Nano Energy 46 (2018) 220–228

Contents lists available at ScienceDirect

Nano Energy

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

Full paper

Managing and optimizing the output performances of a triboelectric nanogenerator by a self-powered electrostatic vibrator switch

Junjie Yang, Feng Yang, Lei Zhao, Wanyu Shang, Huaifang Qin, Shujie Wang, Xiaohong Jiang, Gang Cheng*, Zuliang Du*

Key Lab for Special Functional Materials, Ministry of Education, Henan University, Kaifeng 475004, China

ARTICLE INFO

Keywords:
Triboelectric nanogenerator
Electrostatic vibrator switch
Power management

ABSTRACT

Using a switch is an effective strategy for managing and improving the output performances of a triboelectric nanogenerator (TENG). However, the previous switches designed for the TENGs are triggered by external mechanical motion or integrated circuits, which increase the complexity and fabrication cost of the TENG. In this article, a TENG system with a self-powered switch has been established by using an electrostatic vibrator switch, in which the switch's vibrating is driven by the potential difference of the TENG itself. In a sliding mode TENG, its output properties can be regulated and improved by the vibrating frequency of the switch, which can be adjusted by the switch's length. Compared with the same TENG without a switch, its instantaneous output power and total output energy for a load resistance of 0.1 MΩ are increased by 1.8×10^7 and 4.7×10^3 times, respectively. In a rotation disk TENG, its maximized output voltage and output energy can be achieved, as the switch's vibrating frequency is adjusted to two times the TENG's frequency. Because of the excellent impedance matching ability of the TENG with a vibrator switch, it can be combined with a transformer to form a power management system, which is verified to have better powering abilities as charging a capacitor and lighting a quantum dot light-emitting diode. The self-powered vibrator switch demonstrated here has promising applications in enhancing TENG's output performances and developing power management circuit.

1. Introduction

With the rapid growth of global energy consumption, developing new energy harvesting techniques has attracted more and more researchers. In recent years, the triboelectric nanogenerator (TENG) has emerged as a new technology for converting mechanical energy into electrical energy [1–4], which is based on contact electrification effect and electrostatic induction effect. TENG has different working modes, such as vertical contact-separation mode [5,6], lateral sliding mode [7,8], single-electrode mode [9,10] and freestanding triboelectric-layer mode [11–13]. Based on these basic modes, the TENG can harvest mechanical energy from various mechanical movements of the human motion and environment, such as human walking [14,15], wheel rotation [16], wind blowing [17,18], rain dropping [19], water flowing [20], ocean wave [21,22] and so on. In addition, the TENG has been applied to electrochemical [23], biomedical [24] and self-powered sensors [25–27]. However, the TENG has a huge impedance, which leads to the problem of impedance mismatch when powering electronic products and charging energy storage units. For example, the TENG's output voltage, output power and output energy are almost reduced to zero when the external load resistance is lower than 1 MΩ [28]. Therefore, how to manage and optimize the TENG's output performances is of great importance.

The TENG with a switch has been previously designed and manufactured, which has been verified as an effective method to improve the TENG's electrical output performances [29–36]. For a load resistance of 500 Ω, the same TENG's instantaneous peaks of voltage and power are enhanced 5 and 10 orders in magnitude, respectively, as a switch is introduced [29]. As the standards and figure-of-merits of the TENG are established, it was theoretically proved that the output energy of the TENG can be maximized by using a switch [30]. In recent years, the switch has been widely used in managing the TENG's output performances [31,32], which is verified as a promising strategy for enhancing the energy storage efficiency into a capacitor or a battery [33,34]. However, at present, the operation of the TENG's switch is controlled by externally triggering, such as mechanical triggering [29,31–33] and circuit triggering [34–36]. In these cases, the switch is necessary to match the movement and electrical properties of the TENG, therefore, the structure and parameters of the switch has to be elaborately designed, which increases the complexity and fabrication cost of the

* Corresponding authors.
E-mail addresses: chenggang@henu.edu.cn (G. Cheng), zld@henu.edu.cn (Z. Du).

https://doi.org/10.1016/j.nanoen.2018.02.013
Received 20 December 2017; Received in revised form 5 February 2018; Accepted 5 February 2018
Available online 06 February 2018
2211-2855/

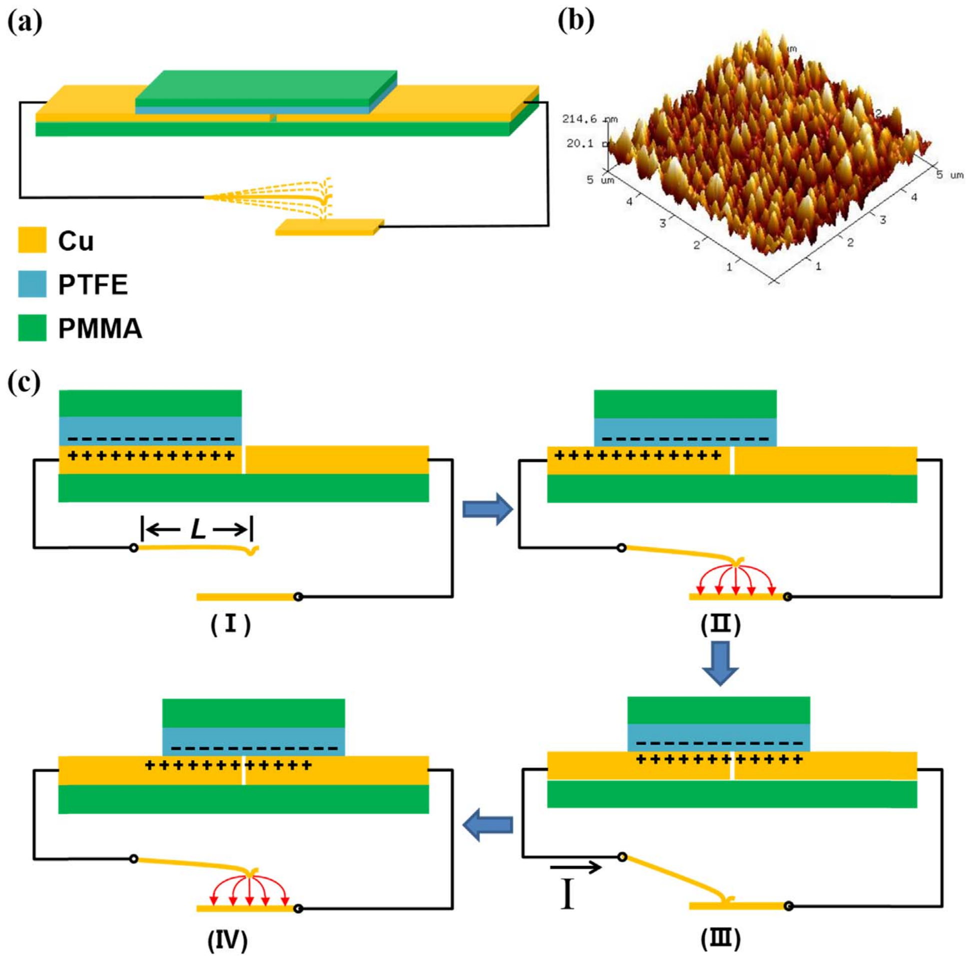

Fig. 1. (a) The structure diagram of the TENG-EVS. (b) The AFM image of the RIE etched PTFE film surface. (c) The diagram of the TENG-EVS's working mechanism.

TENG system.

In this paper, an electrostatic vibrator switch was introduced to fabricate a TENG system with a self-powered switch. During the operation process, the voltage generated by the TENG can drive the vibrating of the vibrator switch, thereby the periodic electrical output is generated when the switch is closed. As using this switch in a sliding mode TENG, the electrical output performance of the TENG can be regulated by changing the vibrating frequency of the vibrator switch. As using this switch in a rotation disk TENG, the optimal output performances can be achieved. Meanwhile, the TENG with a vibrator switch can be combined with a transformer to form a power management system, which is verified to have better powering abilities as charging a capacitor and lighting a quantum dot light-emitting diode (QLED).

2. Results and discussions

The structure of the TENG with an electrostatic vibrator switch (TENG-EVS) is shown in Fig. 1a. A sliding mode TENG is used here to show the working mechanism and performances of the TENG-EVS. For fabricating the sliding mode TENG, a polymethyl methacrylate (PMMA) sheet is used as the substrate, and two pieces of Cu films with a thickness of 60 μm are adhered to the PMMA substrate, which are acted as the left and right electrodes of the sliding TENG. A polytetrafluoroethylene (PTFE) film is adhered to another PMMA substrate as the triboelectric layer. In order to increase the triboelectric charge density of the PTFE film, the nanostructures are fabricated on surface of the PTFE film by a reactive ion etching (RIE) process. Fig. 1b shows an atomic force microscope (AFM) image of the etched PTFE film. After RIE etching, the nanostructures with an average diameter of 118 nm are generated on the surface, and the roughness of PTFE film increases from 28.3 to 44.4 nm, which can increase the contact area and improve the performance of a TENG. The electrostatic vibrator switch consists of a Cu wire and a Cu plate, which are acted as an elastic vibrator and a contact pad, respectively. The Cu wire and the Cu plate are connected to the left and right electrodes of the TENG, respectively, and two micro-manipulation stages are used to precisely adjust the distance between them. In the experiment, the distance between the elastic vibrator and the contact plate is 0.3 mm.

The working mechanism of the TENG-EVS is shown in Fig. 1c. In principle, the self-powered electrostatic vibrator switch is suitable for various modes TENG. For simplicity, we choose a sliding mode TENG to demonstrate the working mechanism of the TENG-EVS. According to the triboelectric series [37], the surface of the PTFE film produces negative triboelectric charges as it is contacted with the Cu electrodes. In the initial state (Fig. 1c-I), the PTFE film overlaps with the left Cu electrode, and positive charges are induced on the left Cu electrode to achieve electrostatic equilibrium. At this state, the potential difference between the two Cu electrodes is zero, no electric field is generated around the vibrator's tip, and no electrostatic attraction force is applied to the vibrator. Therefore, the distance between the vibrator and the contact plate is still 0.3 mm, and the switch is opened. When the PTFE film slides rightward (Fig. 1c-II), the negative triboelectric charges in the PTFE film are laterally separated with the positive charges in the left Cu electrodes, which causes the potential difference between the two Cu electrodes. As a result, an electric field distribution is generated around the vibrator's tip, and an electrostatic attraction force is applied to the elastic vibrator, which drives the elastic vibrator move close to the contact plate. However, before the elastic vibrator is completely