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Electrically conductive fabric based stretchable triboelectric energy harvester

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Electrically conductive fabric based stretchable triboelectric energy harvester

Rubaiyet I. Haque[1,2], Pierre-André Farine[2] and Danick Briand[1]

[1] Microsystems for Space Technologies Laboratory, École Polytechnique Fédérale de Lausanne, Neuchâtel, Switzerland
[2] Electronics and Signal Processing Laboratory, École Polytechnique Fédérale de Lausanne, Neuchâtel, Switzerland

E-mail: rubaiyet.haque@epfl.ch

Abstract. Stretchable conductive fabric-based triboelectric generator (TENG), to develop breathing/chest band for harvesting energy at low frequency has been developed. Stretchable conductive nylon-fabric and carbon-based elastomer composites were used as electrodes. During this work, film casting technique was implemented and combination of different materials, such as, polydimethylsiloxane (PDMS) and polytetrafluoroethylene (PTFE)/ polyurethane (PU) were tested as triboelectric layers. The process was compatible with large scale fabrication. At low operation frequency of 1.0±0.1 Hz for the strain of 13±1.5%, developed TENGs provide output power densities of 0.06 μW/cm^2 and 0.11 μW/cm^2 for the load resistance of 100 MΩ, and energy density of 0.19±0.03 nJ/cm^2/cycle and 0.08±0.01 nJ/cm^2/cycle for the use of capacitor of 2.2 μF, for PDMS-PTFE and PDMS-PU based TENGs respectively.

1. Introduction

Triboelectric effect is known for long time mainly for its negative effects in electronics industries. In recent time, triboelectric energy harvesting, which uses the contact electrification effect and electrostatic induction method [1], have attracted extensive attention to harvest energy from mechanical movements or vibrations. In addition, with the fast development of wearable electronics, there is a strong need for fully compliant wearable, stretchable energy harvesters for users' comfort.

Several advanced next generation applications, such as smart textiles, wearable biomedical systems, and smart sensory skin for robotics, require energy harvester with adaptability to different surface topology and mechanical durability to be highly sustainable and to have capability to withstand high deformations, various movements, twisting and stretching. Flexibility and stretchability provide conformability and great deformability without compromising device performance and higher thus the reliability. Such triboelectric generators (TENGs) can be used to harness energy from human elbow, knee and breathing movements. Working principle of stretchable TENG is mainly based on sliding mode, whose output depends heavily on operational frequency and change in overlapping areas of two dielectric surfaces during sliding. Different stretchable TENGs have been reported [2]–[5], but their geometry and fabrication processes were relatively complex and not scalable, as in most cases individual fibre structures are fabricated, nanotextured and then weaved to obtain TENGs.

Here, we are presenting stretchable lateral-sliding mode TENGs manufactured using a film casting approach and having simpler design. Stretchable conductive composite fabric, dielectric elastomers and conductive elastomer composites were implemented during this work to develop the stretchable TENGs with an easier process compatible with large scale fabrication techniques.

2. Experimental procedure

2.1. Materials and design

The proposed design of the stretchable lateral-sliding mode TENGs is composed of two triboelectric layers, assembled in contact, facing each other, as illustrated in Figure 1. Outer layer is stretchable, whereas the inner layer is flexible but non-stretchable. Stretchable conductive fabric and carbon-based elastomer composites were used as electrodes. In this work, Polydimethylsiloxane (PDMS), polyurethane (PU) and polytetrafluoroethylene (PTFE) were used as triboelectric layers. The geometrical dimensions of the sliding mode TENG-bands are mentioned in Table 1.

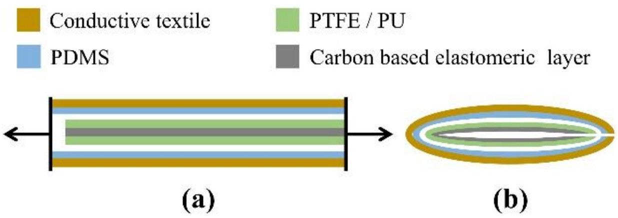

Figure 1. Schematic diagram of stretchable triboelectric generator along the (a) length and (b) width directions.

Table 1. Dimensions of the stretchable TENG-band

Active area	:	72 cm^2
Thickness of PDMS layer	:	80 µm
Thickness of PU/PTFE layer	:	50 µm

Conductive silver-plated nylon fabric (MedTex180) was supplied by Shieldex productions & Vertriebs GmbH. PDMS (Sylgard 186) and PU (MM4520) were purchased from DowCorning and SMP Technology Inc respectively, and PTFE film having thickness of 50 µm was collected from online supplier (Angst+Pfister). Carbon black pellets (Ketjenblack EC-300J & Ketjenblack EC-600JD) that has been used to prepare electrodes were purchased from Akzo-Nobel. Solvents were purchased from Sigma-Aldrich. All products were used as received. Film casting of elastomers were performed on commercially available polyethylene terephthalate (PET) film.

2.2. Process flow

The fabrication process of stretchable TENG-bands was comprised of preparation of two triboelectric layers, one was stretchable and other was flexible, along with electrodes and then assembly. Starting with the casting and curing of PDMS layer on PET substrate along with sacrificial layer; the PDMS layer was then transferred to electrically conductive fabric using elastomeric adhesive to form stretchable triboelectric layer with electrode.

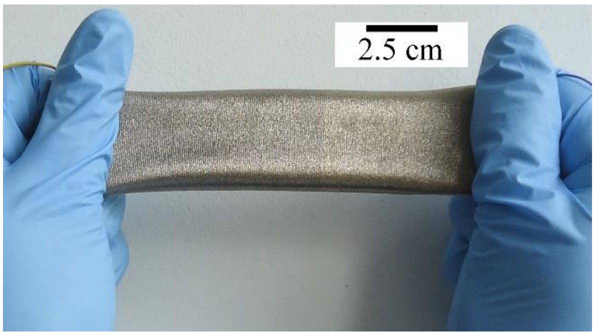

Figure 2. Stretchable triboelectric generator.

In addition, two different flexible but non-stretchable second triboelectric layers were prepared using PTFE and PU materials. In case of PTFE, conductive carbon-based PDMS layer was film casted on PTFE film and cured. Triboelectric PU layer is produced by film casting of dissolved PU layer on casted and cured carbon-based conductive PU layer. At the final stage, layers were assembled by placing triboelectric layers facing each other in surface contact, to form two different stretchable sliding-mode based TENGs with PDMS-PFTE and PDMS-PU triboelectric layer combinations (Figure 2).

The electrical responses of the stretchable TENG-bands were performed via oscilloscope through electronics circuit presented in Figure 3(a). Amount of generated energy of the TENGs were also measured using electronics circuit (Figure 3(b)), where a capacitor (C_L) of 2.2 µF was used. All the tests were performed for the strain of 13±1.5% and the frequency of 1.0±0.1 Hz.

3. Results and discussion

Lateral sliding-mode based stretchable TENGs were fabricated, where PDMS, PU and PTFE were tested as triboelectric layers and stretchable conductive fabric and carbon-elastomer composites were used as electrodes. During stretching, PDMS layer elongated and sliding between PDMS and other triboelectric layer take place. The change of overlapping surface area generates the electrical energy due to triboelectric effect. The performances of PDMS-PTFE and PDMS-PU based TENGs were tested using electronics mentioned in Figure 3(a) and 3(b).

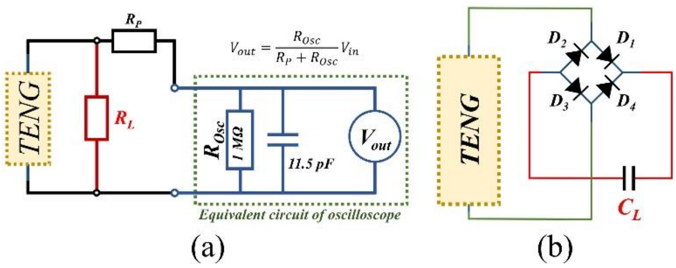

Figure 3. Schematic diagram of the measurement technique (a) to characterize the electrical response and (b) circuit used to store energy/charge generated by TENG based shoe insole during walking.

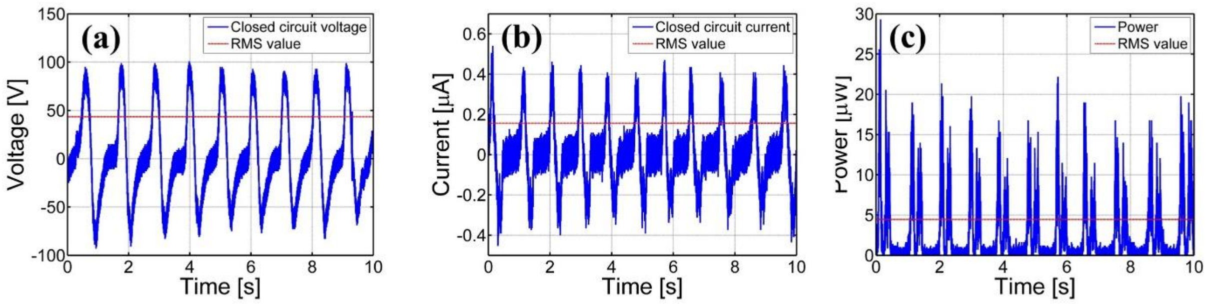

Figure 4. Electrical response of the PDMS-PTFE based stretchable TENGs. (a) open circuit voltage; (b) closed circuit current for the load resistance of 100 MΩ; (c) power generated for closed circuit measurement for the load resistance of 100 MΩ.

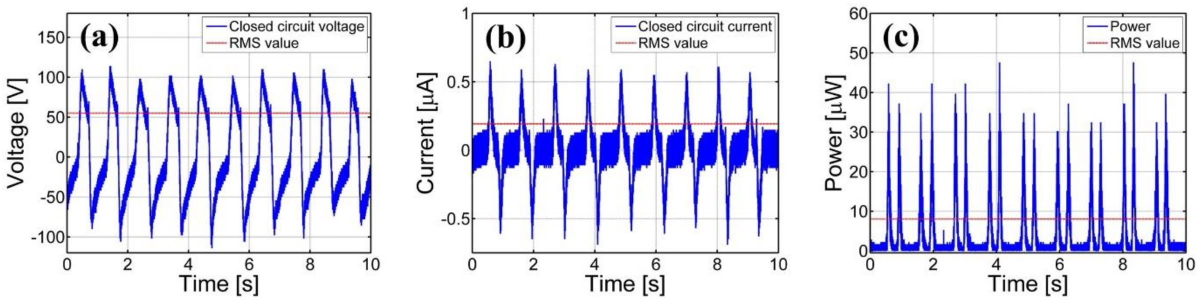

Figure 5. Electrical response of the PDMS-PU based stretchable TENGs. (a) open circuit voltage; (b) closed circuit current for the load resistance of 100 MΩ; (c) power generated for closed circuit measurement for the load resistance of 100 MΩ.

Figures 4 and 5 present the electrical response due to cyclic stretching and relaxing by PDMS-PTFE and PDMS-PU TENG-bands at 1.0±0.1 Hz. According to the observation, for the load resistance of 100 MΩ, PDMS-PTFE based TENG generated open circuit voltage (V_{OC}, rms value) of 43.5 V and closed circuit current (I_{CC}, rms value) of 0.16 μA, which corresponded to the power and power density of 4.5 μW and 0.06 μW/cm^2 respectively. Whereas, PDMS-PU based TENG provided V_{OC} (rms value) of 55 V and I_{CC} (rms value) of 0.19 μA for the load resistance of 100 MΩ, that represented, respectively, the power generation and power density of 8.1 μW and 0.11 μW/cm^2.

Moreover, the amount of charge transfer that occurred during stretching and amount of energy of TENGs were measured using capacitor of 2.2 μF. For PDMS-PTFE based TENG, the achieved amount of electrons transfer in a single charge-transfer process was 0.24±0.02 μC, that corresponded to the surface charge density of 3.35±0.31 nC/cm^2 and energy density of 0.19±0.03 nJ/cm^2. Regarding the other typology, PDMS-PU based TENG provided the surface charge density of 1.65±0.15 nC/cm^2 and energy density of 0.08±0.01 nJ/cm^2 per cycle.

It has been observed that, PDMS-PTFE based TENG provided better performance as lateral-sliding mode based triboelectric energy harvester. The high surface stickiness between PDMS and PU triboelectric layers induced higher friction between layers and thus performing sliding-mode of PDMS-PU based TENG was relatively difficult, which might have led to the reduced performance of PDMS-PU based TENG in comparison with PDMS-PTFE based TENG.

4. Conclusions

In summary, the stretchable sliding-mode based TENGs, with simple design, have been reported. These TENGs can be used to generate energy due to stretching while breathing, keen and elbow movements, and can be developed using simple, economic and scalable fabrication method, like, film casting method. As demonstrated, the developed TENGs were capable of generating energy at low stretching frequency of 1±0.1 Hz for the strain of 13±1.5%.

In comparison to the PDMS-PU based TENG, PDMS-PTFE based TENG perform smoothly due to less friction between triboelectric layers, and provided power density of 0.06 μW/cm^2 for load resistance of 100 MΩ, and charge density of 3.35±0.31 nC/cm^2 and energy density of 0.19±0.03 nJ/cm^2 for capacitor of 2.2 μF during single stretching operation. On the contrary, PDMS-PU based TENG delivered power density of 0.11 μW/cm^2 for load resistance of 100 MΩ, and charge density of 1.65±0.15 nC/cm^2/cycle and energy density of 0.0.8±0.01 nJ/cm^2/cycle for the use of capacitor of 2.2 μF in the circuit during stretching.

However, further investigating is required to explore suitable materials and designs to reduce the friction among the triboelectric layers to ease the sliding mechanism, and in the process, improve the capability and fabrication method. In addition, to protect the TENG from humidity and dust, encapsulation procedures will be studied.

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