Nano Energy 44 (2018) 43–52

Contents lists available at ScienceDirect

Nano Energy

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

Communication

A self-powered brain multi-perception receptor for sensory-substitution application

Yongming Fu[a], Mengyang Zhang[a], Yitong Dai[a], Hui Zeng[a], Cong Sun[a], Yechao Han[b], Lili Xing[a], Shuai Wang[a], Xinyu Xue[a,d,*], Yang Zhan[b,**], Yan Zhang[c,d,***]

[a] College of Sciences, Northeastern University, Shenyang 110004, China
[b] Brain Cognition and Brain Disease Institute, Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen 518055, China
[c] School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu 610054, China
[d] Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences, Beijing 100083, China

ARTICLE INFO

Keywords:
Self-powered
Sensory substitution
Electronic-skin
Wearable electronic
Triboelectrification
Brain receptor

ABSTRACT

The artificial sensory-substitution system can work like real human sensory tissue and participate in the perception of sensory-handicap patient. The power-supply unit is key factor for its wearable, low-cost and long-term application. Here, a new self-powered multi-perception electronic-skin has been presented as brain sensory receptor for sensory substitution of tactility, audition, olfaction, gustation and vision. The device directly outputs the triboelectric sensory signal into brain using human motion energy without external electricity power or battery, and actively involves in multi-perceptions. The sensing unit arrays act as both the power source and brain sensory receptor for tracking force trace, hearing words, smelling odor, tasting beverage and recognizing image. The mechanism can be attributed to the coupling of triboelectrification and surface effect. The device connecting to mouse brain at primary somatosensory barrel cortex can mimic the mouse perception and drive the mouse activities. This new approach can be applied to fabricating new self-powered sensory-substitution systems and multi-perception brain sensory receptor.

1. Introduction

The sensory processing of human being can be replaced by artificial sensory-substitution system that transmits electrical signal into brain [1–5]. This system can establish multimodal brain-electric interaction and help sensory-handicap patients through restoring their ability to perceive certain defective sensory [6–8]. Tactility, audition, olfaction, gustation and vision are five most important recognized methods of perception for human beings. The artificial sensory-substitution system can work like a real human sensory tissue, which can detect different aspects of stimuli, analyze sensing data, transmit bionic electrical signal to brain, participate in perception, and drive body-motion feeding back [9]. Diverse skin-patched flexible perception devices would be as an important step of the sensory-substitution system wiring the human body [10–16]. Recently, a novel implantable multifunctional silicon electronic sensor is developed for *in vivo* continuous monitoring intracranial pressure and temperature in the mouse brain [14]; a skin-inspired organic digital mechanoreceptor is reported for transducing pressure stimulus into frequency electrical signal and sending on to peripheral nerves of brain [16].

Above breakthrough approaches need power-supply unit or battery. There are two main ways to design sensory-substitution systems (*e.g.* the emerging electronic-skins) in practical application [4]. The first is all-in-one integration systems including sensors, information processing and signal transmitting equipment, which usually require external electricity power or battery [17]. The second is that the stimuli detecting, data analyzing and information simulating are performed separately, which can use small-sized devices and has low power consumption in sensing part [16]. From energy consumption point of view, energy and signal have separated ways for the current technologies. A key factor of the miniature sensory-substitution system is the flexible, low cost and efficient power-supply unit.

Self-sustainable electronic-skins may have potential application in the future low-cost/long-term clinical medicine, prosthesis sensory organ and artificial intelligence [18–20]. Recently, a new self-powered system based on triboelectric nanogenerator (TENG) has been developed by harvesting tiny mechanical energy and conversing into electricity for powering functional devices [21–23], which may be an

* Corresponding author at: College of Sciences, Northeastern University, Shenyang 110004, China.
** Corresponding author.
*** Corresponding author at: School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu 610054, China.
E-mail addresses: xuexinyu@mail.neu.edu.cn (X. Xue), yang.zhan@siat.ac.cn (Y. Zhan), zhangyan@uestc.edu.cn (Y. Zhang).

https://doi.org/10.1016/j.nanoen.2017.11.068
Received 13 November 2017; Received in revised form 28 November 2017; Accepted 28 November 2017
Available online 01 December 2017
2211-2855/ © 2017 Published by Elsevier Ltd.

excellent candidate for realizing the new category of perception electronic-skins. Here, a self-powered multi-perception electronic-skin as brain sensory receptor has been presented for sensory substitution of tactility, audition, olfaction, gustation and vision. The device can harvest human-motion energy, directly output the triboelectrical sensory signal into brain, actively involve in multi-perceptions and drive body-motion feeding back.

2. Experimental section

2.1. Device fabrication

Patterned Cu networks were obtained through standard photolithography and wet-etching method. A piece of pure Cu foil (4 cm × 4 cm × 10 μm) as source material was attached on SiO_2 wafer and heated at 100 °C for 100 s. Then 0.8-μm-thinkness positive photoresist (RZJ-304, 25 mPa s, Suzhou Ruihong co., ltd) was spin-coated on Cu foil with 200 rpm for 30 s and 1500 rpm for 120 s. After heated at 110 °C for 120 s, Cu foil was transferred to a UV contact mask aligner (H94-17G, Sichuan Nanguang co., ltd), exposed to UV light (365 nm, 15 mJ cm^{-2}) for 2.1 s and immerged in developer (RZX-3038, Suzhou Ruihong co., ltd) for 30 s. Then, Cu foil with patterned photoresist was hardened at 120 °C for 150 s, washed with deionized water and dried by N_2 airflow. At last, the as-printed Cu foil was wet-etched by immersing in sodium persulfate aqueous solution (0.5 mol L^{-1}) at 50 °C for 30 s to form patterned Cu network. Typically, the Cu network has 4 × 4 individual sensor units, each sensor unit is 6 mm × 6 mm in area and includes ~ 1000 sensing pixels.

PDMS/Cu patterned film was obtained by spin-coating PDMS on patterned Cu network. To obtain the PDMS mixture, elastomer and cross-linker (Sylgard 184, Dow Corning co., ltd) were mixed in a mass ratio of 10:1, ultrasonically treated for 1 h and vacuumized for three times to eliminate the bubbles in the mixture. Then, PDMS was slowly dropped onto Cu network. After heated in vacuum at 90 °C for 45 min, PDMS film (thickness = 0.5 mm) with Cu network inlaid in grooves was lifted off from SiO_2 wafer. At last, the Cu/PDMS film was cut into 4 cm × 4 cm in area.

To further enhance the triboelectric output, the surface of PDMS was dry-etched by inductively coupled plasma (ICP-100A, Potentlube Technology co., ltd). During etching process, Ar, O_2 and CF_4 gases were introduced into the ICP chamber at the flow rate of 15, 15 and 35 sccm, respectively. The PDMS film was etched (plasma-ion acceleration = 100 W) for 20 min to obtain the nanostructures on the surface.

To reduce the thickness of Cu networks and concede space for depositing Ppy, Cu networks in the PDMS grooves were further wet-etched by sodium persulfate aqueous solution (0.5 mol L^{-1}) for 15 s at 50 °C. Ppy derivatives were grown on the Cu networks through electrochemical polymerization by an electrochemical workstation (CHI627D, CH Instruments, Inc.). The growing solution contained various dopants (0.2 mol L^{-1}) and pyrrole monomer (0.1 mol L^{-1}). In different experiment, sulfuric acid, nitric acid, 10-camphor sulfonic acid, sodium oxalate was separately used as the dopant. A Pt wafer, Ag/AgCl electrode and Pt wire served as the working, reference and counter electrode, respectively. During electrochemical polymerization, cyclic voltammetry was carried out at the rate of 20 mV s^{-1} between −0.5 and 1.3 V (*vs.* Ag/AgCl) to determine the optimal oxidation potential of each polymerization reaction. Chronoamperometry was employed at optimal voltage for 200 s to polymerizing Ppy.

100-nm-Cu electrode was deposited on the back of PDMS by electron beam evaporation. In order to improve the uniformity and soundness of the Cu film, the sample holder was rotated at a speed of 50 rpm. During evaporation process, the vacuum chamber was evacuated down to a base pressure of 5 × 10^{-4} Pa, and the distance between the substrate and copper target was fixed at 150 mm. 100-nm-thickness Cu film was prepared with electron beam currents of 60 mA for 30 min.

2.2. Characterization and measurements

The morphology and structure of the device were investigated by scanning electron microscope (SEM; Hitachi S4800). The sensing performance of the device was studied by measuring the outputting current in different conditions. During test, one end of the device was fixed, and the other end was attached to a stepping motor. The stepping motor was conducted by a singlechip microcomputer to control the magnitude, bending angle and frequency of the force. The applied force was measured by a force detector (DS2-X, ZHIQU Precision Instruments). A low-noise current preamplifier (Model SR570, Stanford Research Systems) was used to measure the outputting current, and a low-noise voltage preamplifier (Model SR560, Stanford Research Systems) was used to measure the outputting voltage. All the experimental measurements were conducted under the pressure of 1.01 × 10^5 Pa at room temperature under 30–40% RH humidity.

2.3. Animal preparation and surgery

All of the procedures in this study conformed to the regulations for the administration of affairs concerning experimental animals and were approved by Animal Care and Use Committee of Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences. C57BL6J mice weighting 22–28 g were anesthetized with an intraperitoneal injection of 1% pentobarbital sodium (10 mg kg^{-1}) and maintained with supplemental as needed. Animals were prepared for recording by exposing the dorsal surface with a craniotomy using a micro hand-drive. Then two nichrome wire stimulation electrodes (65 μm in diameter) were stereotactically implanted into primary somatosensory barrel field (AP = +1.0 mm, ML = ± 1.2 mm, DV = −1.5 mm), separately. The other ends of the stimuli electrodes were connected to five parallel-connected electronic-skins. Especially for body swerving test, at least one week was needed allowing post-surgical recovery. After the experiments, the mice were deeply anesthetized and transcardially perfused with saline and 4% paraformaldehyde (Sigma-Aldrich, USA) solution successively. Following with the post-fixation and dehydration of the brain, coronal 35 μm brain sections was cut on a frozen cryostat. Images were acquired on a Zeiss microscope (Zeiss Axio Imager 2) to verify the location of stimulation electrodes.

3. Results and discussion

As illustrated in Fig. 1a, the self-powered multi-perception electronic-skin can eliminate the existing technological gaps between electricity power source, different kinds of sensors and neurobionics of signal transmission/transformation. In one single chemical/physical process of individual sensing unit in the device, it can harvest human-motion energy and output triboelectric signal, acting as both the power source and the sensing information for mimicking tactility, audition, olfaction, gustation and vision. Beyond the real human sensory tissue (different kinds of receptor cells aligned in sequences can bind to particular physical/chemical species with varying affinities and begin a series of action potentials as a distinct code signal), a series of triboelectric code signals generated by the cross-responsive sensor unit arrays can be directly transmitted to brain for sensory-substitution application [24,25]. In a conceivable circumstance (Fig. 1b), the device can be attached on neck surface of a sensory-handicap patient (*i.e.* anosphrasia). When the patient is upon exposure to toxic atmosphere, the device can actively generate and transmit a veracious electrical signal to her/his brain, making her/him smell the odor and keep away from danger. Figs. 1c and S1 show a human subject conformably wearing the device, allowing for real-time sensory substitution accompanying with human activities. To better demonstrate the flexibility and transparency, the device without Cu back electrode is exhibited.

The architecture and fabrication procedure of the device are

Download English Version:

https://daneshyari.com/en/article/7953011

Download Persian Version:

https://daneshyari.com/article/7953011

Daneshyari.com