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Fully casted soft power generating triboelectric shoe insole

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Abstract. Power generating soft triboelectric based shoe insole fully elastomeric and compatible with large-scale fabrication technique has been developed. During the process, film casting and stencil printing techniques were implemented to deposit/pattern elastomeric and soft/flexible materials, such as, polydimethylsiloxane (PDMS) and polyurethane (PU). Carbon-based elastomeric materials were used as electrodes, which were also film casted. The developed triboelectric generator (TENG) was capable of harnessing electrical power effectively from mechanical deformation of the system during walking or running activities. The performance of the device was tested for walking with frequency of 0.9±0.2 Hz. The power (rms value) of 0.25 mW was achieved for load resistance of 100 MΩ, which corresponded to the power density (rms value) of 1.9 μW/cm^2.

1. Introduction

The limitation regarding lifetime, immobility and toxic hazards, of traditional power supply, like, batteries, encourage researchers to explore the alternative sources for energy to develop maintenance-free/ autonomous electronics system. With the fast development of wireless sensors and consumer electronics, the urge for self-powered autonomous system is even stronger. Various ambient kinetics motions and mechanical vibrations, that is generally wasted in everyday life, can be used as renewable source to harvest energy and to develop green technologies.

Nanogenerator technology, that is capable of producing electricity from small variation of mechanical deformation, can be used to power portable electronics [1]. For many years, electromagnetic, electrostatic and piezoelectric mechanism are mainly implemented to harvest mechanical energy [2]–[4]. Triboelectric generator (TENG), which uses the contact electrification and electrostatic induction between materials having opposite electron affinity [5], can be used to convert kinetic energy to electrical energy efficiently. Since its first discovery by Prof. Wang's group in 2012 [1], TENGs have demonstrated the possibilities of exciting applications in mechanical energy harvesting. To date, several TENGs based energy harvesters have been reported [6]–[9]; however, most of their fabrication process is complex and none of them are truly compatible with the large scale fabrication method.

We are reporting the development of highly soft triboelectric based shoe insole using elastomeric materials as triboelectric and electrodes, which is compatible with large scale fabrication process and capable of generating power from human movement while walking or running.

2. Experimental procedure

2.1. Materials and design

The reported triboelectric generator, which uses cycled vertical contact-separation mechanism, was fabricated with casting technique. Elastomers and their composites were used both as triboelectric and electrodes materials during the fabrication process. Both triboelectric layers were facing each other separated by a spacer between them (Figure 1). The dimension/ geometric parameters of the TENG-shoe insole are listed in Table 1.

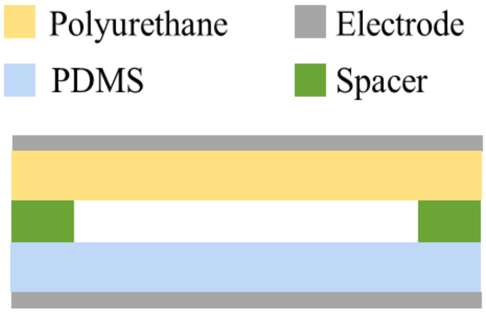

Figure 1. Schematic diagram of triboelectric based shoe insole.

Polydimethylsiloxane (PDMS, Sylgard 186) was purchased from DowCorning and polyurethane (PU, MM4520) was supplied by SMP Technology Inc. Electro-conductive carbon black pellets (Ketjenblack EC-300J & Ketjenblack EC-600JD) were purchased from Akzo-Nobel, which were used to prepare conductive elastomers and used as electrode for the devices. Solvents were purchased from Sigma-Aldrich. All products were used as received. Casting on flexible substrate was performed on commercially available polyethylene terephthalate (PET) film.

Table 1: Dimensions of TENG-based shoe insole

Total area	:	133 cm^2
Gap between two dielectric layers	:	2 mm
Thickness of PDMS layer	:	60 μm
Thickness of PU layer	:	50 μm

2.2. Experimental process

The fabrication process was composed of three parts, namely, preparation of first dielectric layer with electrode, preparation of second dielectric layer, and assembly. Initially, conductive carbon-black based PDMS ink was deposited on flexible PET substrate using film casting technique and baked at 80 °C for 2 hours. PDMS layer was then film casted on conductive layer and cured for 2 hours at 80 °C. On the other hand, conductive carbon-black based PU ink was film casted on thin PET film and cured on hot plate at 80 °C for 2 hours. Thereafter, PU dissolved in solvent was deposited on electrode layer using casting method, which acts as second triboelectric layer, and cured on hot plate. The surface of the substrate was rinsed with isopropanol and dried using blown nitrogen, prior to casting process. Finally, layers were assembled together having dielectric layers facing each-other and separated by a spacer between them. Figure 2 illustrates the process flow of TENG based shoe insole. Figure 3 shows the photograph of the top-view of the developed TENG-based shoe insole structure. Optimization was performed based on the effect of physical parameter, such as, layer stiffness, on output responses.

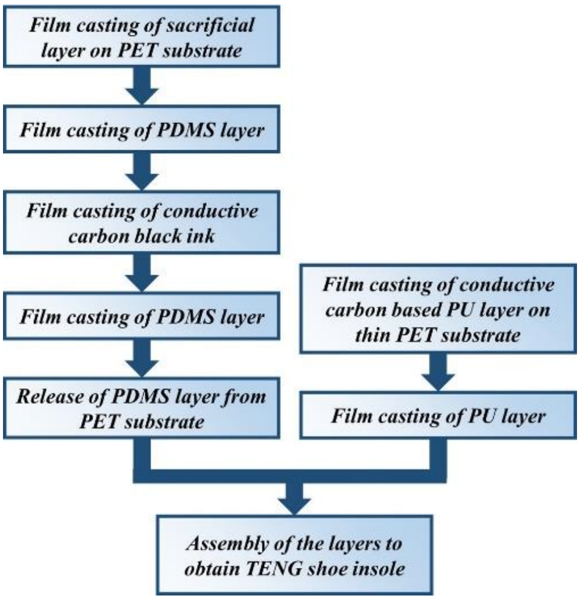

Figure 2. Flow chart of TENG shoe insole fabrication.

Figure 4(a) presents the experimental setup that has been used to record the electrical responses of the TENG-based shoe insole using oscilloscope while walking, and the amount of electrons in a single charge-transfer process was measured using experimental setup showed in Figure 4(b), where a capacitor (C_L) of 2.2 μF was used. Walking experiments were performed for the frequency of 0.9±0.2 Hz.

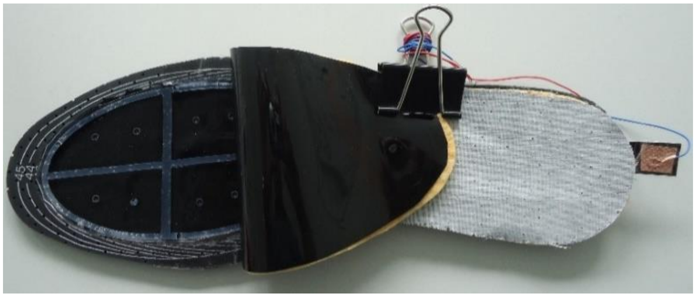

Figure 3. Top view of the TENG-based shoe-insole.

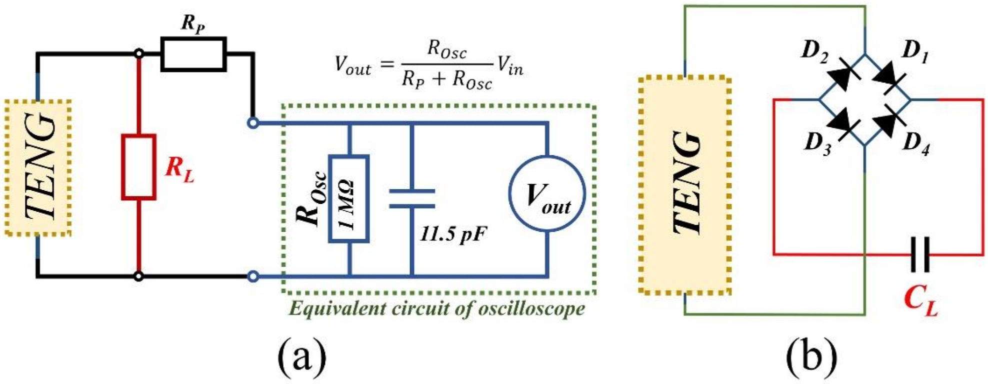

Figure 4. Schematic diagram of the measurement circuits (a) to characterize the electrical response and (b) to store energy generated by TENG-based shoe insole during walking.

3. Results and discussion

Fully casted elastomeric TENG-based shoe insole was tested while walking using electronics described above. Figures 5(a) to 5(c) illustrate the cycle of electrical responses generated by TENG-based shoe insole while walking. At initial state, the two dielectric layers were fully in contact with each other. Since PDMS is much more triboelectrically negative and has higher affinity towards negative charge than PU, electrons were injected from PU into PDMS, leading to the positive triboelectric charges on PU layer and equal amount of negative charges on PDMS layer.

As observed, the developed triboelectric generator was capable of generating open circuit voltage (rms value) of 312.1 V, and closed circuit current (rms value) of 1.14 μA for 100 MΩ load resistance, which corresponded to the power of 0.25 mW. The power density of the developed shoe insole was 1.9 $\mu W/cm^2$.

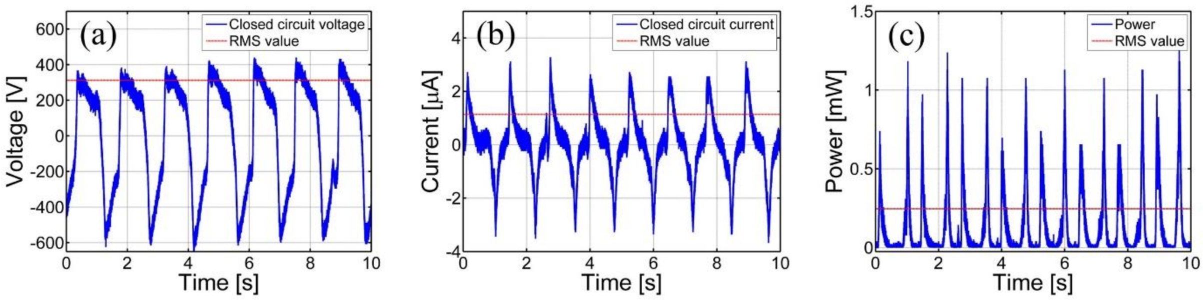

Figure 5. (a) Open circuit voltage; (b) closed circuit current for the load resistance of 100 MΩ; (c) power generated for closed circuit measurement for the load resistance of 100 MΩ.

The total charge transfer (Q_C) was obtained by measuring voltage (V_C) of the capacitor after walking for 10 steps and using relating $Q_C=C_LV_C$. Thereafter, the charge transfer in a single step was measured by dividing the Q_C by number of steps. The amount of electrons in a single charge-transfer process reached 0.89±0.03 μC, which corresponded to the surface charge density of 6.9±0.22 nC/cm^2 generated by TENG-based shoe insole while walking. Moreover, the corresponding energy stored in a 2.2 μF capacitor for single step was 0.18±0.01 μJ.

4. Conclusions

In summary, we have fabricated fully elastomeric, vertical contact separation mode TENG-based shoe insole using elastomeric PDMS and PU as triboelectric layer and carbon based elastomeric composites as electrodes. The developed TENG was capable of producing electrical energy from the kinetic energy/ movements while walking and/or running, and its fabrication process was simple, compatible with large scale fabrication method, and economical. High flexibility increased the durability of the device and capacity to withstand large deformation. Due to the mechanical deformation during walking, the fabricated TENG-based shoe insole provided power (rms value) of 0.25 mW for load resistance of 100 MΩ, which corresponds to the power density (rms value) of 1.9 μW/cm^2, and charge density of 6.9±0.22 nC/cm^2/cycle.

Further work will be focused on the test of different materials and designs, and on the improvement of the processing steps to develop TENGs with higher capability. In addition, encapsulation method and procedure will also be investigated to protect the TENG from humidity.

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