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A sandpaper assisted micro-structured polydimethylsiloxane fabrication for human skin based triboelectric energy harvesting application

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HIGHLIGHTS

- Sandpaper assisted fabrication of micro-structured PDMS has been introduced.
- No surfactant coating is needed to peel off the PDMS from template.
- A wearable triboelectric harvester has been demonstrated using as-fabricated PDMS.
- Custom-made wristband facilitates effective contact-separation actions.
- Influence of variant input parameters on proposed TEG has been investigated.

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ABSTRACT

This paper reports a sandpaper based inexpensive and simple fabrication process of functional micro-structured PDMS (Polydimethylsiloxane) film to be used as a triboelectric layer. The micro-structured PDMS film was replicated directly from the low surface energy sandpaper template without the use of any surfactant coating, high vacuum or high-pressure equipment. A human skin and PDMS interaction based triboelectric generator (TEG) is demonstrated using as-fabricated micro-structured PDMS film. In our proposed TEG harvester, electrical energy is produced by continual contact-separation processes between PDMS and human skin. Four different micro-structures were compared with flat film and the influences of surface structures on the electrical output of the harvester are systematically studied. Results show that the existence of micro-structures on the PDMS films effectively enlarges the contact area and provides more surfaces for charge storage and hence improve the output performance of TEG. The as-fabricated prototype can produce peak-peak open-circuit voltage up to 103 V and 4.8 mW/m^2 of peak power density, which is exceptionally attractive for the fabrication of self-powered and portable devices. This stable PDMS film with functional micro-structures, which is fabricated using reusable sandpaper template facilitates robust and large-scale fabrication, and has potential for future applications in triboelectric energy harvesting devices.

1. Introduction

Due to the fast-growing demand of wearable devices and self-powered sensor systems, energy harvesting technology is playing an important role to convert ambient energy into electricity through different energy conversion principles, such as electromagnetic [1,2], piezoelectric [3,4], electrostatic [5,6], thermoelectric [7,8], pyroelectric [9,10], etc. To address the output performance limitations of those techniques, a number of triboelectric nanogenerators (TENGs) [11] have been introduced to enhance the output performance for different non-resonant structures which shows better energy transformation process than the typical energy harvesters. To effectively convert the ambient mechanical energy into electricity, triboelectric energy harvesters are the quite new generators [12]. When two materials are put in contact with each other, the tendency of getting charged can be illustrated by the difference in the electro-negativity of the two materials. Recently a number of researchers have reported about contact electrification based triboelectric energy harvesters for portable and wearable electronics [13–15], which play excellent roles in this research area. The operation method of TENGs can be classified into three mechanisms, namely, contact-mode, sliding-mode, and single-electrode-mode [16]. Here, the contact-mode TENGs are mostly used for flexible device structures and their operation principle follows certain steps: generating electrified charges, balancing potential difference, and

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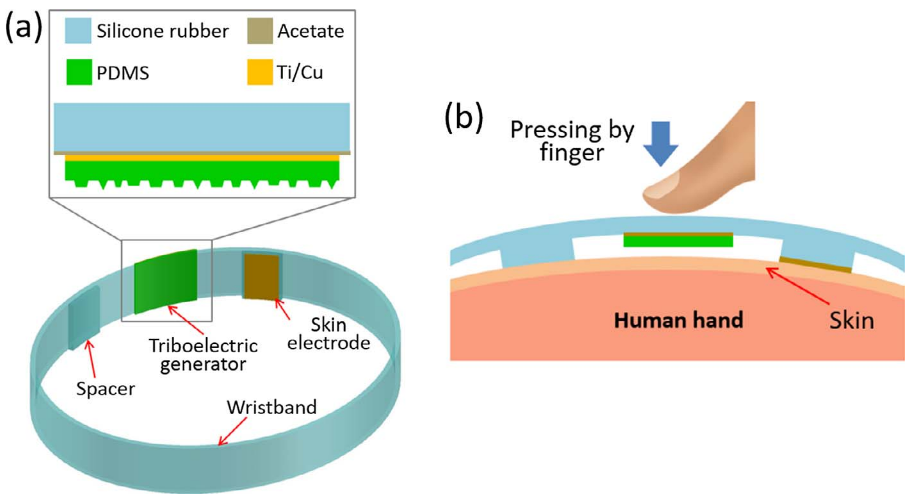

Fig. 1. Schematic illustration of the proposed wrist-band coupled TEG device geometry. (a) Schematic of wrist band coupled human skin based harvester; (b) Contact and separation actions using finger-tip.

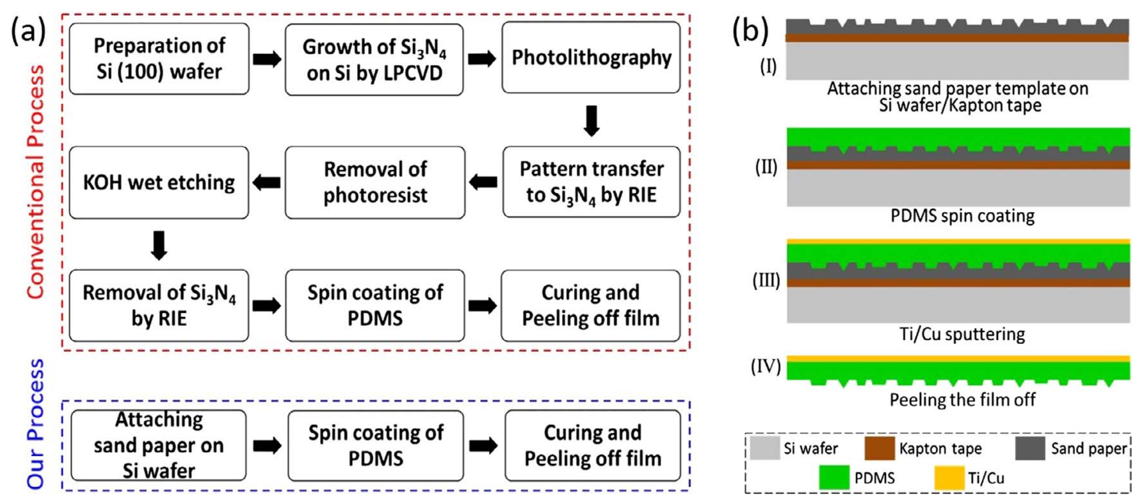

Fig. 2. Fabrication of micro-patterned PDMS film. (a) Difference between conventional process and proposed process of micro-structured PDMS film; (b) Significant steps towards micro-patterned PDMS film preparation.

reaching to electrical equilibrium when an external force is applied or withdrawn.

As reported by series of triboelectric materials [17], human skin is found to be one of the most positive materials which loses electrons when comes in contact with another less positive triboelectric material, such as PDMS [18,19]. Also, PDMS has been widely used as one of the most advantageous materials because it has high flexibility, surface modification ability, and bio-compatibility. To facilitate inexpensive and simple fabrication of micro-patterned PDMS film, we introduced a new method using sandpaper as template for micro-structured PDMS, which doesn't require any surfactant coating. In this paper, we describe the fabrication process in details along with advantages of making micro-structured PDMS film over flat PDMS. Using as-fabricated micro-structured PDMS film, we demonstrated a wristband coupled wearable triboelectric energy harvester using continual contact-separation actions between skin and PDMS surface.

2. Experimental methods

2.1. Motivation for micro-structuration

According to Zhu et al. [20], the transformation of energy consists of two major issues; external force and air gap between layers. Micro/nano structures are often designed on triboelectric material surfaces to enhance the efficient contact area of triboelectric harvesters, which causes enhanced output power [21]. Besides, the modified surface also changes some physical properties largely, like the wetting behavior of polymeric surface, results in larger contact angle between water and micro-structured PDMS than that for flat PDMS surface [22], which is necessary to realize the self-cleaning property [23]. For the structure of flexible contact-mode TENGs, it is generally composed of micro- or nano-patterned polymers, typically polydimethylsiloxane (PDMS), and indium tin oxide (ITO) coated polyethylene terephthalate (PET) [24–26]. During the operation of TENGs, the patterned surfaces play an important role in enhancing the smooth separation and increasing the friction area between the polymer materials and electrodes, which leads to the improvement in device efficiency [27].

To make surface modification for better surface contact area, an increased number of process steps will increase cost and may lead to process compatibility problems, making a single-step fabrication process for PDMS hierarchical structures very attractive. Some one-step techniques have been developed [28,29]. However, a surfactant coating is conventionally required to prevent bonding between the PDMS and the replication mold during baking to cross-link the PDMS, which occurs due to high surface energy. Sadly, the surfactant coating pollutes the desired sample surface and also reduces the accuracy of PDMS replication.