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Full paper

Self-powered artificial electronic skin for high-resolution pressure sensing

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ABSTRACT

Electronic skin (e-skin) comprises a network of tactile sensors, which has broad application prospects in prosthetics, advanced robotics and continuous health monitoring. Here, a self-powered artificial e-skin is fabricated in a simple and cost-effective method for high resolution pressure sensing. No external power supply is needed for the e-skin owing to the triboelectric mechanism. The response time of pressure sensing is approximately 68 ms and the sensitivity is 0.055 nA K Pa^{-1}. With excellent flexibility, the device can be adhered on most curved surfaces for pressure sensing purposes. The fabricated e-skin with resolution as high as 127×127 dpi is capable of mapping the 2D tactile trajectory of a tip. The resolution can proceed to be improved with the enhancement of the pixel density. Furthermore, the unique construction brings about a significant reduction in the number of the test channels from N×N to 2×N, which greatly decreases the measurement costs. This work offers an effective step for e-skin, with superiorities of self-powered, high resolution, simple fabrication and low-cost.

1. Introduction

Artificial electronic skin (e-skin) imitates the functions of biologic skin has attracted wide notice for exciting practical applications in robotics, health monitoring and artificial prosthetics [1,2]. E-skin composed of a network of sensors can convert external mechanical stimuli into readable electrical signals. The major fundamental transduction principles of e-skin consist of piezoresistive, capacitive and piezoelectric mechanisms [3–13]. However, most of these devices rely on external power supply or batteries to operate, which may causes the overall system bulky and greatly limits the practical utilization. High resolution is a key factor of e-skin to further promote the perception of pressure distribution. But the resolution of e-skin in previous works is relatively low and complicated to improve. Hence, it's urgent to find methods to realize resolution enhancement through simple fabrication process.

Self-powered systems capable of harvesting energy from ambient environments and operating without external power source have demonstrated to be promising solutions to facilitate the applications of e-skin under various environments [12,14–23]. Recently, triboelectric mechanism has emerged as an effective approach to scavenge ambient mechanical energy, which has unique merits of simple fabrication, low weight and high efficiency [24–31]. The self-powered sensors based on triboelectric mechanism can harvest electric energy from mechanical stimuli and meanwhile the generated electric signals serve as the sensing signals with high sensitivity.

We designed a self-powered flexible e-skin through simple fabrication processes for high-resolution tactile sensing. The triboelectric mechanism ensures that the e-skin can realize self-powered pressure sensing with no external electrical power needed. The e-skin has a fast response time of about 68 ms and sensitivity of 0.055 nA K Pa^{-1}. The superior flexibility is illustrated by adhered on curved surfaces of the human finger and beetle to realize pressure sensing. The resolution of the fabricated e-skin is 127×127 dpi, which is over 10 times higher than the resolution of mechanoreceptors in biologic skin. The tactile trajectory of the tip moves on the e-skin can be tracked and mapped. This type of e-skin shows bright prospects in many application fields including robotics, artificial prosthetics, wearable electronics and health monitoring.

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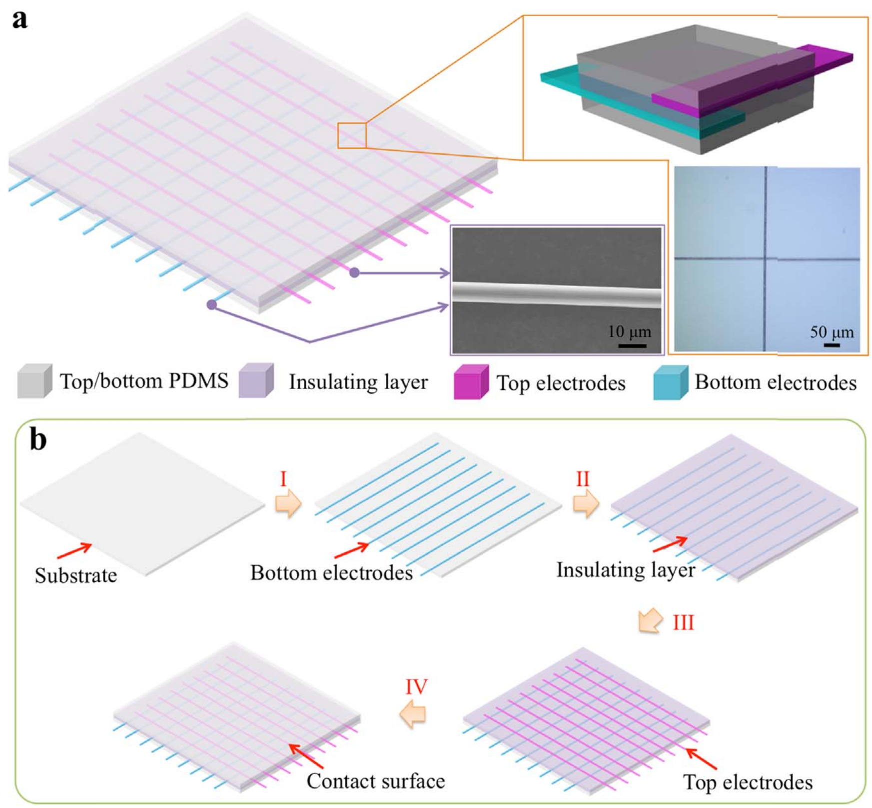

Fig. 1. (a) Schematic diagram of the self-powered 2D e-skin. The top inset is the enlarged diagram of one pixel, the bottom-left inset is the SEM image of single carbon fiber and the bottom-right inset is the micrograph of one pixel. (b) The schematic fabrication processes of the device. Process I: the bottom PDMS layer was formed through curing the PDMS solution. Then a group of carbon fibers were fixed on the bottom PDMS. Process II: a thin PDMS film is formed as an insulating layer between the perpendicular electrodes. Process III: another group of carbon fibers were distributed on the insulating layer along the perpendicular direction. Process IV: afterwards, the PDMS solution was poured to completely cover the top fibers. The e-skin with a sandwiched construction was obtained with the electrodes electrically insulated to each other.

2. Experimental section

2.1. Fabrication of the 1D self-powered e-skin

The PDMS elastomer and cross-linker were mixed in a mass ratio of 10:1 and degassed for 1 h. Then the solution was coated onto a metal mold and cured at 85 °C for 5 min to make the PDMS sticky. The single carbon fiber purchased from Toho Tenax (Japan) was fixed on the surface of the sticky PDMS. The fiber was controlled through the probe under high-maginification optical microscope to realize micro-scale localization. Afterwards, the PDMS solution was poured to completely cover the fiber. Subsequently, the mixture was degassed again, followed by a vacuum oven curing at 85 °C for 30 min. The e-skin with a sandwiched construction was obtained by peeling from the mold.

2.2. Fabrication of the 2D self-powered e-skin

For the self-powered 2D e-skin, two groups of carbon fibers were distributed along perpendicular directions with a fixed interval. A thin PDMS film as an insulating layer is sandwiched between the perpendicular electrodes, which are electrically insulated to each other. Each electrode was connected to the ground as the output channel.

2.3. Characterization and electrical measurement

The morphologies of the carbon fibers were characterized by a FEI Quanta 3D field emission scanning electron microscopy. For the measurement of output voltage and current, a Keithley 6514 System Electrometer and an SR570 low-noise current preamplifier from Stanford Research Systems were used.

3. Results and discussion

Fig. 1 illustrates the schematic diagram of the self-powered 2D e-skin, which is composed of PDMS films and two groups of carbon fibers wrapped inside. The top PDMS layer acts as contact surface according to its biocompatible, high flexibility and low weight. The carbon fibers are used as the electrode due to the advantages of high flexibility, high strength and low weight. The two groups of carbon fibers were electrically insulated to each other as shown in the inset of Fig. 1a. The micrograph shows that the carbon fiber has a diameter of about 7 µm. The fabrication processes of the self-powered e-skin is shown in Fig. 1b.

The working mechanism of the 1D e-skin is schematically sketched in Fig. 2a. When the human finger and the PDMS surface intimately contact each other, positive and negative charges are induced on finger and PDMS respectively [24]. The generated negative triboelectric charges can be remained on the PDMS surface for a long time due to the insulating property. Once the finger separates from the PDMS, the negative charges on the PDMS will induce positive charges on the two electrodes, which requires electrons to flow from the electrodes to the ground. The flow of the electrons lasts until the finger is far away enough, which the negative charges on the PDMS are completely screened by the induced positive charges on the electrodes. When the finger approaches the PDMS, the electrons will flow back from the ground to the electrodes until the finger fully contacts the PDMS.

The sensing performances are investigated by the contact between the steel rod and the surface of the 1D e-skin under the pressure of 35.3 KPa. The output voltage and current is shown in Figs. S1 and 2b, which indicates the good repeatability. The response time of pressure sensing is approximately 68 ms, which is calculated from the enlarged output current signal. The pressure response curve in Fig. 2d shows a linear