A Skin-attachable Flexible Piezoelectric Pulse Wave Energy Harvester

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Abstract. We present a flexible piezoelectric generator, capable to harvest energy from human arterial pulse wave on the human wrist. Special features and advantages of the flexible piezoelectric generator include the multi-layer device design with contact windows and the simple fabrication process for the higher flexibility with the better energy harvesting efficiency. We have demonstrated the design effectiveness and the process simplicity of our skin-attachable flexible piezoelectric pulse wave energy harvester, composed of the sensitive P(VDF-TrFE) piezoelectric layer on the flexible polyimide support layer with windows. We experimentally characterize and demonstrate the energy harvesting capability of 0.2~1.0μW in the Human heart rate range on the skin contact area of 3.71cm^2. Additional physiological and/or vital signal monitoring devices can be fabricated and integrated on the skin attachable flexible generator, covered by an insulation layer; thus demonstrating the potentials and advantages of the present device for such applications to the flexible multi-functional self-powered artificial skins, capable to detect physiological and/or vital signals on Human skin using the energy harvested from arterial pulse waves.

1. Introduction

In recent years, continuous physiological or vital signal monitoring in daily life has become conspicuously prevalent in wearable devices. Wearable devices for physiological or vital signal monitoring need power supply for the stable measurement of Human signals, such as arterial pulse wave, skin temperature, and skin conductance signals. Among the Human signals, the arterial pulsation has been considered as an energy harvesting power source for the wearable devices. The conventional energy harvesting from arterial pulsation was either invasive or non-invasive. The invasive devices [1] need surgery for device implant. Among the conventional non-invasive devices, the piezoelectric energy harvesting [2] is promising due to device simplicity. The piezoelectric energy harvesting devices, however, need rigid layers to support piezoelectric material layers; thus, reducing the device flexibility required for better energy harvesting efficiency through conformal skin contact. In this paper, we propose a non-invasive skin-attachable flexible piezoelectric generator (figure 1), where a silver electrode layer is sandwiched between a P(VDF-TrFE) piezoelectric layer and a polyimide support layer with windows for improving device flexibility, skin conformability and energy harvesting efficiency.

The originality and novelty of our device include: 1) the polyimide support layer design with the windows; 2) the simple fabrication process employing the multi-purpose silver interlayer between the piezoelectric layer and the support layer. The windows in the polyimide support layer are intended not

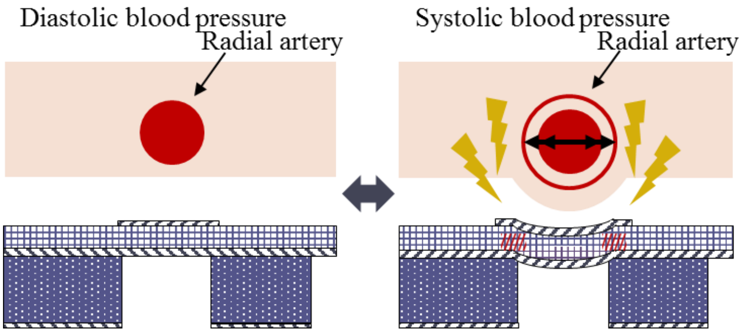

Figure 1. A skin-attachable flexible piezoelectric generator, harvesting energy from heart-beat pulse waves on Human wrist.

only to increase the sensitivity of electric generation from the arterial pulsation, but also to enhance the device flexibility and skin conformability on Human wrist. The purpose and functions of the silver electrode layer (figure 2) are three-fold: 1) an etch stop layer for the wet etching process using KOH, ethanol, and DI to pattern windows on the polyimide support layer; 2) an electrode layer for piezoelectric poling process; 3) an electrode layer for piezoelectric energy harvesting. The idea of triple-purpose silver electrode layer enables us to fabricate the flexible piezoelectric generators with the simple process of figure 3. In addition, the flexible generator devices are covered by the insulation layers, on which additional devices can be fabricated or integrated. The present skin-attachable flexible piezoelectric pulse wave energy harvester has potentials for applications to the flexible multi-functional self-powered artificial skins, capable to detect physiological and/or vital signals on Human skin using the energy harvested from arterial pulse waves.

2. Energy Harvesting Principle and Device Design

The skin-attachable flexible piezoelectric generator is comprised of a silver electrode layer sandwiched between the P(VDF-TrFE) piezoelectric layer and the polyimide support layer with the windows. Figure 1 illustrated the principle of energy harvesting from the arterial pulsation on Human wrist. Due to the systolic blood pressure, the radial artery expends and applies mechanical stress to the P(VDF-TrFE) piezoelectric layer, supported by the polyimide support layer; thus, inducing electric potential across the piezoelectric layer.

We design the skin-attachable flexible piezoelectric generator (figure 2) to have the skin contact area of 25mm x 15mm with the thickness of 70μm. The square windows in the polyimide support layer are designed in the size of 6mm x 6mm, which is large enough to cover the radial artery in the diameter of 3~5mm. We design the thickness of the piezoelectric P(VDF-TrFE) layer (figure 2) as 20μm, which is the feasible thickness [3] for poling process.

3. Fabrication

Figure 3 indicates the fabrication process of the skin-attachable flexible piezoelectric generator. A 50μm-thick polyimide film (Kapton® HN, Dupont™) is attached on the PDMS-coated silicon wafer, followed by the thermal evaporation of 0.5μm-thick silver on the polyimide film. We spin-coat the 75:25 P(VDF-TrFE) (Measurement Specialties) and Methyl Ethyl Ketone (MEK, Sigma Aldrich) solutions of 35wt% to form a 20μm-thick piezoelectric layer on the evaporated silver. We thermally evaporate 0.3μm-thick aluminum layer and patterned the aluminum layer to define the electrodes for piezoelectric energy harvesting. We detach the polyimide film from the surface of the PDMS-coated silicon wafer and attach the electrode side of the detached film to the PDMS-coated silicon wafer.

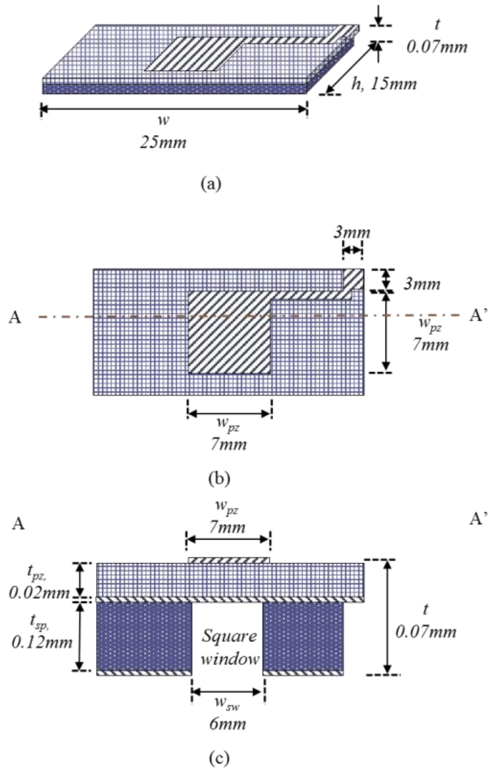

Figure 2. The skin-attachable flexible piezoelectric generator: (a) overall structure; (b) top view; (c) cross-sectional view along A-A' of figure 2b.

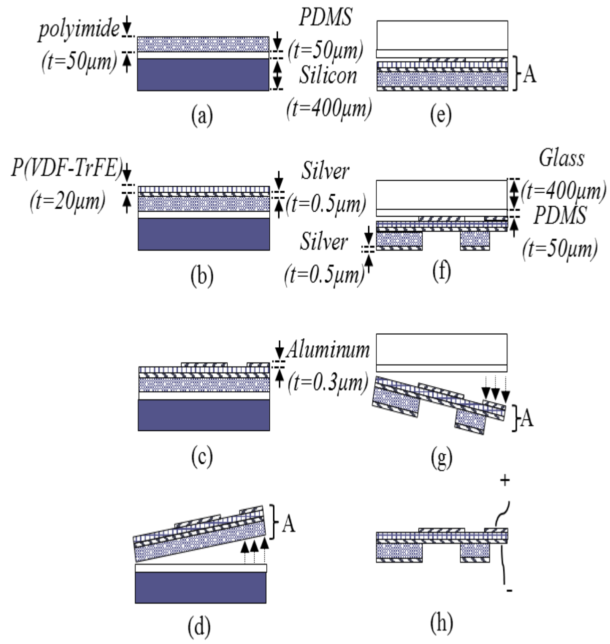

Figure 3. Fabrication process of the skin-attachable flexible piezoelectric generator.

We etch the polyimide film using the KOH, Ethanol, and DI (1:8:2) etchant [4] with the silver shadow mask for 20 minutes, followed by the 21-minute DI water dipping process to remove the high viscous residue; thus, forming the square windows through the polyimide supporting layer and the interlayer electrode on the P(VDF-TrFE) layer. Finally the fabricate device is released from the surface of the PDMS-coated silicon wafer to obtain the skin-attachable flexible piezoelectric generator.

4. Test Methods and Experimental Results

The fabricated skin-attachable flexible generator (figure 4a), having the skin contact area of 24.7mm x 15.0mm, the thickness of 70μm and the weight of 49.5mg, has been characterized by the PDMS artificial pressure actuator (figure 4b), simulating the 4mm-wide human radial artery producing Human arterial pulse waves.

Figure 5 illustrates the output response of the fabricated device for the input pressure pulse of 40mmHg (which is the human systolic and diastolic arterial pressure difference of resting period) for the Human heart rate, varying in the range of 50~220 BPM. We measure the generated energy from the flexible piezoelectric generator in terms of the RMS values of the time-dependent output voltage across 10MΩ resistor. From the 40mmHg pulse waves on the skin contact area of 3.71cm^2, the flexible piezoelectric generator is experimentally harvest the energy of 0.20±0.02μW at 50BPM, 0.70±0.05μW at 135BPM, and 1.00±0.03μW at 220BPM, respectively.

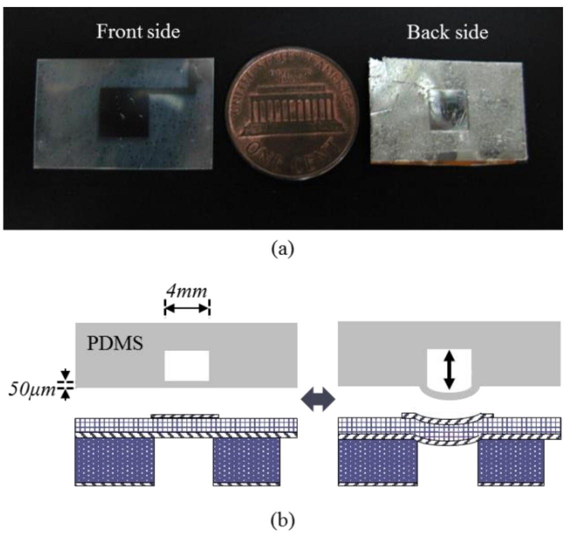

Figure 4. The fabricated flexible piezoelectric generator, (a) compared to US penny and (b) attached to an artificial pulse wave device for experimental energy harvesting performance characterization

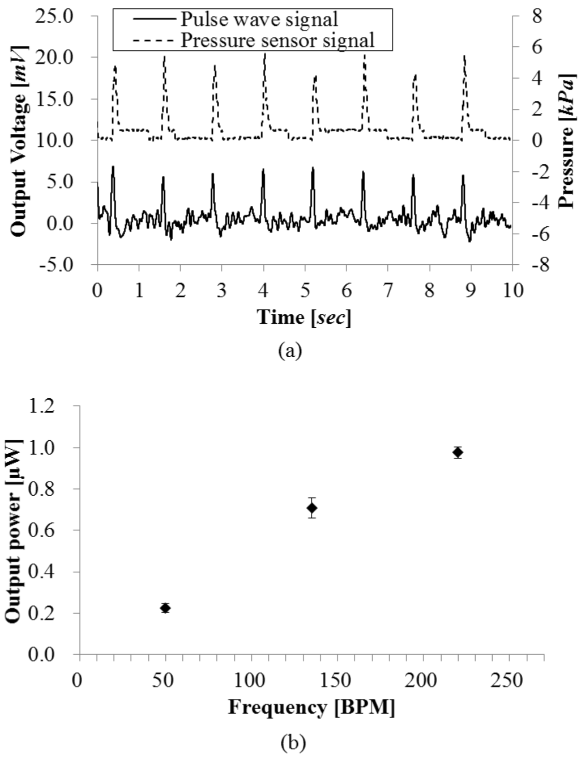

Figure 5. Experimental performance of the skin-attachable flexible piezoelectric generator for the pulse wave pressure of 40mmHg: (a) the time-dependent output voltage of the generator at the pulse wave frequency of 50BPM; (b) the frequency-dependent output power of the generator at 50, 135 and 220 BPM, respectively.

5. Conclusion

We have designed, fabricated, and characterized the skin-attachable flexible piezoelectric generator, composed of the flexible polyimide support layer with windows and the sensitive P(VDF-TrFE) piezoelectric layer, for harvesting energy from human arterial pulsation on Human wrist, We experimentally demonstrate the energy harvesting performance of the device in the range of 0.2~1.0μW from the small skin contact area of 3.71cm^2, where the pressure of 40mmHg (which is the difference of Human systolic arterial pressure and diastolic arterial pressure at Human resting period) is applied at the Human heart rate range of 50~220 BPM. The skin-attachable flexible generator is covered by the insulation layer, on which additional devices can be fabricated and integrated to measure Human physiological and/or vital signals. The flexible piezoelectric generator, capable to collect energy non-invasively from the arterial pulsation on Human wrist, has improved wearing comfort with the higher flexibility and the better conformal skin contact; thereby, demonstrating potentials for applications to the flexible multi-functional self-powered artificial skins, capable to detect physiological and/or vital signals on Human skin using the energy harvested from arterial pulse waves.

Acknowledgements
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