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Self-powered wireless smart patch for healthcare monitoring

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A B S T R A C T

Wearable electronics provides an opportunity for everyone to own personal healthcare systems. Convenience, versatility and energy conservation are vital elements to extend the functions of wearable electronics. Here we present a self-powered smart patch with wireless transmission ability based on triboelectric effect and electrostatic induction to monitor the temperature and motion status of individuals. Spontaneous friction charges are utilized to make the system self-powered. The energy and signal are wirelessly transmitted to the receiver through electrostatic induction. The wireless transmission efficiency achieved 26.6% with a 16 cm^2 receiver while the distance is 1 cm, which shows remarkable capability of near-field wireless transmission. With different load resistances from 1 Ω to 1 MΩ, the output current of the receiver keeps constant like a current source. Using a method that transmits energy and signal at the same time, our smart patch can not only collect energy to drive the commercial sensors, but also work as an active sensor monitoring the motion status of people. To realize the wearable electrode, a fabric-based conductor with high stability is developed. A transparent and stretchable silver nanowire (Ag NW) based electrode is fabricated to ensure the compatibility between the receiver and various surfaces such as smartphones.

1. Introduction

Wearable electronics is advancing to a new era. More and more functions are being integrated into these devices that people can wear wherever they go, through the processing of wearable materials and structures [1–16]. Among all the functions, healthcare monitoring is particularly promising because it is one of those that can help people, especially the elders, monitor physiological status, such as sweat metabolites and skin temperature [1,2], movement disorders [3], pressure and strain [2,4–6], electrocardiogram [7] as well as heavy metal in body fluids [8]. However, at present there are several weaknesses faced by the wearable electronics that prevent them from developing into the paradigm of flexibility and convenience. While the necessity of rigid batteries in the healthcare monitoring system makes it unavoidable for users to frequently recharge as well as inconvenient to carry, the conductive wires between sensors and analyzing computers hampers the integration of the whole system into daily used electronics, for example smartphones. The improvements of self-powered systems, which combine enhanced energy harvester [17–42] and wireless transmission technology [43–45], provide a potential solution for wearable smart electronics to get rid of the bondages of bulky batteries as well as the restrictions of inconvenient wires. Concretely, triboelectric generators are able to drive the self-powered system with highly continuous and low cost energy sources; wireless transmission technology contributes to breaking of limits of charging cables.

Among all those efforts to establish self-powered wireless transmission systems, rectifier circuits and capacitors are frequently utilized to convert the outputs of TENGs, which is usually in the form of short pulse at variable frequency, into direct current and store it before it can be harnessed to drive conventional electronics. In addition, RF emitters, in most cases, are induced to transmit the signal and power to the receivers. The efficiency of these approaches are relatively low due to the complicated additional circuits which have low conversion and transmission efficiency as well as high cost. In addition, they are inconvenient to carry as wearable devices. Here, by means of the electrostatic induction effect, we present that the power as well as signal can be received wirelessly from the TENG without other devices and circuits, which aims to make them feasible for wireless transmission and wearable applications.

Herein, we present a self-powered wireless smart patch for monitoring the physiological status, including temperature and motion status. Our system is based on the triboelectric effect and electrostatic induction to realize self-powered wireless transmission which utilizes electric field built by spontaneous friction charges as the propagation medium of power and signal as is shown in Fig. 1a. Multi-walled

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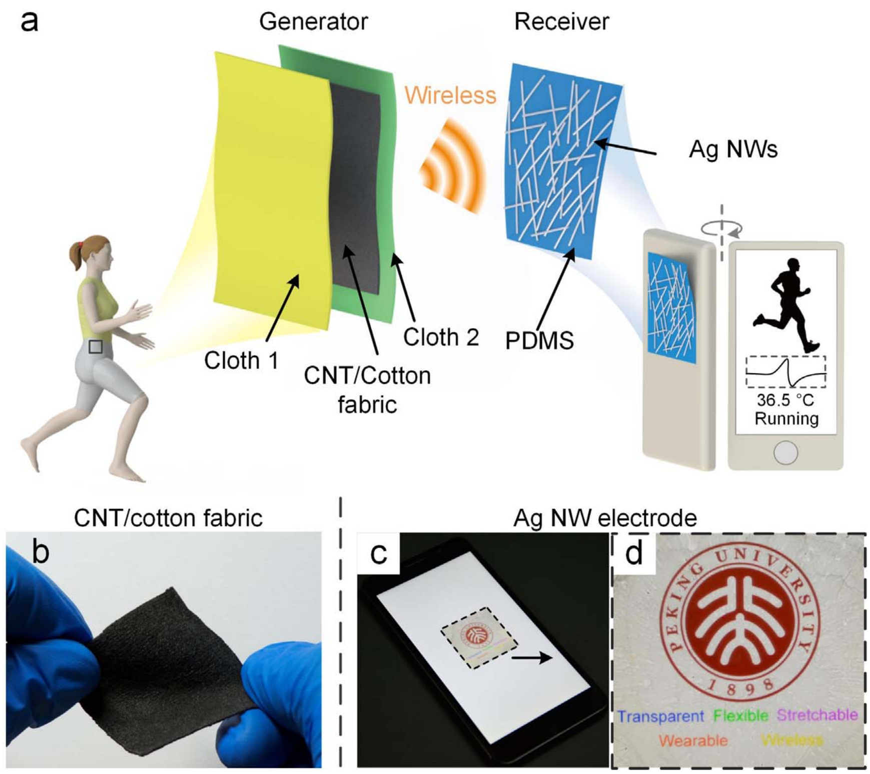

Fig. 1. Structure of self-powered wireless smart patch. (a) Schematic diagram of a self-powered wireless smart patch. (b) Photograph of the stretchable conductive fabric after coating PDMS. (c), (d) Transparent and stretchable Ag NW/PDMS electrode pasted on the screen of a smart phone.

carbon nanotubes (MWCNTs) and polydimethylsiloxane (PDMS) is composited with commercial knitted cotton fabric to fabricate a wearable stretchable electrode with high stability. (Fig. 1b) Moreover, the sandwich structured film receiver, which is transparent and stretchable, is fabricated by silver nanowires (Ag NWs) and PDMS. It is compatible with a variety of surfaces on which it can pasted based on van der Waals interactions alone in order to receive the power and signal wirelessly transmitted by the triboelectric generator (Fig. 1c and d).

2. Materials and methods

2.1. Processing of CNT based electrically conductive cotton fabric

In processing, commercial knitted fabric was coated with MWCNTs through dipping and drying process. To enhance the stability, the conductive fabric was then coated with PDMS. First of all, 1 mg/ml of commercial carbon nanotube powder was dissolved into the deionized water, then 10 mg/ml of SDBS was added. Afterwards, the solution was placed into an ultrasonic treating device for 1 h. After preparation of MWCNT solution, a knitting cotton fabric was immersed into the carbon nanotube solution and was exposed to an ultrasonic environment for 5 min, as is shown in Fig. S1a. Then the cloth was picked up from the solution and placed on the hot plate for 15 min. The two steps mentioned above was repeated for 10 times. In the final cycle, the cloth should be heated until it was dried.

Elastomer and the cross-linker (Sylgard 184, Dow Corning) were prepared in the ratio of 10:1 (w/w). The cotton fabric was then immersed into liquid PDMS. After a few seconds, the fabric was taken out from the liquid PDMS and placed onto the hot plate to solidify the PDMS layer. Then the electrically conductive fabric was ready.

2.2. Characterization of CNT based electrically conductive cotton fabric

Fig. S1b–d show the SEM image of PDMS coated conductive fabric. In the top view shown in Fig. S1b, surface with high roughness was formed by the PDMS coated fibers. Moreover, Fig. S1c and d shows that PDMS was filled into the gap of the fiber frame. There are two main advantages of PDMS coating. The first one is to protect the MWCNT network on the surface of cotton fibers [11]. Another advantages of PDMS coating is that PDMS is of high efficiency to catch electrons from common clothing materials, so that it can enhance the efficiency of the generator. Because of the stretchability of PDMS, the fabric remains stretchable after coating.

2.3. Processing of a PDMS covered silver nanowire electrode

Elastomer and the cross-linker (Sylgard 184, Dow Corning) were prepared in the ratio of 10:1 (w/w). First, liquid PDMS was dropped on a glass substrate and was spin-coated at 500 rpm for 60 s. The sample was then placed on the hot plate at 100 °C for 20 min until the PDMS was solidified. Afterwards, the PDMS layer was detached from the glass substrate and pre-strained. Then it was treated with oxygen plasma to form a hydrophilic surface. 2 mg/ml of silver nanowire solution was dropped onto the pre-strained PDMS film and spin-coated at 1000 rpm for 30 s. This step was repeated for 10 times. After that the strain in PDMS film was released. The sample was then placed on the hot plate at 100 °C for 30 min to anneal. Finally, liquid PDMS was dropped onto the AgNW layer and spin-coated at 400 rpm for 30 s. After the sample was placed on the hot plate at 100 °C for 20 min to solidify, a PDMS covered silver nanowire electrode was ready.