Micro-fabricated Liquid Encapsulated Energy Harvester with Polymer Barrier Layer as Liquid Electret Interface

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Abstract. This paper addresses the electret discharge issue for liquid based electret energy harvesters. An interface structure of PDMS/PTFE polymer barrier layer between liquid and electrets is introduced, achieving 75% charge retain rate over 100h, compared with 0% without the proposed layer over 100h. Further, the PDMS/PTFE layer is introduced into liquid encapsulated energy harvester (LEEH) and is compatible with micro-fabrication process. The retain rate of device voltage is about 47%~65% over 100h. At 100h after corona charging, the device generates maximally 3.7V, 0.55μW @1Hz rotation.

1. Introduction

Liquid based electrostatic energy harvesters are recently brought forward in [1-2] with working frequency typically on the order of 0.1~10Hz, which is suitable for harvesting energy from low frequency vibrations. Such low working frequency can hardly be achieved by resonance based harvester structures such as cantilevers [3] or spring mass damper systems [4-5].

However, among the reported electrostatic energy harvesters using liquid, most only measure the capacitance change, while power output is estimated using external voltage source rather than using electrets [1,6]. One key reason is that the electrets discharge significantly when in contact with liquid, as is shown in Fig.1(a). Possibly, charges recombine with positive groups in the liquid, or transfer to sidewalls or electrode from the electrets. In either circumstance, surface potential of electrets decreases significantly, which implies very short lifespan of the harvester.

It is essential to solve the electret discharge issue for liquid based energy harvesters. In this paper, a method of polymer barrier layer is presented, which isolate electret surface from direct contact with liquid and from the infiltrative liquid vapor. The proposed polymer barrier layer is compatible with the micro-fabrication process of liquid encapsulated energy harvester (LEEH), and the power generation capability and improved reliability of LEEH are experimentally verified.

2. Concept

As is shown in Fig.1(b), polymer barrier layer is introduced at the liquid electret interface. The polydimethylsiloxane (PDMS) layer protects charges in electrets from direct contact with liquid and guarantees large contact angle for liquid motion. Further, in terms of fabrication it is feasible to bond PDMS liquid cavity with the barrier PDMS layer. Since PDMS layer is of high moisture permeation rate, it is important to introduce beneath the PDMS layer an additional polytetrafluoroethylene (PTFE) layer, which is of low moisture permeation rate and thus protect trapped charges in electrets from moisture. The combined effects of PDMS/PTFE polymer barrier layer can further improve charge storage stability of electrets in liquid environment.

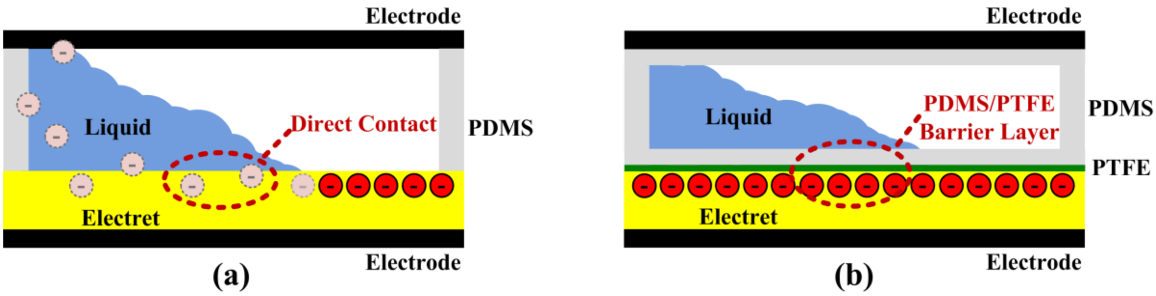

Fig.1 Concept of liquid electret interface: (a) direct contact, electrets discharge in contact with liquid; (b) this design, with PDMS/PTFE polymer barrier layer as liquid electret interface.

3. Experiment

3.1. Fabrication

The proposed PDMS/PTFE polymer barrier layer is utilized in micro-fabrication of LEEH, and the process flow is shown in Fig.2. PDMS is poured into SU-8 mold (600µm thickness) and cut into cavity units after curing and peeling-off. The PDMS cavity units are then bonded with a flat PDMS mold layer with controllable thickness (50µm-1mm). PTFE aqueous solution is curtain coated on the flat PDMS layer.

Assembly process includes three steps. First, di-methylformamide (DMF) is injected into PDMS cavity using micro-syringe. DMF is chosen due to its large dielectric constant and low viscosity [2]. The hole for injection is covered with a small amount of liquid PDMS and cured to keep watertight. Second, thin film PTFE electrets are attached on the electrode and corona charged. Surface potential of thin film PTFE electrets is recorded using electrometer (TREK 344), which is approximately -700V. Finally, the above two parts are combined by pasting the edge together, with curtain coated PTFE layer facing the electrets, so as to reduce the possible parasitic capacitance.

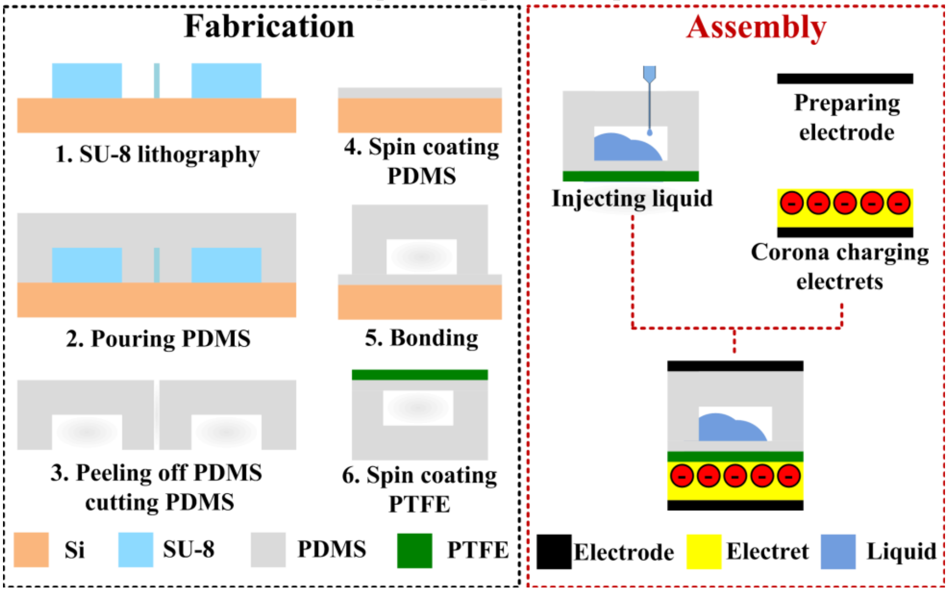

Fig.2 Fabrication and assembly process

Fig.3 shows the fabrication results. In Fig.3(a), the thickness of curtain coated PTFE layer is not uniform, achieving average thickness of 80µm. This is because the non-wetting feature of both PDMS and PTFE renders it difficult to fabricate a flat and smooth interface layer. Fig.3(b) is the photo of fabricated PDMS cavity arrays after demolding. Cavity dimension is 4.4mm×3.4mm×0.6mm. Fig.3(c) shows the assembled LEEH. The size of the entire device is 6.5mm×5.4mm×4.3mm.

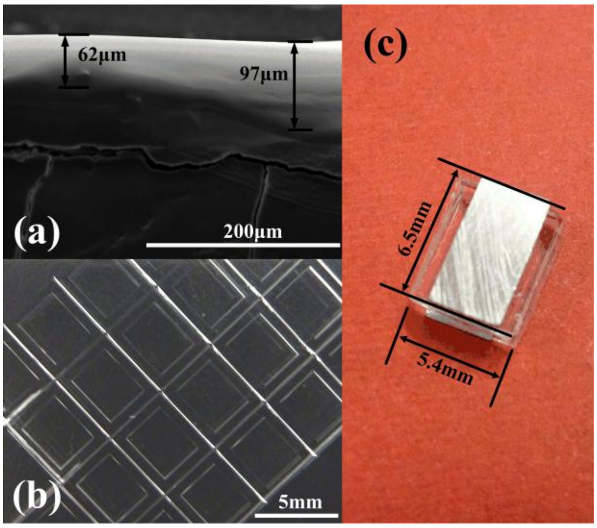

Fig.3 Fabrication result: (a) SEM image of PTFE/PDMS interface; (b) optical image of PDMS cavity arrays after demolding; (c) photo of micro-fabricated and assembled LEEH.

3.2. Testing

Our previous work shows that LEEH generates more power in rotation than in in-plane vibration [2]. Therefore, only rotary test is adopted here. LEEH is positioned on one side of the stepping motor shaft, and is driven by out of plane rotation (0~360° continuously). The rotation frequency is controlled at 1Hz. During test, output voltage is recorded using Agilent 34410A digital multimeter with 10M input resistance probe.

4. Results and discussion

Fig.4 shows that thicker PDMS/PTFE layer is conducive to more stable charge storage in liquid environment, at the cost of lower surface potential due to the dielectric loss within the thick layer. Thus thickness of PDMS/PTFE layer should be traded off between high surface potential and high charge retain rate in liquid environment. In this work, PDMS/PTFE layer with 200μm/80μm thickness is adopted, corresponding to -636V surface potential and 75% retain rate over 100h.

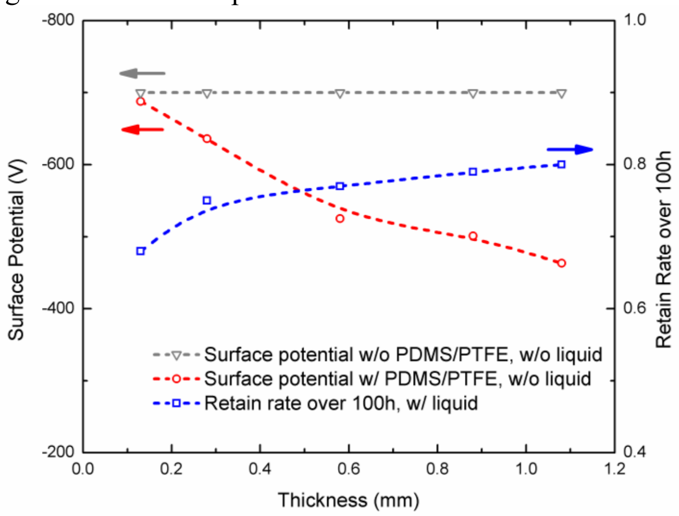

Fig.4 Surface potential and retain rate (over 100h) for different thicknesses of PDMS/PTFE layer.

Fig.5 shows the effect of the 200μm/80μm PDMS/PTFE layer in maintaining surface potential in liquid environment. Within 0.5h, the surface potential retain rate is 93% for both PDMS/PTFE layer and PDMS layer (200μm), while that of direct contact is 12%. From 0.5h to 100h, the retain rate decreases to 75% for PDMS/PTFE layer and 44% for PDMS layer, indicating the necessity of PTFE layer for shielding moisture over the long term. The retain rate of direct contact is 0% over 100h.

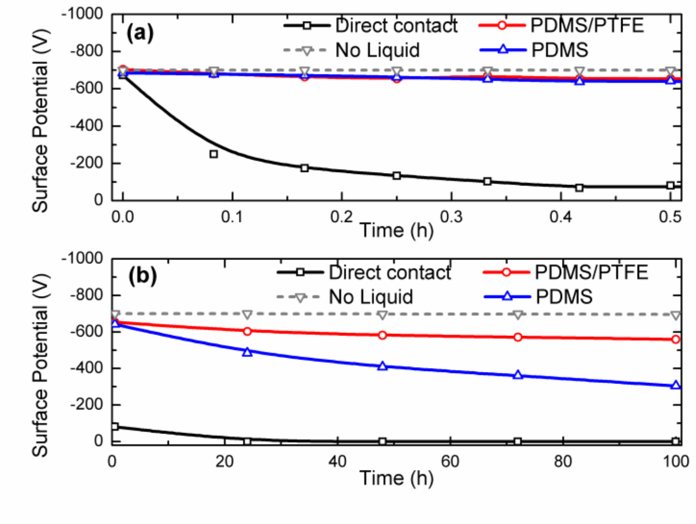

Fig.5 Surface potential decay curves for (a) short term (0~0.5h); (b) long term (0.5~100h).

Fig.6 shows the voltage-time trace @1Hz rotation on 5MΩ resistance at 0.5h and 100h after corona charging. The frequency of voltage-time traces are typically 2Hz, because during one rotation (1s) the capacitance change is symmetrical. In Fig.6(a), maximal and minimal voltage are 1.20V and -1.99V, while that in Fig.6(b) are 0.79V and -0.95V. Thus device voltage retains by 47%~65% over 100h.This lower retain rate is possibly related to degraded paste for package in liquid environment.

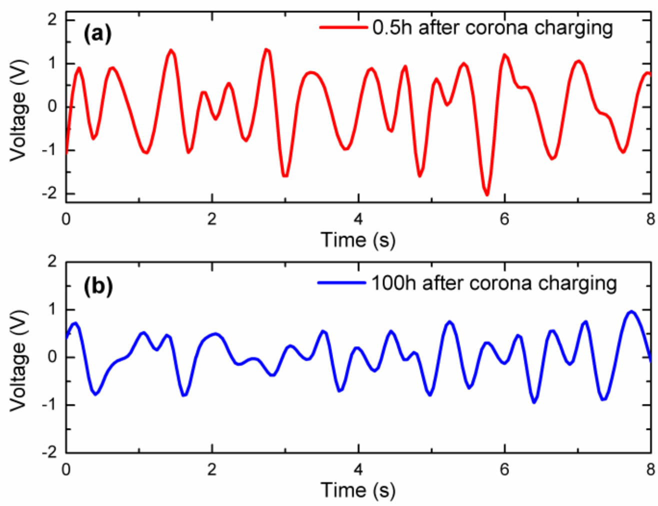

Fig.6 Voltage-time trace of LEEH with PDMS/PTFE layer: (a) 0.5h after corona charging; (b) 100h after corona charging.

Fig.7 shows power-resistance trace of micro-fabricated LEEH at 100h after corona charging. Load resistance changes from 1MΩ to 60MΩ. Maximally, 3.7V voltage and 0.55μW power are achieved on

25MΩ resistance @1Hz rotation. These results prove that the PDMS/PTFE polymer barrier layer is effective in extending the lifespan of liquid based electret energy harvester. It is believed that a thinner and more uniform polymer barrier layer will further enhance the long-term reliability and improve device output power.

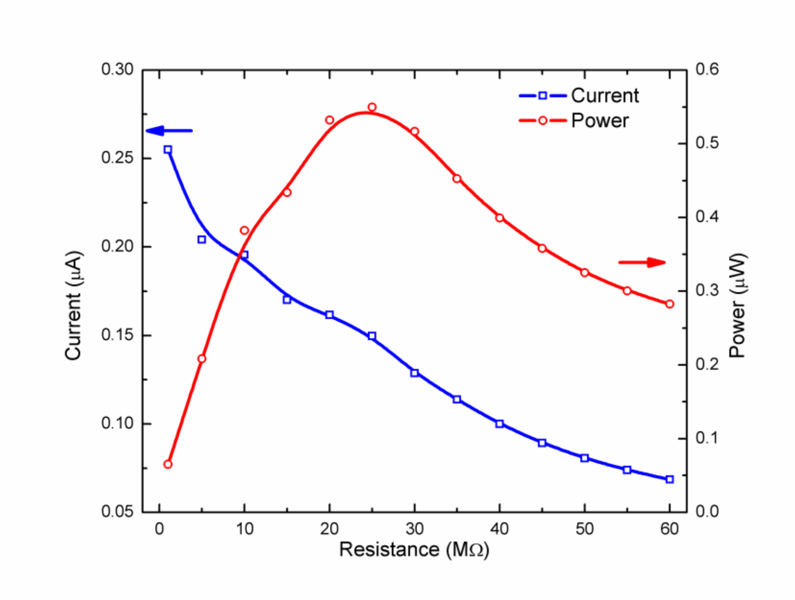

Fig.7 Power-resistance trace of LEEH with PDMS/PTFE polymer barrier layer.

Conclusion

This paper presents PDMS/PTFE polymer barrier layer to address the electret discharge issue for liquid based electret energy harvesters. the PDMS/PTFE layer is compatible with micro-fabrication process of liquid encapsulated energy harvester (LEEH). The PDMS/PTFE polymer barrier layer achieves 75% charge retain rate over 100h, compared with 0% without the proposed layer over 100h. Device voltage retain rate is about 47%~65% over 100h. At 100h after corona charging, the device generates maximally 3.7V, 0.55μW @1Hz rotation.

Acknowledgements

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