the PZT membrane will affect δ. Figure 2 shows the calculated results of Z(A,B) in Equation (1) versus K with a measured A of about 9. One can see that when B is near 0.2, Z(A,B) is maximum. Therefore an SS membrane with a thickness of 38μm was chosen, which is the thinnest available for sensor fabrication with considerations regarding the inconvenience caused by handling very thin samples taken into account. When the PZT film thickness is about 190μm, Z(A,B) reaches a maximum. However, if the film thickness is too thick, then the bending ability of the film which enhances the δ will be reduced. Because of this and the consideration of the parameter $(L/t_{PZT})^2$, the PZT film thickness should be ≤190μm depending on the requirement of L.

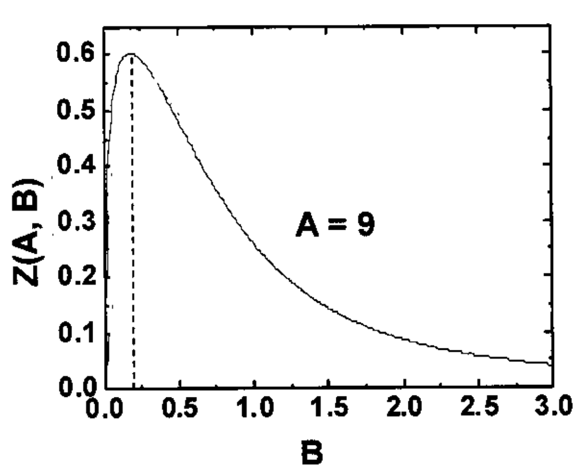


Fig. 2: Relation between Z(A,B) and B

Fabrication of PZT films

In this study, PZT film was made using a sol-gel spray technique [8,9]. First, PZT powders and PZT solutions were well mixed into a slurry via a ball milling process which reduces the powder to submicron size. The slurry was then sprayed onto the SS membranes. Heat treatments were then carried out to make the slurry into a solid PZT/PZT composite film (in short PZT film). The spray and heat treatment were repeated to obtain a proper film thickness to achieve high energy harvesting efficiency. The heat treatment was carried out using a furnace with a temperature of up to 650°C. A unique consideration of the PZT film for energy harvesting sensor fabrication is the compromise between the bending ability of the unimorph or bimorph, which is affected by the film thickness as well as the density, and the piezoelectricity of the film. The higher the density of the PZT film, the larger is the piezoelectricity, but the poorer is its bending ability. For this study, the density of the PZT film was less than 85% of the bulk PZT. A corona poling technique was used to make this composite film piezoelectric. Finally, silver paste painting at room temperature was used to form the top electrode. The electrode size defines the sensor size. The colloidal silver spray method can be also used to fabricate complicated electrode configurations such as interdigital transducers [9].

With a 38μm thick brass mask, PZT films with different sizes can be made onto one 38μm thick SS membrane as shown in Figure 3. At present, a PZT film thickness of 60μm has been made and from Figure 2 such film thickness enables Z(A,B) to be about 66% of its maximum value. The silver paste top electrode in Figure 3 is used to evaluate the piezoelectricity of the PZT film. Such silver paste can be enlarged as shown in Figure 4 or removed by acetone. Using a cutter, the energy harvesting sensor with specific sizes can be made as shown in Figure 4. The latter shows a silver paste top electrode with a diameter of 17mm that was made. Two gold wires in which one is redundant were used for the electrical connection to the top electrode. The sol-gel spray fabrication approach can be used to conveniently fabricate bimorphs as well. Figures 5(a) and 5(b) show typical bimorphs with and without top silver paste electrodes, respectively. Using an optical interferometer, the transverse piezoelectric constant d_{31} of the PZT film was measured to be -30×10^{-12} m/V.

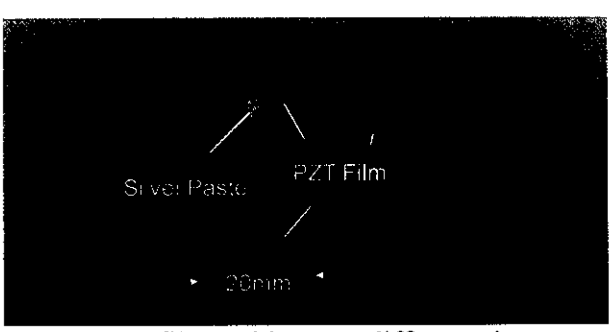


Fig. 3: PZT films with many different sizes on 38μm thick SS membrane.

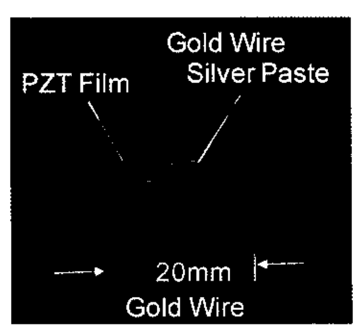
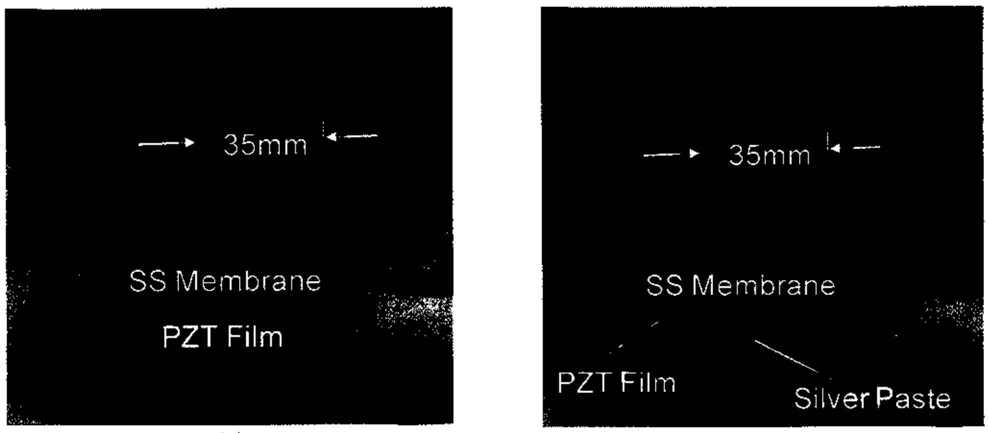


Fig. 4: One unimorph energy harvesting sensor.



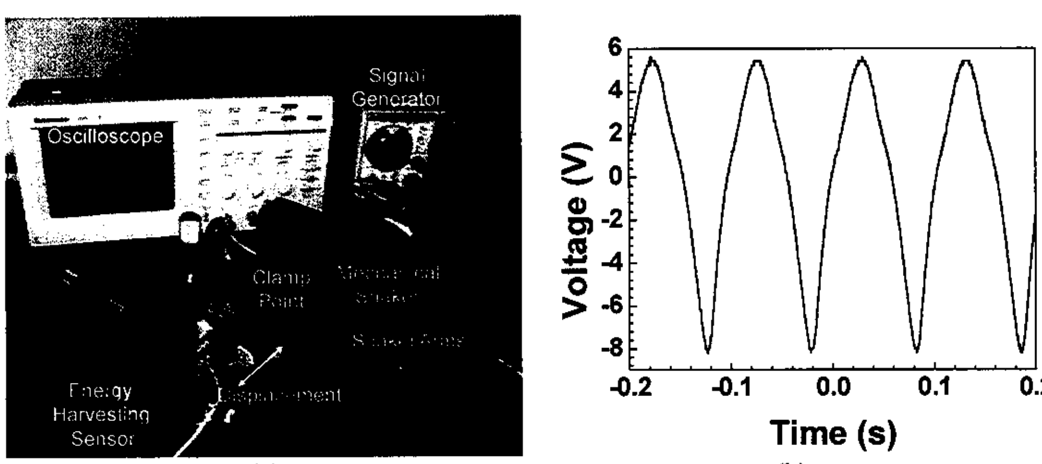
(a) (b)

Fig. 5: A typical bimorph (a) with and (b) without electrodes.

EXPERIMENTS

Displacement measurement and power evaluation

Figure 6(a) shows the experimental setup of the displacement measurements. This setup is composed of an energy harvesting sensor as shown in Figure 4, an electro-mechanical shaker, a clamp, a signal generator to drive the shaker, and an oscilloscope to monitor the generated voltage. In Figure 6(a) the δ induced by the shaker at 10Hz is 5mm. The generated V waveform is given in Figure 6(b). At 10Hz, the peak to peak voltage generated was 13.6 volts. With a load resistance of 150KΩ, the voltage obtained was 3.5volts and the average power is estimated to be 41μW.



(a) (b)

Fig. 6 (a) Experiment setup for the displacement measurement and (b) the generated voltage waveform at 12 Hz.

Vibration durability test

The durability of the vibration based energy harvesting device is a critical issue. An experimental setup for the vibration durability test of the energy harvesting sensor is shown in Figure 7 and consists of an energy harvesting sensor like the one shown in Figure 4, a vibrator, a clamp, a signal generator to drive the vibrator via a drive, and an oscilloscope to monitor the generated voltage waveform. The vibration frequency was 10Hz and the displacement was about 1mm. After sixty days of continuous test, there is no deterioration of the energy harvesting sensor. This indicates that the sensor fabricated by the sol-gel spray method is rugged.

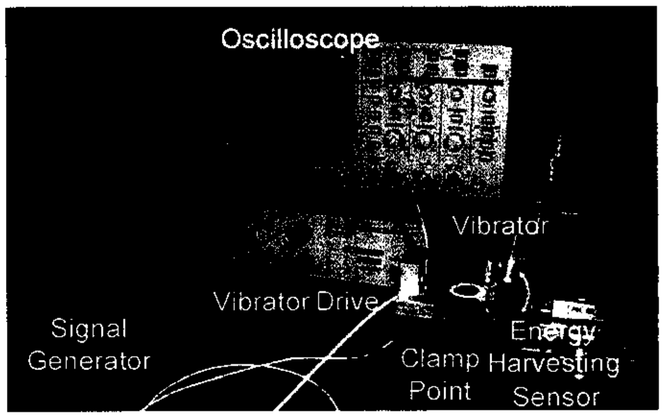


Fig. 7: Experimental setup for the vibration durability tests of the energy harvesting sensor.

CONCLUSIONS

Using a unimorph theory which provides the relation between the voltage, V, generated and the displacement of the free end of a unimorph, δ, energy harvesting sensors consisting of a 38μm thick stainless steel membrane and PZT composite films were designed and fabricated. The PZT composite film was made of a sol-gel spray technology, which may be used to fabricate unimorph and bimorph sensors conveniently. At present, the thickness of the PZT films made was 60μm. The top electrode was made with silver paste. A compromise was made between the density and the bending ability of the PZT film. The higher the density of the PZT film, the larger is the piezoelectricity, but the poorer is the bending ability. For this study, the density of the PZT film was less than 85% of the bulk PZT. Using a 20 mm diameter unimorph, the voltage generated from a 5 mm deflection displacement was 13.6 volts peak-to-peak at 10Hz. With a load resistance of 150KΩ, the measured average power generated by this sensor was estimated to be 41μW. The durability evaluation of a vibration test that lasted for sixty days with a frequency of 10Hz and at a displacement of about 1mm showed that the sensor is rugged.

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