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Metal Layer reinforced multilayer ferroelectret-based energy harvester

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Metal Layer reinforced multilayer ferroelectret-based energy harvester

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Abstract. This paper presents a flexible insole energy harvester made from multiple layers of ferroelectret polymer foams and nickel metal films. The ferroelectret stack has been fabricated by distributing a number of layers of nickel film through the ferroelectret. The addition of the thin metal films has improved the mechanical coupling to the ferroelectret foams within the stack and enhanced its voltage and energy output.

1. Introduction

A ferroelectret is a polymer foams with porous structure (void) filled with air and the elastic polymer-air composites has electric charge stored at its air-polymer interfaces around the void. When compressed, the ferroelectret polymer foam generates an electrical signal that can be used as a sensor output or energy harvester [1, 2]. When used as an energy harvester, the electrical output is typically rectified and stored in a capacitor. Polypropylene (PP) film is a flexible and porous polymer film with thickness between 70 to 80 µm, and young's modulus of about 1 MPa in the thickness direction, this soft and thin film is very suitable for an insole energy harvester providing a comfortable solution for users [3]. The energy harvesting ability of porous PP film has been investigated in our previous study, each single piece of PP ferroelectret can only generate 1.12 µJ under 800N of compressive force. When used as an energy harvester, the electrical output from a single piece of PP ferroelectret is not enough to power any commercial low-power chipsets at present. Therefore it is essential to stack up multiple number of parallel connected PP films.

Previous work showed that an 80-layer insole ferroelectret could switch on and maintain transmission a low-power ZigBee transmitter chipset [4]. However this work also showed that the energy output of the multilayer ferroelectret is not proportional to number of PP ferroelectret films parallel connected in the device. This is because when the stack is compressed, each individual pp layer experiences a different amount of stress. The stress experienced by the PP film located at the centre of the stack decreases as the number of layers increases.

This paper presents an investigation into the influence of additional thin metal films inside the multilayer energy harvester to improve the mechanical coupling to the ferroelectret foams within the stack. In this work all of the PP ferroelectret films were coated with silver layer on the top and bottom surfaces and connected in parallel. Three thin nickel films were placed in between the PP layers, distributed evenly through the stack and bonded together. The PP ferroelectret energy harvester stack was tested with quantified force and frequency to study their performance as energy harvester.

2. Concept

Figure 1 shows the schematic of the multilayer ferroelectret made with 10 PP films with three nickel films distribute through the stack symmetrically around the centreline. When force is applied to the stack, the voids deform and generate an electrical output due to the movement of individual electric dipoles. In comparison with the PP films located at the top and bottom of the ferroelectret stack, the PP films close to the centreline (PP layer 5 and 6) experience the least deformation and generate a lower output voltage. This lower voltage causes an uneven distribution of charge throughout the thickness of the stack reducing the net voltage and energy output.

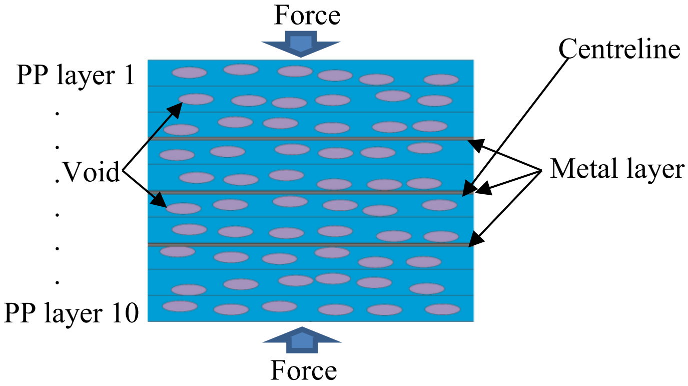

Figure 1 Schematic of the multilayer ferroelectret made with 10 PP films and three metal layers

In this design the Young's modulus of the metal layers are far greater than the Young's modulus of the PP films. When compressed, the metal films distribute the load more evenly across the stack resulting in a more consistent strain in each PP layer.

3. Experimental

The device presented here was fabricated using commercial available PP films (230 mm × 210 mm) purchased from Emfit Ltd. These films were cut into size of 45 mm × 70 mm and they were charged by the manufacturer. A silver paste (DuPont d5000) was printed onto each side of the PP film using a Dek 248 screen printer to form the top/bottom electrodes. Each silver electrode has an area size of 40 mm × 65 mm and the silver was cured in a box oven for 10 minutes at 50ºC.

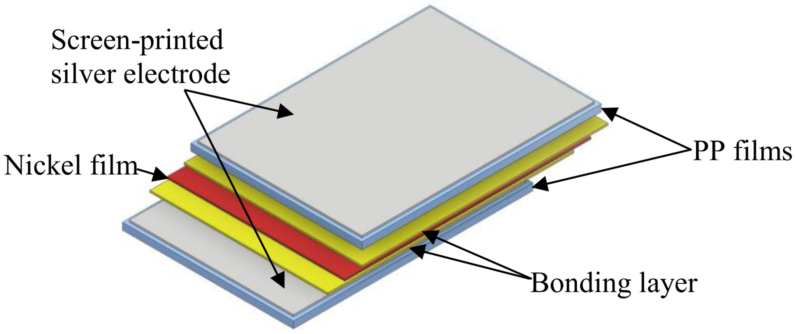

Figure 2. Device schematic showing a two PP layer and one nickel film stack with printed silver electrodes on each PP layer and with adhesive bonding layer.

The multilayer ferroelectret made by stacking 10 layers of silver coated PP films using adhesive films (Tesa® 64621). The adhesive film bonds layers together and provides insulation between layers that prevents self-discharge. All of the ferroelectret layers stacked in the device were connected in parallel. The three pieces of nickel films (40 µm thick each and Young's modulus of 1 GPa) were placed at the

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3th, 6th and 8th bonding interface (figure 2). A cross section photograph of the multilayer ferroelectrets fabricated with and without nickel inserts are shown in figures 3(a) and 3(b). Both were fabricated simultaneously from the same PP sheets to enable comparison between them.

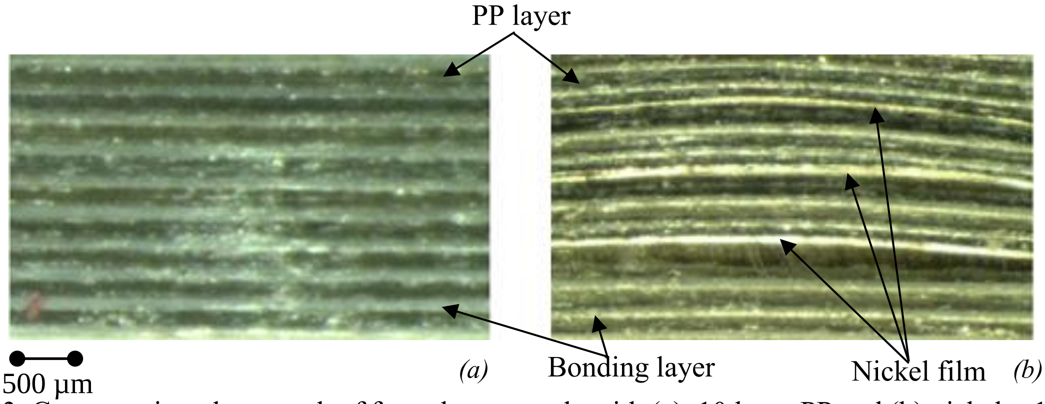

Figure 3. Cross-section photograph of ferroelectret made with (a), 10 layer PP and (b) nickel + 10 layer PP

The output voltage of the 10 layer PP and nickel + 10 layer PP ferroelectret were measured using an oscilloscope when the samples were compressed using an Instron electrodynamic instrument (ElectroPuls E1000, Instron Ltd). This applied a periodical square wave force of 800 N on the ferroelectret energy harvester samples at 1 Hz frequency. The electrical pulses generated from both ferroelectret stacks was rectified and stored on a 10 µF capacitor.

4. Result and discussion

The output voltage obtained from the ferroelectrets made with 10 layer PP and nickel + 10 layer PP are shown in figure 4(a). The maximum voltage output of the nickel + 10 layer PP ferroelectret (2.62 V) is 0.52 V higher than the 10 layer PP ferroelectret (2.1 V).

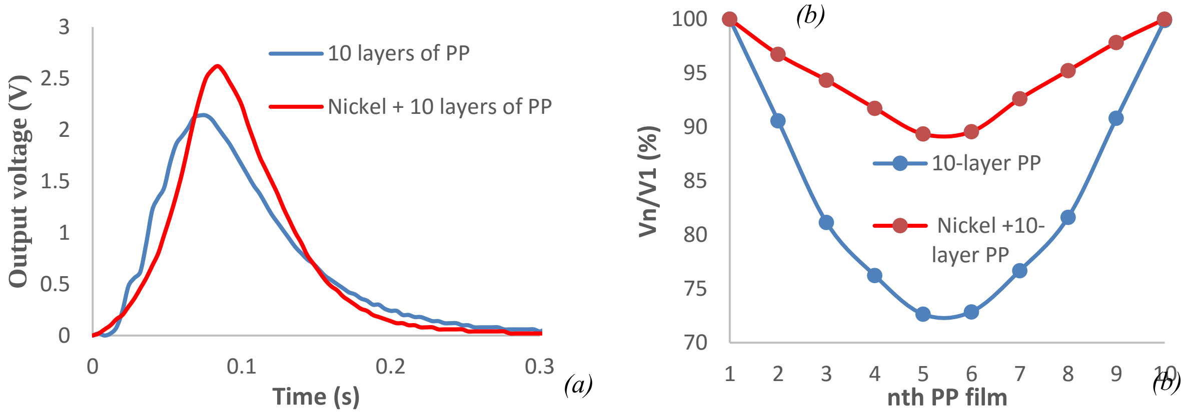

Figure 4 (a) Voltage output of ferroelectret made with 10 layer PP and nickel + 10 layer PP; (b) maximum voltage output of the each individual PP layer in the ferroelectret stack for both the 10 layer PP and nickel + 10 layer PP.

In figure 4(b) the maximum voltage output of the each polymer layer has been indexed to the voltage of the outer most layer (n = 1 and 10). The voltage output of layer n = 5 and 6 are only 72 % of V1. However, in nickel + 10 layer PP ferroelectret, the layers n = 5 and 6 achieve over 90 % of the maximum voltage output. These results indicate the additional nickel films improves the maximum voltage output deformation of the PP ferroelectret films close to the physical centre of the multilayer stack.

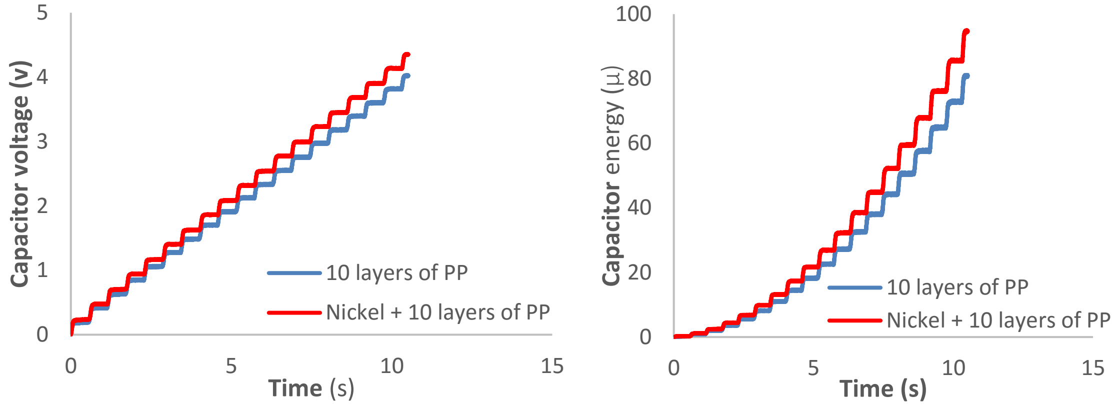

Figure 5 (a). Voltage charging curve of a 10 μF capacitor charged by ferroelectret made with 10 layer PP and 10 layer PP + Nickel, (b) Energy stored in a 10 μF capacitor charged by ferroelectret made with 10 layer PP and nickel + 10 layer PP

The charge output was stored on a capacitor to enable accurate calculation of the energy output. The capacitor voltage during the test was recorded and found to be 4.35 V for the nickel + 10 layer PP ferroelectret and 4.01V for the 10 layer PP ferroelectret after 10 mechanical cycles (figure 5(a)). Using the equation $E = 0.5CV2$, where C is the capacitance of the capacitor, V is the voltage of the capacitor, the energy E collected in the first 10 cycles by a nickel + 10 layer PP ferroelectret (94.6μJ) is 17.6% higher than a 10-layer PP ferroelectret (80.4 μJ) (figure 5(b)). It shows the additional nickel film increase not only the maximum voltage output of the multilayer PP ferroelectret but also improve its energy output.

5. Conclusion

This paper presents the design, assembly and test results of an energy harvester made of multilayer PP ferroelectrets and nickel metal films. Mechanical test indicates that the nickel layers couple the mechanical forces more effectively through the multilayer ferroelectret stack, in comparison with the multilayer PP ferroelectrets without the nickel metal films. The additional nickel layers increases the deformation to PP ferroelectrets at the centre of the energy harvester stack and this improves the voltage and energy output. It will enhance the performance of insole energy harvester, without affecting user comfort. Future work will focus on further improving the energy harvester voltage and energy output by using metal film with different thickness and Young's modulus.

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References
[1] J Hillenbrand and G M Sessler, IEEE Trans. Dielectr. Electr. Insul 2000, 7, pp. 537-42
[2] G S Neugschwandtner, R Schwodiauer, S Bauer-Gogonea, S Bauer, M Paajanen, and J Lekkala, J. Appl. Phys 2001, 89 pp. 4503-11
[3] Z Luo, D Zhu, J Shi, S P Beeby, C Zhan, P Proynov and B Stark, IEEE Trans. Dielectr. Electr. Insul 2015. 22 pp. 1360-68
[4] Z Luo, D Zhu and S P Beeby, PowerMEMS 2015, pp. 660-65