Nano Energy (2015) 12, 19–25

Available online at www.sciencedirect.com

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journal homepage: www.elsevier.com/locate/nanoenergy

RAPID COMMUNICATION

Wearable electrode-free triboelectric generator for harvesting biomechanical energy

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Received 14 August 2014; received in revised form 10 December 2014; accepted 12 December 2014
Available online 19 December 2014

KEYWORDS
Triboelectric generator;
Electrode-free;
Human-body electrode;
Biomechanical;
Human motions

Abstract
In this article, we present an electrode-free triboelectric generator for harvesting biomechanical energy from human motions through triboelectrification between shoe sole and ground. A thin film of porous ethylene-vinyl acetate copolymer (EVA) is designed and pasted on shoe sole to serve as the friction surface. Electricity is generated by the contacting friction of shoe sole with ground surface during walking, which makes no initial vertical gap needed in shoe sole. At the same time, human body is employed as the natural electrode instead of fabricated electrodes, and the electricity can be obtained from any part of human body. In addition, output performances are characterized by using three different conductors as reference electrode. The output voltage of 810 V is achieved and charge of over 550 nC is transferred in one step of an adult's walking. Meanwhile, 76 blue LEDs are lighted through a watch as output node. Owing to the advantage of body electrode, it has potential applications in wearable electronics and implantable devices.

Introduction

Harvesting energy from ambient vibrations and human motions has attracted much attention in the past few years. It has been considered as an attractive alternative to replace traditional rechargeable batteries for low power devices and wireless sensor nodes [1-3]. Existing research about energy harvesting techniques mainly based on electromagnetic, electrostatic, and piezoelectric mechanisms [4-6].

Recently, a new type of triboelectric generator (TEG) was proposed by ZL Wang's group [7,8], which based on the coupling effect of contact electrification and electrostatic induction. It has shown a great prospect of promising since it's easy to fabricate and has high output power density, voltage as well as

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http://dx.doi.org/10.1016/j.nanoen.2014.12.009
2211-2855/

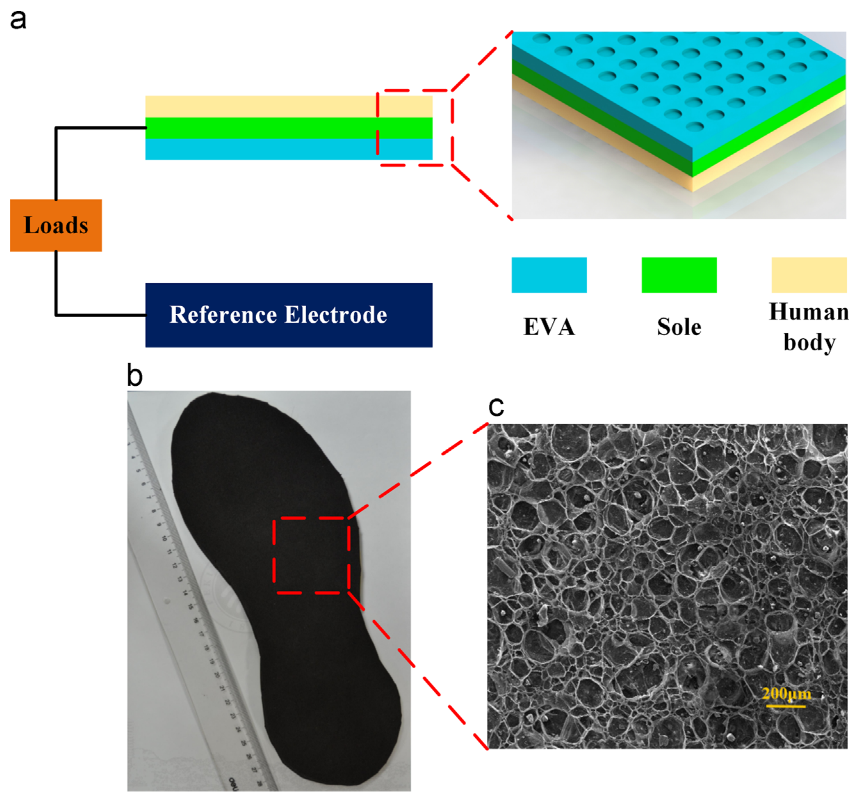

Fig. 1 (a) Schematic diagram of the e-free TEG. (b) Photograph of the EVA foam. (c) Scan electron microscope (SEM) image of the EVA foam.

high power conversion efficiency [9-11]. Due to the numerous advantages, TEG has made much possible application in wireless systems, portable electronics, active sensors and biomedical microsystems [12-17].

As a major energy resource, human motion is being an attractive part for TEG researchers. In previous studies, energy harvesters placed in the sole have been proved to be an effective way to scavenge human walking energy [18,19]. However, a stable initial vertical gap is needed for introducing deformation in such a design. Though attaching a conductor film at the back of the friction layer to form a single-electrode-mode TEG can solve this problem [26]. Transferring the power from the shoe to the electronics devices of other parts is another big challenge which limits its applications.

In this work, we report a novel wearable electrode-free triboelectric generator (e-free TEG) to harvest human walking energy. Human shoe sole is employed as the first friction surface. When human is walking on ground, the ground surface serves as the second friction surface in the friction pair. This avoids the difficulty in introducing an initial vertical gap in sole. Meanwhile, the human body is used as a natural electrode to supply power for electronic devices. Compared with single-electrode mode TEG [23,24], this natural electrode makes no fabricated electrode needed in this generator and the output can be connected to the devices at right place. Facilitated by its simple design and low cost, this e-free TEG has potential applications in wearable electronics and implantable devices.

Results and discussions

Fig. 1(a) shows the schematic diagram of e-free TEG. The EVA foam was pasted on sole to increase the contact electrification between sole and ground. Human body was employed as natural electrode making no extra electrode needed. Conductors of different size were used as reference electrode during the e-free TEG operating. Fig. 1(b) presents the photograph of sole-sized EVA foam. And top view of SEM picture of EVA is shown in Fig. 1(c). We can see the porous of EVA foam with different sizes, which can increase the contact area.

A cycle of electricity generation by human walking is illustrated in Fig. 2a. At original state in Fig. 2a<i>, human shoe soles are fully contacted with marble floor. Since EVA foam is much more triboelectrically negative, electrons are injected into EVA foam from marble floor, leading to positive triboelectric charges on the marble floor side and an equal amount of negative charges on the EVA foam side. Once a separation between shoe soles and ground forms (Fig. 2a<ii>), the reference electrode possess a lower electric potential than human body, producing an electric potential difference. Such a potential difference can drive electrons from human body to the reference electrode, leading to an electric current from the reference electrode through external load to the human body in order to reach an electrostatic equilibrium state (Fig. 2a<iii>). Afterwards human steps down, the shoe soles and ground get closer (Fig. 2a<iv>), producing an electric potential difference with reversed polarity. As a result, electrons flow in a reversed direction. So when human walking on the marble floor, an alternating current can be formed between human body and the reference electrode.

This e-free TEG can be classified into a contact-separation mode triboelectric generator [7,20]. According to the previous developed theoretical model of TEG, the optimum load resistance was about several megohm to hundreds megohm [20,25]. In the experiments, the maximum output power was